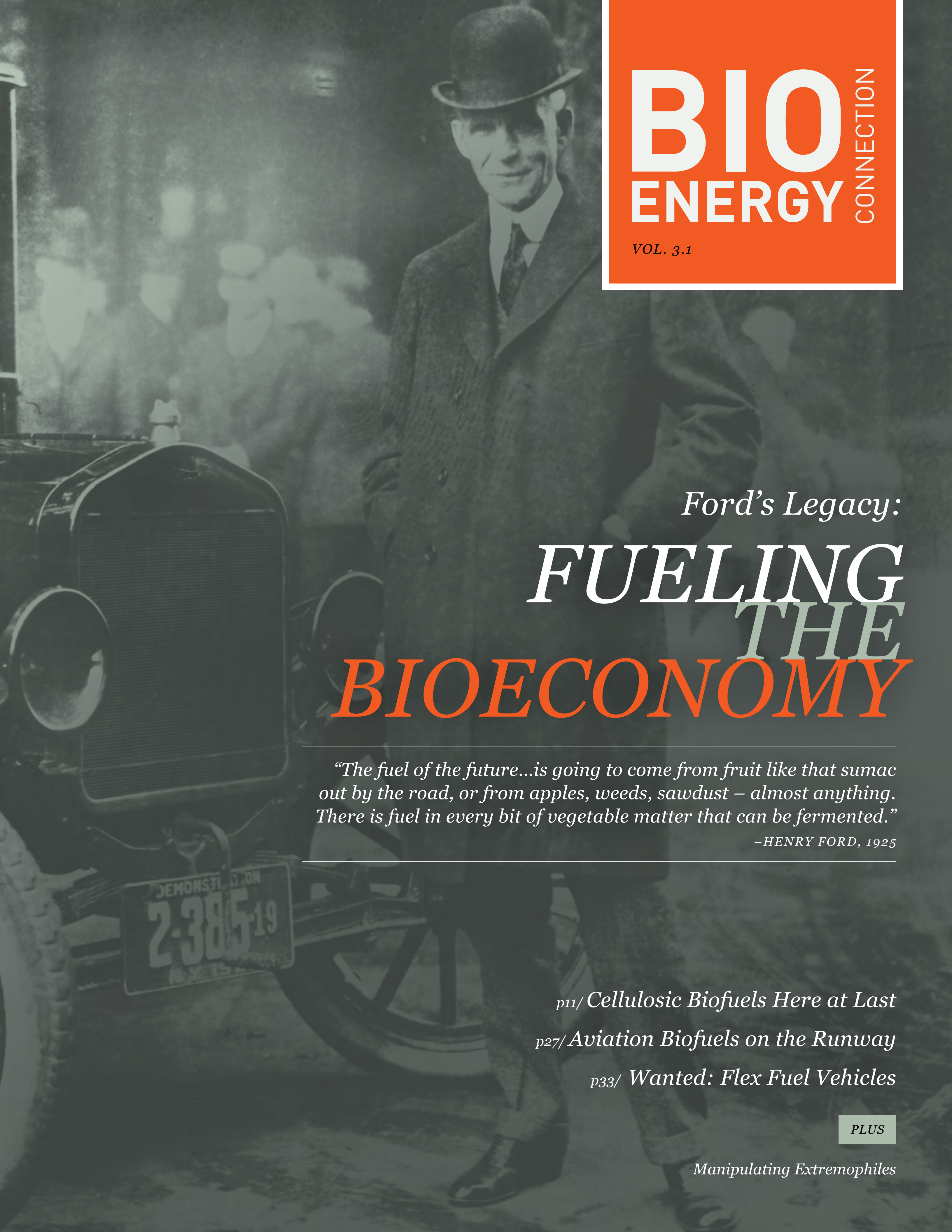

BIO ENERGY CONNECTION

*VOL. 3.1*

*Ford's Legacy:*

# *FUELING THE BIOECONOMY*

*"The fuel of the future…is going to come from fruit like that sumac out by the road, or from apples, weeds, sawdust – almost anything. There is fuel in every bit of vegetable matter that can be fermented."*

–HENRY FORD, 1925

## *FROM BIO...*
## *TO FUEL*

*JATROPHA:*

A NEWLY ENGINEERED VARIETY SHOWS PROMISE

### *WHAT IS IT?*

Jatropha is a hardy tropical plant whose name is derived from the Greek words for "physician" and "nutrition." Its leaves and seed pods are poisonous, but the plant has been used in medicines, mulch, and basket-weaving, made into organic fertilizer and rodent repellent, and as a cover crop to shelter other crops and prevent erosion. And inside the pods are beans that can be crushed and made into oil for soap, cosmetics, lamps, and biofuels.

### *WHY IS IT OF INTEREST?*

Almost a decade ago, the drought-tolerant, inedible bush that grows on marginal land in the tropics was hailed as the next big thing in biofuels. Investors poured hundreds of millions of dollars into jatropha plantations only to discover that the plants yielded far too few oil-rich seeds to be commercially viable, especially as petroleum prices fell sharply in the wake of the Great Recession. Recently a San Diego startup called SGB, however, has identified potentially high-yielding hybrid jatropha strains, combining years of intensive selective breeding, high-throughput genotyping, and agronomy.

### *WHERE DOES IT GROW?*

Originally from Central America, jatropha is most commonly found in Indonesia, the Philippines, Cambodia, India, Mexico, and South America.

### *WHY DOES IT MATTER?*

Often used as a hedge to control cattle, jatropha has been used successfully to make diesel in places like the Galapagos Islands, where the island Floreana has replaced fossil fuels with cold-pressed jatropha oil. Tourist busses in some parts of India are already running on jatropha oil. And a bioengineered variety of jatropha has boosted yields by 900 percent, according to some reports.

### *WHAT'S NEXT?*

Besides producing local jatropha biodiesel, regions in some countries are planting jatropha seeds for aviation biofuel. One biofuel company has deals in place to plant jatropha on 250,000 acres in Brazil, India and other countries that would produce an estimated 70 million gallons of biofuel a year. Jatropha can't supply all the fuel needed for aviation, since, as one commentator has noted, the 1.6 billion gallons of jet fuel needed each year would require 285 million acres of jatropha to satisfy our annual demand – a land area about the size of four large U.S. states combined – but it could make a dent in our fossil fuel use.

### *WHO IS WORKING ON IT?*

Besides Brazil, India, and the U.S., companies are investing in jatropha in countries ranging from the Bahamas and Costa Rica to Ethiopia, Ghana, Guatemala, Jamaica, Kenya, Mexico, Sudan, and Zimbabwe.

# *FACING THE CHALLENGE*

LETTER FROM THE EXECUTIVE EDITOR

*Follow me on Twitter @phytophile*
*Follow Bioenergy Connection Magazine @BioenergyMag*

*2014 // VOL. 3.1*



*Bioenergy Connection* is published by the Energy Biosciences Institute, a partnership of the University of California at Berkeley; the University of Illinois at Urbana-Champaign, the Lawrence Berkeley National Laboratory, and BP. To help the world transition from fossil fuels to responsible, renewable energy sources, more than 300 EBI researchers are applying advanced knowledge of biological processes to the energy sector. To learn more about EBI, visit the EBI website at www.energybiosciencesinstitute.org. To subscribe to *Bioenergy Connection* or change your address, please contact: Bioenergyconnection@berkeley.edu

*Bioenergy Connection* is printed on recycled paper with soy ink. Cover image: Henry Ford beside a Model T in Buffalo, New York, 1921. Credit: Benson Ford Research Center, University of Michigan. Front inside cover photo of jatropha curcas and back inside cover photo of Clostridium courtesy of Wikipedia Commons.

It's safe to say that Henry Ford would be amazed by modern automobiles, but what would he think about the fuel in the tanks? As an early proponent of the bioeconomy, he would likely be disappointed that our economy is largely fueled by fossil materials, not plants harvested from the fields.

While we inch our way toward Ford's dream, it's worth appreciating the incredible advances that fossil resources have enabled in the last 200 years.

The availability of energy-dense material in concentrated areas of the globe has slowed destruction of forests for light and heat, enabled flight and space exploration and helped create an instantaneous global economy.

Unfortunately, the use of fossil fuels has contributed serious injury to our climate, air and water. The total costs and benefits to future generations are uncertain. While we have learned to reduce some of the impacts of using fossil carbon, weaning ourselves from the benefits of this mature industry is a hard and slow process.

The application of modern biology to energy, nutrition, and medicine is critical to our transition from fossil resources. This shift toward a sustainable modern bioeconomy entails large fundamental changes in how we do things, and is subject to a phenomenon I'll call "the futurist trilemma."

Imagine a three-way tug-of-war between people with fundamentally differing philosophies of progress. The sunshine-and-rainbow optimists make all things seem possible – giving us the will to try despite technological or economic challenges. The stubbornly immobile complacents push us toward cost-effective, innovative solutions. The dark cloud skeptics point to the heavy footprint of the pre-fossil fuel bioeconomy – cautioning us to use our shared resources with care and planning. It is in the midst of this strife that we collectively move forward, and 2014 has been a year of important advances.

In this issue of *Bioenergy Connection,* our focus is the bioeconomy. Greg Breining explores the exciting debut of cellulosic ethanol, Judith Horstman delves into scientific advances in freeing sugars from biomass, and Peter Jaret goes bioprospecting. Todd Woody and Ashie Bhandiwad explore developments in advanced biofuels and Jim Lane shines a light on timelines for new technologies.

Also in this issue, we spend time in Brazil with Jose Goldemberg, the father of Brazilian sugarcane ethanol, and his colleague Horta Nogueira, who track the evolution of the world's most renewable transport fuel system. Katherine Griffin profiles Vonnie Estes, managing director, US, for GranBio, Brazil's new cellulosic ethanol company. Finally, Steve Pietsch explores why flex fuel vehicles, a centerpiece to success in Brazil, are so rare elsewhere in the world.

We also invite you to *Bioenergy Connection*'s new interactive website, where you can read exclusive on-line material and comment on articles and blogs, adding your voice to the issues. Please visit us at http://www.bioenergyconnection.org and follow us on Twitter @ BioenergyMag.

Heather Youngs, Ph.D.

*EXECUTIVE EDITOR, BIOENERGY CONNECTION*
*SENIOR ANALYSIS FELLOW, ENERGY BIOSCIENCES INSTITUTE*

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# *CONTRIBUTORS*

*1/ASHWINI BHANDIWAD, PH.D.* ("Bio-butanol: Back to the Future," p.22) is a bioenergy analyst at the Energy Biosciences Institute. Her work focuses on process modeling of ongoing projects at EBI to understand the impact, synergy and feasibility of each for large-scale implementation. Over the past several years she has worked on various aspects of biofuel production leveraging synthetic biology through a doctorate in engineering from Dartmouth College. In her spare time, she also works with the CleanTech Open, a non-profit accelerator program for cleantech startups.

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*3/SAUL BROMBERGER AND SANDRA HOOVER* (portrait of Vonnie Estes, p. 42) are an award-winning photography team in the San Francisco Bay Area whose clients included Time Inc., Getty Images, universities, hospitals, and fortune 500 companies. Saul also worked for years as a newspaper photographer. In their spare time, Saul and Sandra enjoy outings with their two sons.

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*8/JUDITH HORSTMAN, M.L.A.* ("Breaking Down the Wall," p. 46) Over a wide-ranging career specializing in science writing, Horstman has been a newspaper reporter, a Washington correspondent, a journalism professor, and the recipient of a Vannevar Bush science journalism fellowship at MIT and two Fulbrights to establish a journalism center in Budapest. She has written for the internet and for numerous publications including the Stanford University Medical Center News Office, Time Inc. Health, the *Harvard Health Letter*, the *Johns Hopkins White Papers*, and was a contributing editor of *Arthritis Today*. She is the author seven books, including the four-book *Scientific American series: Day in the Life of Your Brain* (2009), *Brave New Brain* (2010), *Book of Love, Sex and the Brain* (2011) and *Healthy Aging Brain* (2012); and is the editor of *Mindfulness in Public Schools: Building Wellness and Resilience in Our Children* (2013). She and her aging brain live in California near her children and grandchildren, and travel as widely and often as possible.

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*10/LAURA LANE, M.S.* ("At the Pump: Flex Fuel Drivers," web exclusive) works as a freelance journalist in the San Francisco Bay Area. She has covered topical issues for the *Dallas Morning News*, the *Contra Costa Times*, WebMD, *Yoga Journal*, and *Men's Journal*. With a master's degree in biology from Stanford University, she has also written for professional audiences in publications such as *Diagnostic Imaging*, the International Medical News Group, *The Scientist, Bio IT World* and *Biocompare.*

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*12/CHRIS WOOLSTON, M.S.* ("Brazil: Bioenergy Powerhouse at a Crossroads" and "Green Chemistry on the Rise," web exclusives) is a freelance writer and editor who specializes in science, health and travel. A reformed biologist, Woolston says, he studied algae and nitrogen dynamics in Antarctic lakes before the Science Writing Program propelled him out of the lab. He is a former staff writer for Time Inc.'s *Hippocrates* magazine, author of the late "Healthy Skeptic" column for the *Los Angeles Times,* and co-author of *Generation Extra Large* (Perseus). He lives in Billings, Mt., with his wife – novelist Blythe Woolston – and their two children.

*COVER PACKAGE*

# *FUELING* THE *BIOECONOMY*

# THE BIOECONOMY IS EVERYWHERE

BY
HEATHER YOUNGS, PH.D.

## *"IT LOOKS LIKE WE FOUND A BIT OF A GOLD VEIN."*

It was the spring of 2008, and Dr. John Pierce was describing the "green" breakthrough technology developed by his team at DuPont to a reporter from the *New York Times*[1]. Today that breakthrough, Bio-PDO, is just one of many "green chemicals" with lower environmental footprints than petroleum-based chemicals.

*In fact, the bioeconomy is everywhere, in your refrigerator, your pantry, your living room, and your medicine chest. Simply put, the bioeconomy is commerce related to living things – all the products derived from plants, animals and microbes.*

Food, forest products, and natural textiles like cotton and wool represent the material commodities of the traditional bioeconomy. Beer, wine, cheese, and naturopathic medicines can be considered early biotechnology components, leveraged by scientists to build the modern bioeconomy.

### *A GROWING MARKET*

The modern bioeconomy, largely based on advances in biotechnology, has two main goals: replacing fossil-fuel

*The modern bioeconomy, largely based on advances in biotechnology, has two main goals: replacing fossil-fuel-based fuels, chemicals and materials with products made from renewable biomass, and bringing new products with novel properties to the table.*

based fuels, chemicals and materials with products made from renewable biomass, and bringing new products with novel properties to the table.

These products run the gamut from bio-medicines (with low market volumes and high value) to fuels (with high market volumes and low value). For some biomaterials, the market opportunities are limited by the creativity of the products (applications) and consumer choices related to performance and cost.

The traditional bioeconomy is still big business. In 2012 the U.N.'s Food and Agriculture Organization valued agricultural products at nearly four trillion U.S. dollars. Forest products contribute an additional quarter of a trillion dollars to the global economy. But the modern bioeconomy is catching up.

*Advances in biotechnology have improved medicines, crops, food, fuels, and chemicals, broadening the reach of the bioeconomy.* In 1983, at the beginning of the biotech revolution, the sale of biotechnology products including biofuels, food additives, enzymes, lubricants, detergents, and nutraceuticals (vitamins and dietary supplements) was only $13 billion.[2]

By 2010, the value of biotechnology-derived products in the bioeconomy would exceed $500 billion, contributing roughly 2 percent of the GDP in the U.S.[3]. The global enzyme market alone was worth $3.3 billion. The biofuel market value had grown to $87 billion, and revenues for genetically modified crops approached $100 billion.

Meanwhile, the market for health-related bio-based products skyrocketed. The so-called "biologics" – including therapies such as ZMapp, the monoclonal antibody recently used to treat two Ebola patients at Emory University – approached a market value of $149 billion in 2010; by 2015, the market for biologics is expected to near $239 billion. The global bio-based nutraceutical market, valued at $142 billion in 2011, is expected to nearly double to $205 billion by 2017.

## THE BIOTRANSFORMATION OF CHEMICAL MANUFACTURING

Stunning advances in genomics and microbial metabolic engineering have allowed scientists to construct new, "greener" pathways to make specific chemicals and the tools to scale up the production.

The development of bio-based propane-diol at DuPont, a chemical used to make synthetic polymers, cosmetics, adhesives, detergent, and antifreeze, is an iconic example. It represents not only a pioneering technical feat, but a change in thinking among the corporate giants of industrial chemistry.

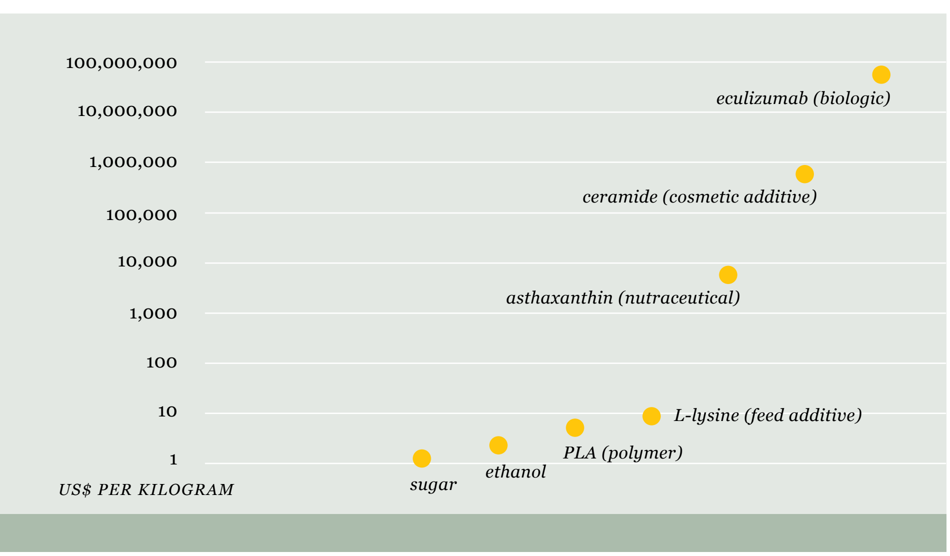
In both his former role as Vice-President for Technology at DuPont and his current role as Chief Bioscientist at BP, Dr. John Pierce has helped steward bio-based initiatives.

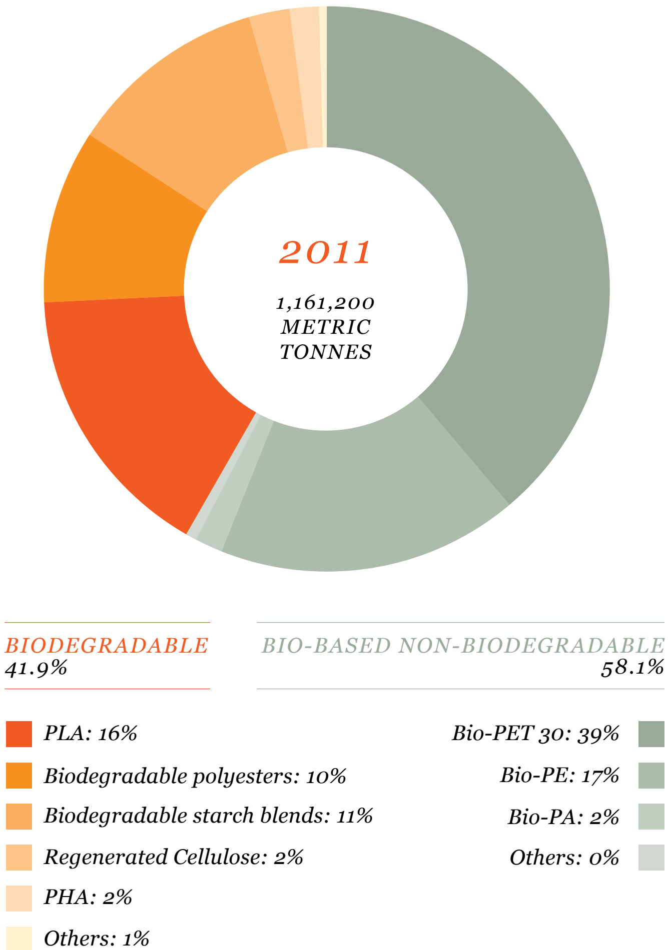
"If the end-goal is to add technical innovation to marketplaces – which you can do with modern biotechnology – you need two things: Some freedom around the basic science of discovery, and the ability to find or create market opportunities for what you find," he says. "Those efforts need vision, talent, luck, and a fairly long-term commitment to the endeavor."

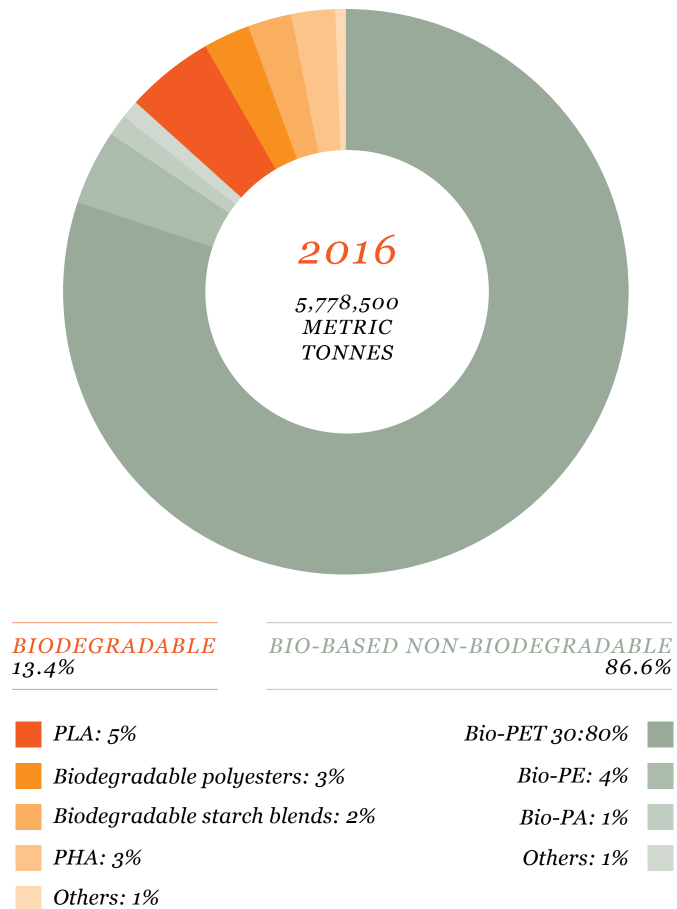
According to Pierce, the bio-based program in DuPont – now a flagship of the company – was really the product of such freedom and market opportunities, combined with a long-term basic science tradition. "You really can think of DuPont as a market-driven science company," says Pierce.

Pierce joined DuPont in the early 1980s, when the program for bioproducts was concentrated mainly on exploring applications to agriculture and medicine. The company was already shifting towards

### MARKET VALUE OF VARIOUS BIOMATERIALS






more environmentally sustainable practices.[4] There was even a small effort to develop bio-derived monomers and polymers, including poly-lactic acid (PLA), a biodegradable plastic made from sugar, discovered at DuPont in 1932.

It was early days for modern bio-based chemicals, and achieving the performance of petroleum-based chemicals was challenging. Despite its environmental benefits, PLA had inferior strength, flexibility, and melt stability compared to petroleum-based plastics. Several companies explored producing the polymer but only Cargill moved forward, entertaining a short-lived joint venture with Dow Chemical Company from 2000 to 2005. DuPont would come back to PLA in 2006 when its researchers dusted off Biomax Strong, an additive to improve PLA performance. Also that year, DuPont's joint venture with Tate & Lyle would begin commercial production of bio-1,3-propanediol (Bio-PDO).

The molecule, made in a modified bacterium, could be used directly in products from cosmetics to de-icers and could substitute for a petroleum-based pathway to make Sorona™, a linear aromatic polyester used in textiles from spandex to carpet. According to the company, the bio-process required 40 percent less energy (the equivalent of 10 million gallons of gasoline each year) while reducing costs and greenhouse gas emissions – a win-win for economics and environmental stewardship.

*"You can't just have a cool discovery," says Pierce. "You need to be able to monetize your research investment.* Sometimes that just takes getting the creative juices flowing and fostering some sideways thinking. Modern biotechnology has really changed the equation. The engineers toss up a potential process and the biologists can now say, 'Hey, we can do that.'"

Of course, getting a bioprocess to work economically at commercial scale isn't necessarily easy. Bio-PDO took years of innovation and technology development.

"When we started in the mid-90's, there was just a lot about microbial metabolism we didn't know. By today's standards, our tools were still pretty crude," says Pierce. By 2003, after hundreds of mutations and the convergence of several independent work streams, the team had developed a strain of E. coli fit for commercial production. "The learning during that time period was really amazing," he recalls.

(Continued on page 8)

*“Modern biotechnology has really changed the equation. The engineers toss up a potential process and the biologists can now say, ‘Hey, we can do that.’”*

*DR. JOHN PIERCE, BP BIOFUELS*

Other bio-based chemicals would follow. By 2010 bio-based chemicals would constitute an estimated 5-10 percent of total global chemical sales. In spring of 2011, DuPont Tate & Lyle BioProducts signed a partnership agreement with Genomatica to demonstrate fermentation of sugars from corn to 1,4-butanediol (BDO), a sustainable precursor chemical with a $4 billion market potential for use in plastics, elastic fibers, and solvents. Building on the learning and infrastructure from bio-PDO, the BDO process was at commercial scale by February 2013.

That same year, BASF, who was also pursuing bio-BDO, announced the fruits of a long-term investment in producing bio-acrylate in partnership with Cargill and Novozymes. Rather than using a petroleum-based process, their route would involve fermentation with an engineered microbe to make 3-hydroxyproprionic acid which can then be dehydrated to form acrylic acid.[5,6] The prize: a piece of the $10 billion dollar acrylate market – consisting of diapers, coatings, adhesives, textiles, and detergents – and populated with companies like Kimberly-Clark, Unilever, Glidden, Sherwin-Williams and Valspar, all looking to use greener materials in their products.

By 2013, bio-acrylate would be one of nearly 900 individual products registered with the USDA biopreferred program.[7]

### *THE QUESTION OF THE GREEN PREMIUM*

Which raises a big question: Are people willing to pay more for bio-based products?

The quick answer is yes – but not much. There certainly are consumers that prefer products from renewable sources. A survey of consumers in the U.S. and the E.U. found that nearly 80 percent were willing to pay an additional 5 percent for renewable content. But fewer than 10 percent of consumers would pay a 25 percent “green premium.”[8]

*A survey of consumers in the U.S. and the E.U. found that nearly 80 percent were willing to pay an additional 5 percent for renewable content. But fewer than 10 percent of consumers would pay a 25 percent “green premium.”*

Even so, companies may have other motivations to invest in bio-based products, including leveraging sustainability goals to boost their corporate image and build brand loyalty.

Take Coca-Cola as an example. In 2010, after years of criticism for using unsustainable plastics for bottled water, the company’s Dasani brand got a new “Plant Bottle,” containing up to 30 percent bio-derived plastic. In 2013 Coca-Cola partnered with Ford Motor Company to use the PlantBottle Technology™ as material for upholstery fabric on seat cushions, seat backs, head restraints, door panel inserts and headliners in the Ford Fusion Energi. The effort was enough to win the 2014 Sustainable Bio Award Industry Champion of the Year, an accomplishment Henry Ford himself would have loved to see.

Ford was an early champion of the bioeconomy. Along with Thomas Edison and George Washington Carver, Ford was a supporter of the early “chemurgy” movement dedicated to expanding the use of agricultural products for materials, chemicals and fuels. Besides running his model T on ethanol in the U.S. and Brazil (see page 38), Ford wore suits made of soybean polyester. In 1941, Ford and Carver unveiled a prototype of the world’s first car made from “agricultural plastic”[9]. Unfortunately, the car fell victim to challenging economics and disruption in car manufacturing during World War II.

### *FUELING THE BIOECONOMY*

Ford’s vision for the bioeconomy means that bio-based alternatives for both chemicals and fuels must be at scale. So, can the revolution in commodity chemicals extend to the lower margin fuel market?

*According to Kes McCormick of Lund University’s International Institute for Industrial Environmental Economics in Sweden, transportation biofuels are “the most visible output of the bioeconomy at present.”* He further suggests that the mix of bio-products from biorefineries is “expected to underpin the shift towards an advanced bioeconomy”.

Pricing carbon emissions and thus creating markets for carbon offsets – as British Columbia, California, and others are trying to do – will further expand the value of the bioeconomy. Green energy is already partially monetized through feed-in tariffs in some countries and regions. If favorable government policies remain in place, standards, mandates, and markets for renewable fuel credits will also stabilize investment in cellulosic and advanced biofuel technologies.

*Because the margins for fuel are so slim, co-producing bio-products is one way to spur biofuel development.* Heat and power from biomass, an often overlooked sector of the bioeconomy, is the largest source of renewable energy next to hydropower. Electricity from wood, municipal waste and even biogas from manure can power homes, industry and the electric vehicle fleet.

For example, the Beta-Renewables cellulosic ethanol plant in Crescentino, Italy produces biomethane and bioelectricity, which both earn renewable energy credits.

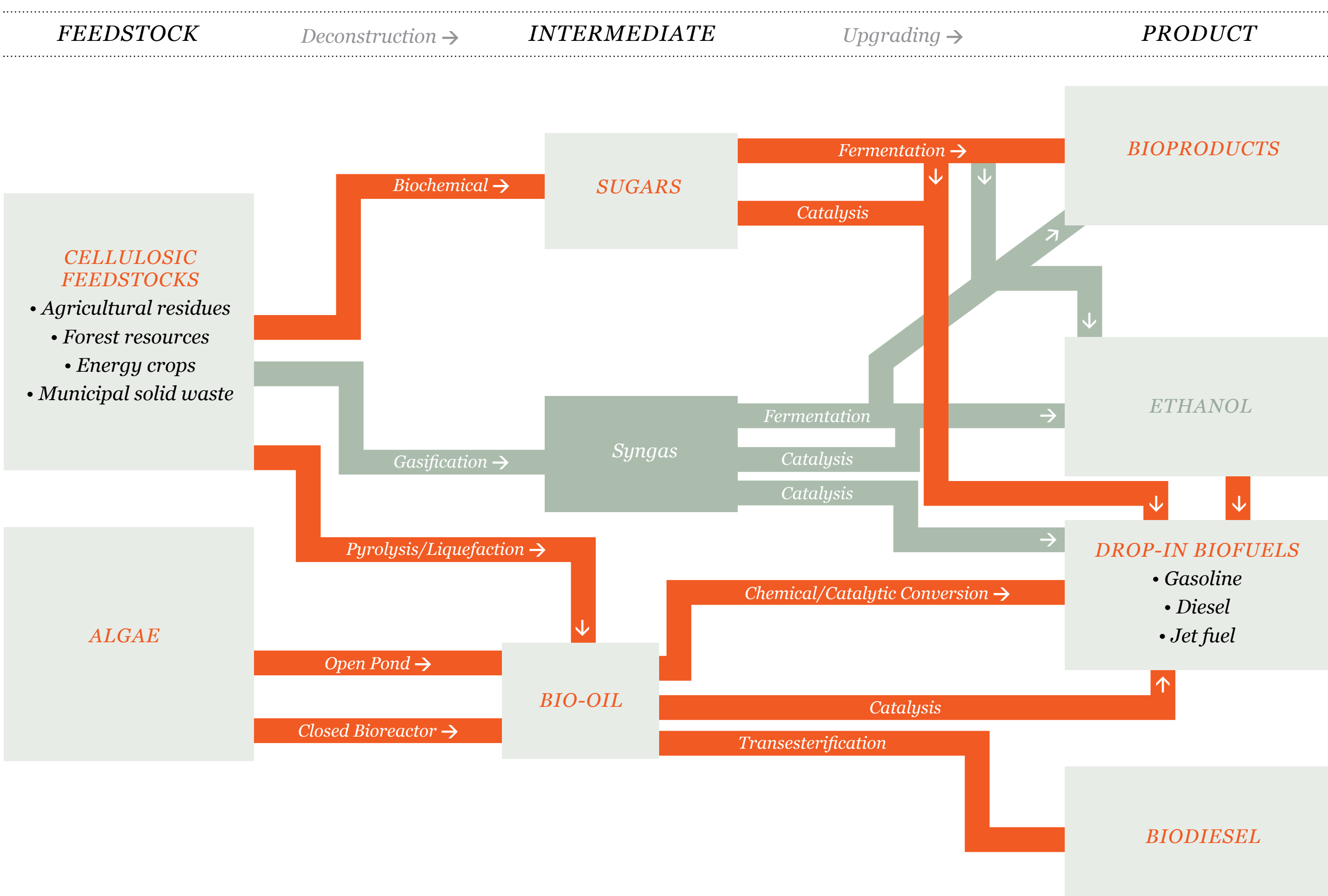
This "residual energy" can be substantial. In 2012, sugarcane mills provided 15.4 percent of Brazil's total energy in 2012 from bagasse, the dried stalks left over from juicing the cane.[10] In the U.S., the corn ethanol industry provides high-protein animal feed in the form of distillers grains to the pork, poultry, dairy and cattle industries.

While many algae companies include the possibility of supplying feed for aquaculture as part of their economic equations, Solazyme, a company producing oils from sugars with microalgae, has embraced the high-value cosmetic and personal care market. Originally funded by the Department of Energy and venture capital to produce advanced algal biodiesel, the company has been raising cash with alternative bio-products made from algal oil.

Other companies would like to do the same, but navigating the price points of low-volume markets can be tricky. High-value markets such as personal care, nutraceuticals, and fine chemicals are relatively small. Flooding a market with co-product can substantially lower the price – and the profit.

That's exactly what happened in 2006 with the "glycerin glut." Glycerin, used in soaps, epoxy resins and other materials, is a byproduct of conventional biodiesel production.

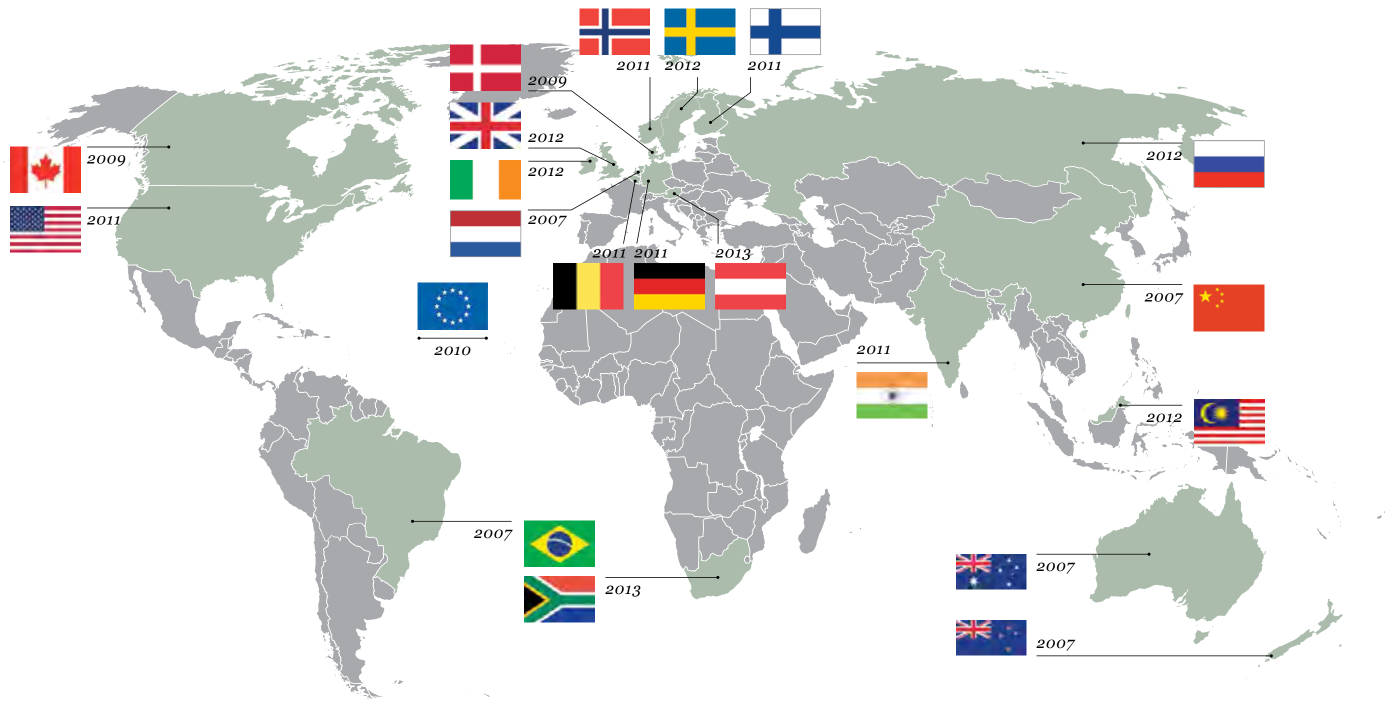
Increased global production of biodiesel sent a lot of glycerin into the market – about 10 pounds for every 100 pounds of fuel – resulting in a drop in glycerin price from 25 cents a pound to 5 cents. But importantly for the bioeconomy, the new low-cost



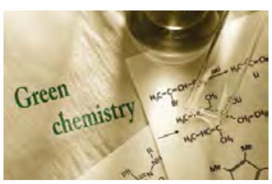

Pathways in which biomass can be converted to cellulosic biofuel, hydrocarbon fuels, and intermediaries that lead to 'drop-in' replacements for gasoline, diesel, jet fuel, and other petroleum-based products. Graphic adapted from the DOE's Bioenergy Technology Office (BETO).

*EMERGING TREND: COUNTRIES ESTABLISHING BIOECONOMY OR BIOTECHNOLOGY INITIATIVES*

*The OECD estimates that the bioeconomy will contribute a global average of 2.7% to GDP by 2030.*




*WEB EXCLUSIVES*




*Read "Green Chemistry on the Rise," by Chris Woolston, M.S., on our website at www.bioenergyconnection.org*

feedstock spurred research efforts to use glycerin for higher value bio-based chemicals.

While many early products of the modern bioeconomy are derived from feed crops, researchers have renewed their focus on technologies to expand use of lignocellulosic biomass, or biomass from parts of plants indigestible to humans. Overall, the synergies between biofuels and other bio-based chemicals are extremely strong. Using biotechnology to replace the "whole barrel" by providing fuels and chemicals from biomass, including lignocellulose, is crucial to reaching long-term sustainability and breaking the dependency on fossil fuels.

"The move to the bioeconomy and away from fossil fuels is inevitable," says Dr. David Zilberman, a professor of agriculture and resource economics at UC Berkeley and principal investigator at the Energy Biosciences Institute. "The modern era brought us technologies that improved the human condition, but many are not sustainable. The addiction to non-renewable resources cannot last forever. Sooner or later we need to move to a renewable economy, and the bioeconomy is driving that."

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COVER PACKAGE

# The Cellulosic Biofuels ODYSSEY

## CROSSING THE FINISH LINE

*BY GREG BREINING*

When *Bioenergy Connection* first covered the progress to commercial cellulosic ethanol in 2011, a dozen biofuel companies were claiming they would go big by 2015. After years of industry-wide anticipation and delays, commercial-scale cellulosic ethanol is finally here. What can we learn from the pioneers?


*"The Cellulosic Biofuels Odyssey," artwork by David R. Dudley; concept by Heather Youngs, Susan Jenkins, and David Dudley.*

In 2011, several years after the Renewable Fuel Standard set quotas for cellulosic ethanol, second-generation biofuel companies were working furiously to create it. The cellulosic quotas applied to renewable fuels made from cellulose, hemicellulose, or lignin – the parts of plants indigestible to humans. Using everything from cornstalks to tall grasses and wood waste, a dozen firms declared that commercial production was just around the corner.

At the same time, critics were having a field day. In the first 12 months of the RFS program, from July 2010 to June 2011, no companies managed to register any cellulosic biofuel for sale and use, and Forbes called the activity "fields of pipedreams."[1]

Efforts to repeal the 15 billion gallon cellulosic ethanol mandate in the Renewable Fuel Standard reached a fever pitch. Impatience, loan defaults, public failures among companies like Range Fuels, and a sluggish financial landscape helped propel the narrative that making fuels from biomass would never happen.

**BUT AFTER YEARS OF INDUSTRY-WIDE ANTICIPATION AND DELAYS, COMMERCIAL-SCALE SECOND-GENERATION BIOFUEL COMPANIES ARE TAKING THEIR FIRST WOBBLY STEPS ACROSS THE FINISH LINE.** The stories of some of the winners follow a classic pattern – long-term research and methodical scale-up.


Ineos, a chemical company based in Switzerland, began research in waste gasification in 1991. It spent 12 years developing the technology, launching a demonstration scale hybrid gasification and fermentation plant in Fayetteville, Ark., in 2003. Construction of its commercial plant in Vero Beach, Fla., began in 2012, with the first ethanol production in 2013. "We are producing commercial quantities of bioethanol from vegetative and wood waste, and at the same time exporting power to the local community – a world first," said Ineos CEO Peter Williams, Ph.D., at the time.[2]

Enerkem, a Canadian waste to energy company, opened its doors in 2000, but moved quickly through a pilot project and demonstration of cellulosic biofuel production. The grand opening of its commercial plant in Edmonton was in June of 2014. Where Enerkem was vocal about its commercial scale plan for fuels and chemicals, Ineos was more of a silent runner, developing its technology without much fanfare.

POET-DSM was not far behind. With 26 corn ethanol plants, POET is one of the world's largest ethanol producers and has been a U.S. renewable fuel provider for 25 years. Partnering with the global biotech company Royal DSM, POET's next-generation facility opened in September of this year and is leveraging agricultural waste. Located in Emmetsburg, Iowa, the cellulosic plant is designed to produce 20 million to 25 million gallons of cellulosic

*Credit: Ineos, Vero Beach facility/Ineos.com (top); Enerkem, Westbury plant/ Enerkem.com (bottom)*

*Abengoa headquarters, Seville, Spain / Credit: Abengoa.com*

ethanol from corn cobs, leaves, husks and stalks as a "bolt-on" to a traditional corn ethanol plant.[3]

The latest to open is Abengoa, a 73-year-old technology company based in Spain that celebrated the grand opening of its Hugoton, Kansas, plant this October. The facility plans to produce 25 million gallons of cellulosic ethanol a year, plus 22 megawatts of renewable energy from non-food crops and agricultural and wood waste. Its platform will also allow it to expand its revenue stream by developing bioplastic, biochemical, and drop-in jet fuels.

**THE BIG SURPRISES IN THE FIELD ARE TWO RELATIVELY NEW UPSTARTS FROM ITALY AND BRAZIL — BOTH USING THE SAME TECHNOLOGY.** "They've just come out of nowhere very quickly," says Jim Lane, editor and publisher of *Biofuels Digest*.

Beta Renewables began shipping cellulosic ethanol made from wheat straw from its plant in Crescentino, Italy, last year, just two years after the company was created. GranBio, in Alagoas, Brazil, is another such dark horse. It began commercial production of cellulosic ethanol this spring from unused leaves and tops of sugarcane, three years after the company was founded.

"Crescentino is a project many thought would never get built," Lane says. "Several years of industry skepticism preceded a decision by Beta's parent Biochemtex to build the project off its own balance sheet." The result, he says, is a 20-million-gallon cellulosic biofuels project that lies just south of the Italian Alps in the vicinity of Torino, with towering columns that dominate the sprawling farmland surrounding it.

Both companies are pursuing biological routes to cellulosic ethanol using the Proesa process which uses heating and enzymes to break down biomass, (see "Breaking Down the Wall," page 46) and fermentation to produce ethanol. Beta Renewables and Proesa[4] are the product of a long evolution in M&G (the Mossi Ghisolfi Group), beginning with the 2004 acquisition of Chemtex, an engineering and process company specializing in plastics and polyesters. The company shifted cellulosic ethanol R&D to its research facility in Rivalta Scrivia, Italy in 2011. The next year, Chemtex partnered with Danish enzyme company Novozymes to garner a USDA loan guarantee for a cellulosic plant in North Carolina, and the separation of bio-based technologies into Biochemtex came about in 2013.

In a sense, the Crescentino plant serves as a proof-of-concept for other companies to evaluate licensing the Proesa process, as did the Brazilian GranBio sugarcane bagasse facility in Alagoas.

"GranBio brings more vision, finance and relationships to execute projects in Brazil at scale. They've licensed appropriate technologies and made technical partnerships, and their focus has been more about translating these great technologies, mostly from the States and also from Italy down to Brazil," says Lane.

Alan Hiltner, GranBio's executive vice-president, says the company's president, Bernardo Gradin,

*Beta Renewables in Crescentino, Italy, at night / Credit: Beta-Renewables.com* recognized an opportunity and had resources to spare.

"When he started the company three years ago, we looked at the sector and we realized that there was a big mismatch—the people who had the technology didn't have the money. The people who had the money didn't have access to land. The people who had the land didn't have the technology," says Hiltner. "So we realized that if some company could put everything together—technology, access to competitive feedstock, capital, and execution capabilities—that would be the key to success. So from the beginning we decided to address these four challenges at the same time. Everything came together at the same moment."

### *THE SLOW RACE TO COMMERCIALIZATION*

The shortcomings of "first-generation" biofuels, such as corn-based ethanol, have been apparent for a decade. Fuels derived from crops have the potential to drive up the cost of food. They're more expensive than fossil fuels. They share the environmental shortcomings of the crops they come from—high use of pesticides and fertilizers, soil erosion, overuse of water, and the release of greenhouse gases, though to a much lesser extent than fossil fuels.

All this was supposed to change with "second-generation" biofuels, derived from fibrous biomass rather than high-energy sugars and grain. To kick-start the production of these fuels in the United States, the federal

# NORTHERN EXPOSURE

## CELLULOSIC ETHANOL IS NOT AS NEW AS IT SEEMS. PAPER COMPANIES HAVE BEEN DOING IT FOR A CENTURY.

BY HEATHER YOUNGS

Wood product companies began coupling the production of cellulosic ethanol with higher value chemicals more than a century ago.  Although many people see the commercial production of ethanol as a new process, at least two of these companies — Borregaard in Norway and SEKAB in Sweden — have been making ethanol from wood for 60 to 100 years, respectively. In almost every sense of the word, SEKAB has been functioning as a biorefinery for more than a century.

What inspired this ingenious process? Paper. Spurred by the growing demand for high quality paper, the process of using sulfite to produce cellulose fibers was invented in a Philadelphia mill in 1866.

By 1874, the process was up and running in Sweden, where chemists began to tinker with the spent liquor containing sugars from the hemicellulose fraction of wood. The first sulfite ethanol plant opened in Skutskär in 1909.

The process spread, with more than 50 plants operating in Sweden, Finland, Norway, Russia, Austria, and Switzerland over the last 80 years. Producing local fuel proved invaluable during war-time. The majority of plants operated from the 1940s to the 1960s — a period when other biomass to fuel options also flourished.

Wood ethanol was not an economically viable process on its own. The companies that have survived have leveraged higher value markets for the co-products they make.

For example, Norway's Borregaard only uses the hemicellulose – about a third of the biomass – for ethanol. The high quality cellulose fiber that once went to low-value paper is now turned into textiles or used as a specialty chemical. The sulfated lignin that was once burned to run the mill is used to make vanillin and additives for construction. Even the yeast and carbon dioxide made during in ethanol fermentation are sold.

The same economy of biomass is being explored in the new wave of cellulosic biorefineries. According to UC Berkeley Philomathia Professor and EBI Director Chris Somerville, "Many products come from a barrel of oil. Replacing the whole barrel is a challenge, but cellulosic biomass has the potential to do just that."

*Photo credit: Borregaard*

government amended the federal Renewable Fuels Standard in 2007 to require increasing proportions of these more environmentally friendly renewable fuels to be blended into gasoline.

The mandate required 6.5 million gallons of cellulosic ethanol be blended in 2010. Unfortunately, there was virtually no cellulosic fuel to blend—not that year or the years that followed. RFS mandates were lowered for 2010, 2011, and 2012. Total actual production in 2013 was barely more than 800,000 gallons. The EPA is expected to revise its mandate for cellulosic fuels again this summer.

### *WHY HAS PRODUCTION LAGGED SO FAR BEHIND PROJECTIONS?*

The high cost of capitalization has complicated investment in cellulosic plants, especially since the rules governing which fuels qualified under RFS2 weren't final until 2010. To get financing for the technology, get through five or six scale-ups, construct a plant, and build a biomass supply chain was a tall order, and not surprisingly, only now are four U. S. commercial plants coming on line. Says Lane, "The wave is here now, but it has been a slow train coming."

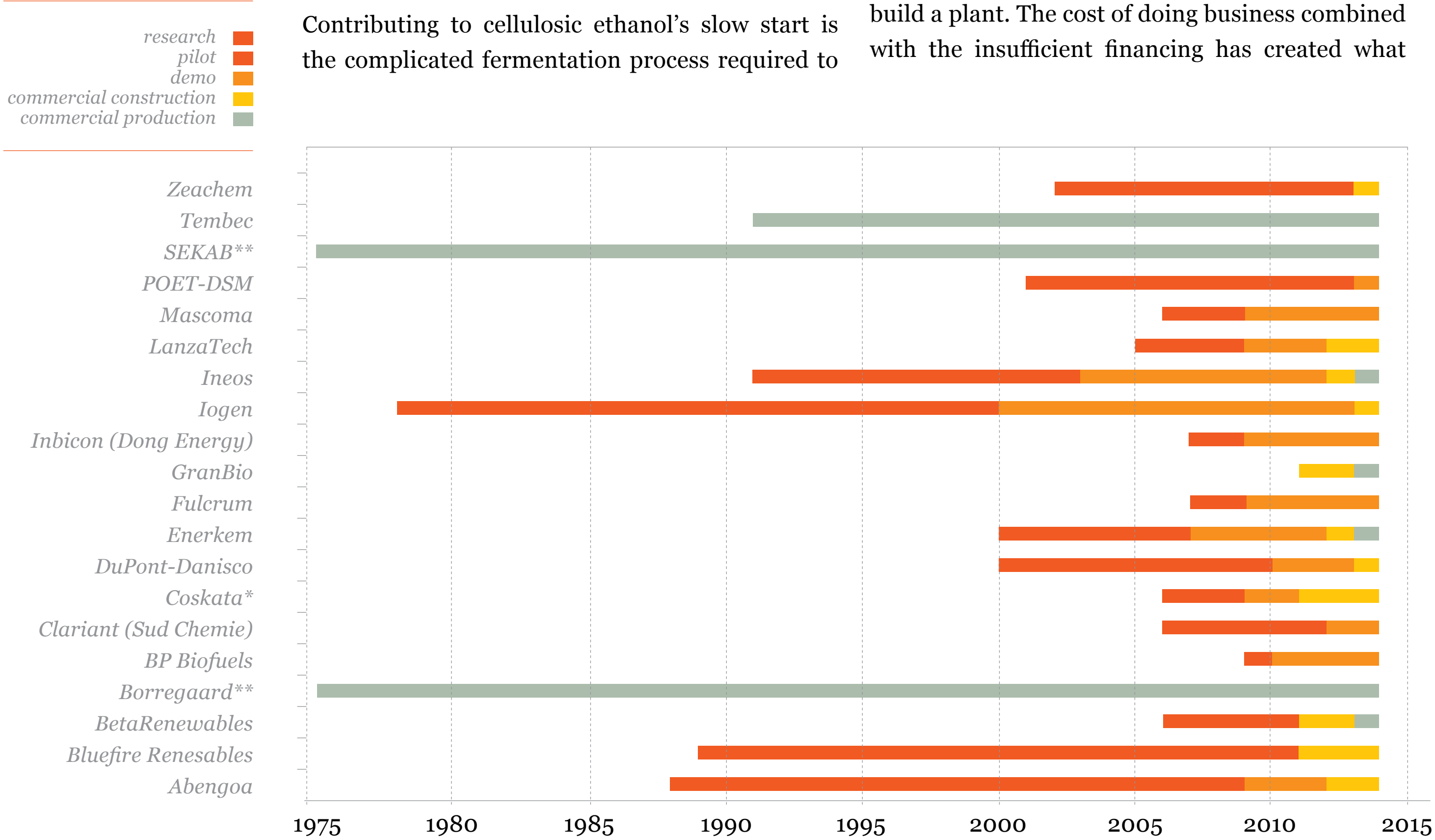
Contributing to cellulosic ethanol's slow start is the complicated fermentation process required to make it. Compared to the well-established chemical processes used to make diesel from oil, the biological fermentation process to brew ethanol from lignocellulose is much less predictable and much harder to scale up.

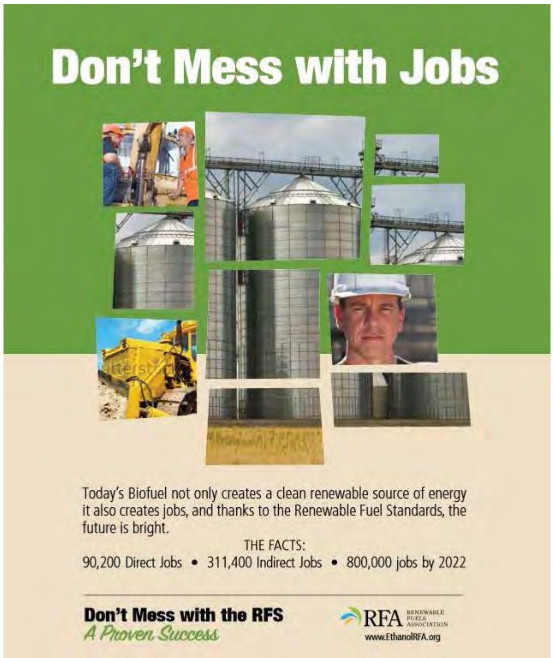
Finally, the pace of cellulosic ethanol production looks all the worse through the lens of "some very crazy expectations," says Lane. Federal regulators set targets to create demand for cellulosic ethanol but ramped up targets several years too soon. The mismatch between the mandate and actual production, says Lane, has been "absolutely crazy."

In some cases, delays came down to problems in obtaining adequate feedstocks (plant biomass needed for production). In other cases, the technology has been less efficient than expected. Much-heralded Kior announced last spring that it had to temporarily halt operations in its Columbus, Miss., plant because the overall yield of transportation fuels from each ton of biomass has been lower than expected "due to a delay introducing our new generation of catalyst" and mechanical failures interfering with the desired chemical reactions in its reactor.

But most problems come down to money—either the cost of production or the financing needed to build a plant. The cost of doing business combined with the insufficient financing has created what

### *CELLULOSIC TIMELINES CHART*






*"Don't Mess with Jobs," an ad that is part of the Renewable Fuels Association's advertising campaign "Don't Mess with the RFS"*

some observers have dubbed the "Valley of Death" for next-generation fuel companies.

The industry's high costs and production shortfalls frightened off many investors and have created an additional obstacle – something that Lane calls "the 'Valley of Disbelief' – the period when companies have figured out a means across the Valley of Death but the market remains irrationally skeptical."

Brooke Coleman, executive director of the Advanced Ethanol Council, agrees that expectations for advanced biofuels were unrealistic. "There's a pervading thought out there that cellulose has not come through like we thought," he says. Instead, he adds, it's almost inevitable that federal mandates and cellulosic ethanol production would be mismatched – at least in the beginning.

Any new technology, he says, "has a hockey stick development curve, so the initial years are incremental and slow. And then all of a sudden you have replication of the technologies that work, and it becomes a very efficient and aggressive growth curve if the marketplace is prepared for that type of growth.

The big hurdle now, says Coleman, is federal policy – specifically, uncertainty whether revised mandates will be high enough to guarantee a market.

Abengoa chair Felipe Llorente has singled out attacks on biofuel mandates by fossil fuel producers as an obstacle. **THE AMERICAN PETROLEUM INSTITUTE, FOR EXAMPLE, LAUNCHED A MASSIVE CAMPAIGN IN 2013 TO REPEAL THE RENEWABLE FUEL STANDARD.**

"Technologically we're fine," says Coleman. "The problems we're having are primarily with the administration of the program. The thing that is keeping cellulosic biofuels at bay – one, two and three on the list – is policy uncertainty, policy uncertainty, policy uncertainty." As a result, he says, plans for a second wave of plants are frozen until revised RFS mandates are announced. "With a handful of notable exceptions," he says, "they're on hold."

## *THE DARK HORSES*

The rocky ground for new cellulosic plants in the U.S. may have allowed Beta Renewables and GranBio to nose ahead in the race to production.

To some extent, their quick progress in comparison to other companies is an illusion. The parent companies of Beta Renewables were working on cellulosic technology long before forming Beta Renewables. GranBio engineers had the chance to work several months at Beta Renewables' Crescentino plant to understand the technology they were licensing. According to analyst Claire Curry of Bloomberg New Energy Finance, "It's kind of easy for the licensee because everything is done for them. And Beta Renewables guarantees performance."

Nonetheless, GranBio did several things extraordinarily well, especially in its strategic partnerships and its "don't reinvent the wheel" approach to cellulosic biofuel. One reason GranBio has been able to start production so quickly, says Vonnie Estes, U.S. managing director of GranBio, is that "we're not developing technology; we're deploying technology." (See interview with Vonnie Estes, p, 42).

Another advantage is location. Bioflex 1 is located only about 34 miles from the Atlantic port of Ma-

*"The problems we're having are primarily with the administration of the program. The thing that is keeping cellulosic biofuels at bay – one, two and three on the list – is policy uncertainty, policy uncertainty, policy uncertainty."*

*BROOKE COLEMAN, EXECUTIVE DIRECTOR OF THE ADVANCED ETHANOL COUNCIL*

*Nonetheless, GranBio did several things extraordinarily well, especially in its strategic partnerships and its "don't reinvent the wheel" approach to cellulosic biofuel.*

WEB EXCLUSIVES


*For more on GranBio, read our web exclusive at www.bioenergyconnection.org*

ceió – a good place to be since GranBio plans to export half of its ethanol production. "I am an economist, and I have to say that the price of ethanol is what makes an economist humble, because it is so hard to predict how the ethanol prices are going to evolve," says Hiltner. "If we had to export it today, 50 percent would probably be directed to California." He says that demand and prices are also subject to any revisions of the cellulosic biofuel standard by the U.S. Environmental Protection Agency, another indication of the importance of stable policies. (For more on GranBio's strategy, see our web exclusive at www.bioenergyconnection.org.)

To Jim Lane, the key to GranBio's quick rise has been people, resources, and an eye to the bottom line. He adds that BetaRenewable's exciting Proesa technology is one of the factors behind its success, along with its partnerships, extensive research, and the willingness to take risks. And their swift ascent offers lessons to other aspiring next-generation companies, fast on their heels.

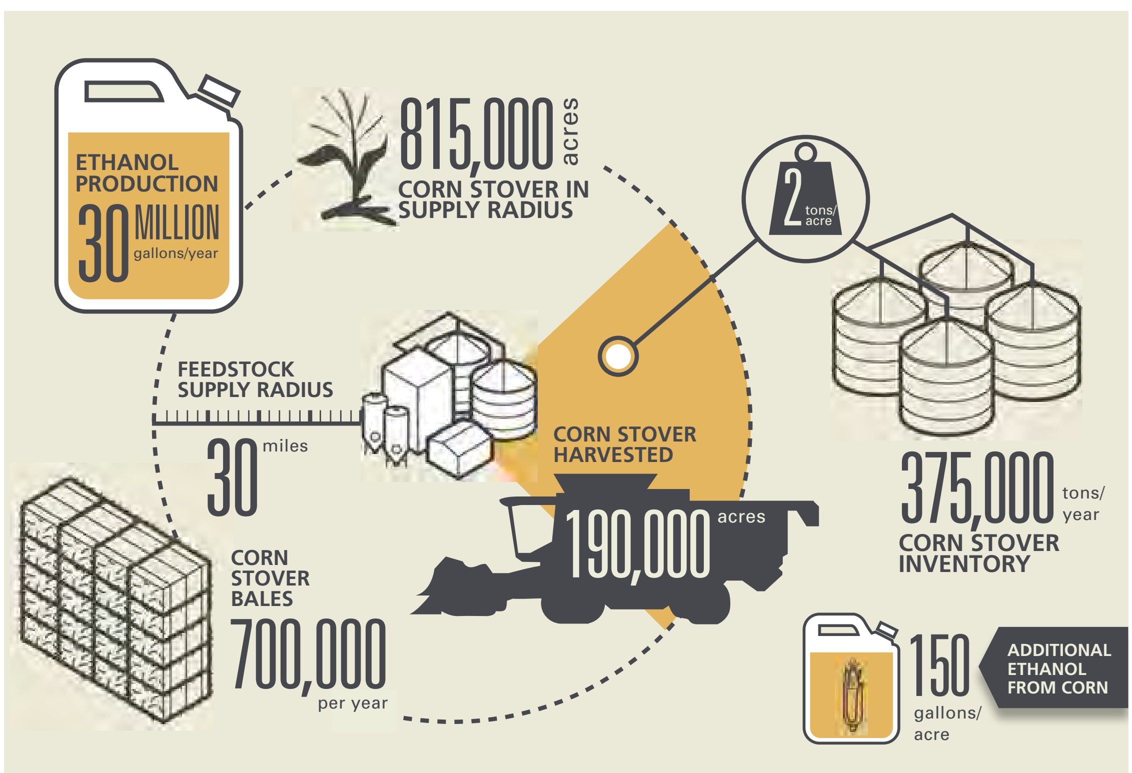
## THE NEXT WAVE

Also keeping its eye on Brazil, Canadian company Iogen Corp. has been working on cellulosic ethanol in its Ottawa facilities since 1978. Iogen's 1 million gallon per year demonstration plant has been operating since 2004. The demo has given the company extensive insight into the technical and economic challenges of next generation fuel production and led to more than 300 patents. In 2012, Iogen partnered with Raizen Group in Brazil to build a 10-million gallon-a-year cellulosic plant alongside the Pinto sugarcane mill in Piracicaba, São Paulo. Construction began in November 2013, with production expected by the end of this year. The Brazilian Development Bank has already approved funding for a second plant in Brazil.

In the U.S., activity has been frenzied since inception of the Energy Independence and Security Act of 2005, with several dozen companies launching pilot and demonstration scale programs (see *Bioenergy Connection*, Spring 2011, "Are we there yet?").

DuPont broke ground on its $200 million, 30-million-gallon cellulosics plant in November 2012. Located in Nevada, Iowa, it will produce cellulosic ethanol from corn stover – the stalks and leftovers from a corn harvest. "The plant's entire operation will be greenhouse gas neutral – it is fully sustainable and has zero net $CO_2$ emissions," DuPont reports.[5]

### MAKING CELLULOSIC ETHANOL A REALITY: BY THE NUMBERS




The DuPont Nevada Site Cellulosic Ethanol Facility is expected to be completed in 2015. Situated in a prime agricultural location, this over $200 million facility will be among the first commercial-scale cellulosic biorefineries in the world.

Meanwhile, Biochemtex, in partnership with Novozymes and Leaf Technologies, continues to expand its reach. The venture is moving forward with a plant in Clinton, N.C., using the energy grass Arundo donax, a wheat-straw to ethanol plant in the Fuyang region in China in partnership with Guozhen, and a partnership with Energochemica for a cellulosic plant in Strazske, Slovak Republic.

Of course, what some proponents see as the finish line is really just a starting point. One of the most pressing questions is whether cellulosic ethanol can be produced in a cost-effective manner. Another is whether the RFS and its policy incentives will stay in place and be strong enough to drive demand and attract investors. Still another challenge is growing and harvesting feedstock in a manner that is truly sustainable.

Along with the frontrunners, there are many other companies still at the pilot and demonstration scale facing these challenges. They will be pushing forward as the lessons learned from these pioneers are gleaned in the coming years. With licensing as a catalyst to adoption, cellulosic ethanol production could spread quickly if government incentives remain in place.

"This is a real fuel," said Steve Mirshak, business director for DuPont's cellulosic ethanol business, at a recent renewable fuels summit in Iowa. "We've been talking about it a long time, and in 2014, it's here. We need Washington to reinforce its commitment to the (RFS). With stable policy, we'll see rapid growth."

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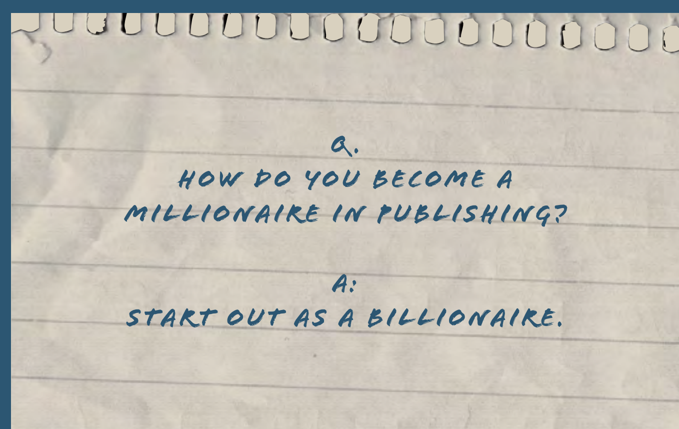
COMMENTARY

# GREAT EXPECTATIONS

Let's cut the biofuels industry some slack. After all, it took **1,631** U.S. automotive company failures to give birth to the massive auto industry that emerged.

By Jim Lane

There's an old joke in magazine publishing (one since adapted to many other industries) that goes like this:




It's been a long time since a new industrial sector has debuted — especially one aimed at the transportation sector. In a world more used to the costs and timelines of creating apps, iPads and other consumer electronics, investors have displayed a notable lack of enthusiasm for the timelines, the infrastructure dependencies, the capital requirements, and the risks in progressing to scale.

So let's look back into history for some guidance. After all, it wasn't so long ago that transportation industries were all the rage — steamships, railroads, airlines. Back in the 1890s, almost half of the stocks considered by Bradstreet's (precursor of Dun & Bradstreet) as the leading stocks were railroads.

COMMENTARY

# GREAT EXPECTATIONS

For something more recent, let's look at the automobile manufacturing industry. It has long since achieved scale and transformed society. And it's well worth a look back in understanding what it takes to make a successful and transformative new industry in the transportation sector. In particular, three items stand out at the dawn of the automotive era:

## 1. INFRASTRUCTURE

Consider that there were no freeways, improved roads of any type suitable for automobile traffic, no fueling stations, and the dominant fuel (gasoline) was not broadly distributed even at the wholesale level. There were no pipelines, speed limits, highway patrols, motels, highway diners or fast-food outlets, driving maps or navigation aids of any meaningful kind, traffic lights or parking garages, and the steel, rubber, glass and plastics industries would have to invest zillions to re-tool their supply capabilities.

A daunting task — and overwhelmingly a crisis of capital. The automotive industry was generally not expected to supply any of it – capital, that is. Instead, the public supplied it through highway taxes, general taxes, fuel taxes, and road tolls — and private industry tossed in millions and millions.

So as we look at infrastructure challenges in renewables and we hear cries for "no government intervention in industrial markets" and "no picking winners and losers," let's keep all that public spending in mind.

## 2. TIME TO SCALE

We hear a lot of things like "we've been researching it for 20 years, with no results," or "these technologies are always five years away."

What about automobiles? Generally, the explosion in demand began to occur around 1908, with the development of the Model T. It's instructive that the first automobile company — not basic research or lab work, but company formation — was formed in 1857. This company, Dudgeon Steam, died within 10 years of its birth and used a fuel technology (steam) that would ultimately not be a winner.

So, we have a 51-year stretch of innovation from first company formation to success at world-class scale. Reasons? One, cost. Two, infrastructure — which is to say, market access.

Begins to sound familiar, eh?

*This article was adapted with permission from an essay that first appeared in* Biofuels Digest.

*photos: Horse and buggy in the 1900s/Getty; Dudgeon Steam Car, 1847/Automotive Quarterly, 1971; Edsel, a car make now synonymous with "failure" / Getty images*

## 3. FAILURE RATE

We have heard an awful lot of blowback aimed at the Department of Energy for backing failed companies with loan guarantees – despite the fact that the DOE recorded a lower default rate than the general project finance market during its loan guarantee heyday.

The loan guarantees were aimed at reducing the cost of capital sufficiently so that adequate returns in the early days existed for companies that built towards scale –given that investors have choices and focus on investments that maximize return on investment (ROI), rather than maximize good public policy outcomes.

Let's look at the failure rate for automobile manufacturers in the United States. Today, there are less than 10 that operate at scale. Add another 15 or so if you like to account for foreign makes that have U.S. manufacturing – e.g. Mercedes-Benz, Honda, Toyota, Nissan, and so on.

**NOW, LET'S LOOK AT THE FAILS: 1,631 IN TOTAL – A COMPANY FAILURE RATE OF SOMETHING LIKE 95 PERCENT.**

The auto companies were operating for an average of 4.86 years before they failed. The failure rate, over the history of the industry, in the U.S. averaged 10.64 companies per year. In the more intensive earlier stage, between 1895 (around the debut of the gasoline engine) and 1964, the failure rate was 21.39 companies per year.

In the most intensive development stage of the industry, when company launches were a regular occurrence and consolidation was rampant — the period between 1899 and 1930 – the failure rate was an astonishing 42.7 companies per year.

### NOT AN ARGUMENT FOR EMBRACING FAILURE

Of course, failure is failure. It's bad for investors. And just because there is a lot of failure in, say, the automobile industry, that doesn't grant permission to fail to biofuels companies. Nor does it entitle them, automatically, to support on the public dime.

They have to work with public policymakers to build consensus on the value of accelerating biofuels at scale, and tie that perceived value to smart investments that will appropriately shorten a development timeline that would be experienced in the general market, sans incentives.

But it is instructive for observers to put time, infrastructure investment and failure rates in perspective.

**NO TRANSFORMATIVE TRANSPORTATION TECHNOLOGY EVER WAS BUILT – RAILROADS, RIVER MARINE, CARS, OIL COMPANIES, OR THE AIRLINES — WITHOUT GENEROUS GOVERNMENT SUPPORT IN THE FORM OF CONTRACTS, INCENTIVES, AND INFRASTRUCTURE.**

So long as they are tied to generally agreed and positive public outcomes, they are popular and effective.

So when talking about the "crash" of the clean tech industry, let's remember how long it took the auto industry to get up and rolling.

BY
ASHWINI BHANDIWAD, PH.D.

COVER PACKAGE

# BIO-BUTANOL:
## BACK TO THE FUTURE

With higher energy content and better blending compatibility with gasoline than ethanol and widespread applications for synthesis of chemicals and polymers, it's no wonder that bio-based butanol has created a lot of buzz.

In addition to an energy density 48 percent greater than ethanol, butanol has a lower vapor pressure, is less susceptible to water contamination, and is less corrosive – properties that make it more attractive for use in the existing transportation infrastructure, including pipelines, storage tanks, and vehicles.

In August 2005, Ohio inventor and entrepreneur David Ramey drove his '92 Buick Park Avenue 10,000 miles across the U.S. exclusively on 100 percent butanol. He averaged 24 miles per gallon, beating his average of 22 miles per gallon on gasoline. Ramey wanted to prove that bio-butanol was a superior alternative to ethanol. "That event demonstrated to the public that a power-grade fuel alcohol made from corn is already available – butanol – with the potential to replace gasoline, gallon for gallon," he wrote afterwards.

*Ohio inventor and entrepreneur David Ramey drove his '92 Buick Park Avenue 10,000 miles across the U.S. exclusively on 100 percent butanol.*

DAVID RAMEY, INVENTOR AND ENTREPRENEUR

Since then, this alternative fuel has made great strides. In 2012, the U.S. EPA approved 16 percent butanol blending in gasoline and 20 percent blending in diesel fuel. That same year, a 24 percent bio-butanol gasoline blend was used at the Olympic Games in London.

Besides its use as a fuel, butanol is used as a building block to make chemicals for the $85 billion paints and coatings market and the $700 billion polymers and plastics market. Industry also uses butanol to produce key derivatives, including acrylates, acetates and glycol ethers. Two different isomers of butanol are most common – n-butanol, a straight chain molecule; and iso-butanol, a branched molecule. Each has similar fuel properties but different applications in the chemical industry.

*Given its versatility, it is not surprising that small and large companies worldwide are racing to scale up this renewable source of butanol.*

The big players include Butamax (U.S. – U.K.), Gevo (U.S.), Cobalt Technologies (U.S.), and Green Biologics (U.K.), Cathay Industrial Biotech (China), Metabolic Explorer (France), and Tetravitae (U.S., now part of Eastman Chemicals).

Smaller companies are also offering innovative solutions including Optinol, Microvi Biotechnologies, Butrolix, Elcriton, Calysta, Butalco, EnerGenetics, and Gourmet Butanol. Ramey's company, Environmental Energy, became Butyl Fuel, which later merged with the biotechnology company Green Biologics and focused on butanol and other four-carbon bio-based chemicals.

Bio-based butanol was first discovered in 1862 by famed microbiologist Louis Pasteur. Microbes capable of producing acetone, butanol and ethanol (A-B-E) were used industrially as early as 1902, to make solvents and for making synthetic rubber and cordite (smokeless gunpowder). The A-B-E fermentation went on to become the second largest fermentation industry next to ethanol. A-B-E was viable until the 1950s, when the industry could no longer compete with the lower cost of the petroleum-derived molecules.

Today's bio-butanol companies have several advantages. First, they can leverage the existing highly efficient infrastructure for corn ethanol. Second, companies in the 1950s were limited to naturally occurring strains. New tools in metabolic engineering, better controls for the fermentation, and improved methods for solvent recovery have improved efficiency. Third, new material markets, combined with better life-cycle performance, government incentives and higher oil prices have improved the economic opportunities for bio-butanol.

The example was set by Butamax and Gevo, arguably the most contentious rivals in advanced biofuels. In 2010 Gevo collaborated with ICM to acquire and retrofit an 18 million gallon per year ethanol plant from AgriEnergy in Luverne, Minn., for isobutanol production. Butamax, a joint venture between BP and DuPont formed in 2009, partnered with Highwater Ethanol LLC, to retrofit a 50 million gallons per year corn ethanol plant in Lamberton, Minn., to produce isobutanol in 2011.

Butamax has engaged ten other ethanol facilities, with a combined production capacity of up to 900 million gallons per year, as part of an Early Adopter Group for its technology. It's not the first time the two companies have taken similar strategies. Both have invested in metabolic engineering, microbial strain improvement, and solvent separation technologies: advances at the heart of an extensive patent dispute.[1]

Advances in cellulosic technology and the availability of other feedstocks will further expand opportunities for bio-butanol and its derivative products. This little four-carbon molecule could very well end up a giant in the future bio-economy.

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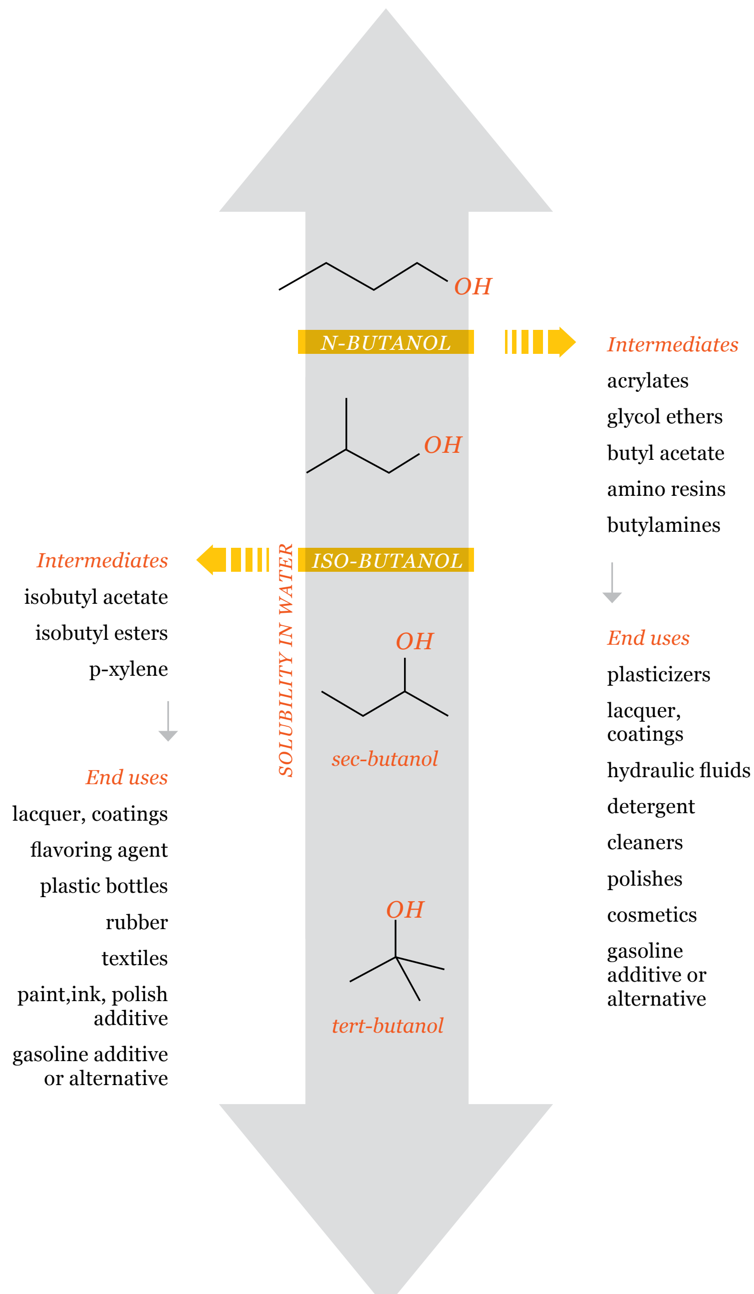
*The Butanol Isomer Family*



COVER PACKAGE

# BIOMASS Diesel

## Rising Star of the Renewable Fuel Standard

By Greg Breining

While cellulosic ethanol is just getting off the ground, the production of biomass-based diesel has climbed steadily, generally meeting its target volumes in the revised Renewable Fuel Standard (RFS2) with capacity to spare.

# How has diesel made from biomass become the current star of renewable fuel production while commercial cellulosic ethanol production has been hamstrung by delays?

The short answer: Biomass-based diesel is a cheaper, more mature technology than cellulosic ethanol. In addition, the needed technology and production capacity were available before the Great Recession of 2008, the fallout of which has continued to plague investment in expensive cellulosic ethanol plants.

"The economic collapse really took the wind out of the entire biofuels industry," says John Plaza, founder and CEO of Imperium Renewables, one of the largest U.S. producers of biodiesel. "Most of the biodiesel industry capacity was built prior to the economic collapse. And cellulosic ethanol was not yet built, not yet really ready to be commercialized, and needed some more work before it could really move forward. That led to sort of a stagnation in the scale-up of cellulosic ethanol."

## BIODIESEL VS. RENEWABLE DIESEL

Two kinds of biomass-based diesel fuel qualify as advanced biofuels under the Renewable Fuel Standard (RFS2). The first is biodiesel. It is made from vegetable oil or animal fats, which are converted to fuel by a chemical process known as *transesterification*. While biodiesel is compatible with conventional diesel fuel, it is not identical. It is usually blended with conventional diesel in ratios of 5 to 20 percent biodiesel, often denoted as B5 and B20, which can be burned in diesel engines without modification.

The second kind of biomass-based diesel is called "renewable diesel" or "green diesel." Like biodiesel, it is made from the oils of seeds, algae, or animal fats. Unlike biodiesel, it is transformed into fuel by a process used in conventional petroleum refining called *hydrotreating*[1]. The resulting fuel is chemically identical to conventional diesel and can be blended in any proportion. It has a higher energy content than biodiesel and works better in cold weather. Because renewable diesel duplicates conventional diesel, Plaza acknowledges, it's "a product that everybody would rather have."

Biodiesel has made up the great majority of biomass-based diesel production, but renewable diesel production has increased rapidly in the last year. If the fuels meet a 50 percent reduction in greenhouse gas emissions compared to fossil diesel, they qualify as advanced biofuels in the U.S. under the RFS2 and meet California's Low Carbon Fuel Standard (LCFS). This advantage has spurred both increased domestic production and imports, which spiked at nearly 60,000 barrels per day at the end of 2013.[2]

## ADVANTAGES OVER CELLULOSIC ETHANOL

Both biodiesel and renewable diesel have the advantage over cellulosic ethanol of being cheaper to capitalize – way cheaper. "Biodiesel is the cheapest biofuel production facility you can build," says Plaza. According to an industry rule of thumb, says Plaza, a biodiesel plant costs about $1 per gallon of capacity. A renewable diesel plant costs about $3. And cellulosic plants range from $8 to $25 per gallon of capacity. Though cellulosic promises to be much cheaper to produce in the long run, says Plaza, "the cost of capital for construction is a major factor in deciding what industry scales."

But biodiesel has its own set of issues. "The political angle of this industry is fraught with all sorts of problems," says Plaza.

Two challenges in particular stand out. First is a $1-per-gallon tax credit for biomass-based diesel that Congress has repeatedly allowed to expire with uncertain expectations about its renewal. Second is waning support for the RFS2. Political maneuvering that many suspect is backed by the fossil fuel industry is undermining standards and threatens the industry, Plaza says.

"It's great when that policy is in place," says Plaza. "If that policy would remain in place, I think that industry could start to develop new feedstocks, start to develop a better business plan long term that allows it to be more cost-competitive. Of course, everybody forgets the fact that petroleum is already heavily subsidized."

(Continued on page 26)

*Biomass-based diesel is a cheaper, more mature technology than cellulosic ethanol.*

> *"Of course, everybody forgets the fact that petroleum is already heavily subsidized."*


*Top photo: President Barack Obama shaking hands with the principal of Philadelphia's Workshop School, where students built a biodiesel car, on June 18, 2014/AP Images; Bottom: Flasks of biofuel in a University of Florida laboratory; Credit: Tyler Jones/UF/FAS archives*

But there are politicians in the U.S. willing to step forward for biodiesel. *In July 2014, 52 representatives from 22 states went to President Obama, asking him to raise volumes for biodiesel in the RFS2.*

The mandate calls for only 1.28 billion gallons in 2014 but the industry produced 1.8 billion in 2013. As a result, some plants began cutting back production or chose to go idle. In a letter to the Obama administration on October 1, the Governors' Biofuel Coalition stated that "[t]he EPA's proposed volume cuts for biodiesel are creating turmoil, resulting in production cutbacks and layoffs."

The U.S. is not the only country trying to absorb increased production. Argentina raised its blending mandate from 8 percent to 10 percent, largely to offset a decrease in exports to the E.U. in response to mandates in the Renewable Energy Directive (RED). But the E.U. is struggling with sustainability restraints that offer economic protection of domestic fuel production and incentivize biodiesel from waste more than plant oils such as soybean. In a controversial move, the E.U. implemented anti-dumping duties against Argentinian biodiesel last year and scaled back their biodiesel targets (which vary by nation) from 10 percent to between 5 and 7.5 percent.

But the greatest impact on bio-based diesel is yet to come. Several companies are working to scale up production of diesel from sugars through new microbial pathways, "micro-diesel" or new catalysis. As of 2014, 19 countries have biodiesel mandates in place. How these new technologies develop may well depend on whether these policy decisions remain stable over the long term.

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COVER PACKAGE

# AVIATION BIOFUELS

## *ON THE RUNWAY*

BY TODD WOODY

Biofuels have powered luxury business jets and military planes. Now they're revving up for a takeoff in commercial flights

In 2011, as a reporter for *Forbes* magazine, I was invited to chronicle the first transatlantic flight to be powered by biofuels, in this case a camelina-derived blend refined by Honeywell's UOP subsidiary. On June 17 of that year, I settled into the soft leather seats of Honeywell's Gulfstream G450 and sipped a chilled sauvignon blanc as the corporate jet reached cruising altitude en route to Paris from New Jersey and made history.

Later that month international regulators approved the commercial use of aviation biofuels like camelina that are made from hydroprocessed esters and fatty acids.

A little over a year later, again on assignment for *Forbes*, I found myself on a decidedly less luxurious but just as historic flight. Strapped into the cabin of a dimly lit Navy C-2A Greyhound transport wearing a helmet and goggles, I braced for impact as the plane hit the deck of the USS Nimitz at 150 miles an hour and became the first biofueled transport to land on an aircraft carrier. In fact, the entire strike force cruising off Oahu was running on a mix of algae and cooking oil in a demonstration of the Great Green Fleet, an initiative to power half the Navy's operations from renewable sources by 2020.

It's now 2014, but I have yet to board a routine commercial flight powered by biofuels. Quantas, China Eastern Airlines, United, and Continental are among the airlines that have done such flights, often using a 50-50 blend of conventional and biofuel. But the green jet age is yet to take off, even though there have been hundreds of test flights using drop-in biofuel since Virgin Airlines made the first biofuel test flight in February 2008.[1] Still, the age of biofuel flights is on the runway, revving its clean green engines. The global airline industry has committed to becoming carbon-neutral by 2020 with a 50 percent reduction in greenhouse gas emissions by 2050. And in June, California biofuel maker Amyris and French energy giant Total announced they would soon begin selling a green jet fuel derived from sugarcane. Some airlines, such as KLM, already have begun limited flights using aviation biofuels. Simply put, the world's airlines will buy as much competitively priced aviation biofuel as manufacturers can make.

*The green jet age is yet to take off, but it is on the runway, revving its clean green engines.*

"They know they have a long-term, committed customer in aviation for biofuels," says Jonathon Counsell, head of environment for British Airways.

The Honeywell flight, Great Green Fleet demo and the numerous test flights conducted by major airlines in recent years have used a variety of green jet fuels, from algae to jatropha. All, however, were what you might call bespoke biofuels, produced in small, expensive batches.

The question now is how to scale up biofuel production. Even meeting the industry's short-term goal of burning biofuels to meet just 1 percent of annual global aviation jet fuel demand means producing 600 million gallons a year, according to Boeing.

"Everyone wants to build the nth plant – no one wants to build the first plant or the second plant," says Dr. Wallace Tyner, a professor of agricultural economics at Purdue University who studies biofuels. "You have to get some plants functioning and producing product at spec to attract investors.

"The uncertainty for investors is just huge," he added. "There's uncertainty on capital cost and feedstock price."

Much of that ambiguity owes to the United States Environmental Protection Agency's continuing changes to the Renewable Fuel Standard, which sets quotas for advanced biofuels production. The credits associated with biofuel production, called Renewable Identification Numbers, or

RINS, are crucial to the financial viability of refineries.

Over the past two years, the EPA has dramatically ratcheted down the quotas to reflect the dearth of refining capacity. For instance, the official 2013 target was 1.75 billion gallons. The EPA subsequently reset that to 6 million gallons and finally to 810,185 gallons to reflect actual biofuels production last year. This November, the EPA announced that it would delay setting quotas for 2014 through 2016 until next year.

Those constantly changing quotas have roiled the nascent biofuels industry. "That's not helping get those feedstock plants viable," says Veronica May, vice president and general manager for renewable energy and chemicals at Honeywell UOP, which sells biofuel-refining technology. In other words, the farmers needed to grow non-edible food feedstocks will be reluctant to invest in new crops if they're not assured of a market. And even once they do, it can take three years before there's a viable crop supply for biofuel production.

And the European Union's Renewable Energy Directive, which seeks to reduce greenhouse gases by 20 percent within the EU from 1990 by 2020, has thrown another wrench into the mix by its mandate that 10 percent of all road transport must come from renewable energy by 2020.[2] Some critics fear that this will divert nearly all available biofuels to road transportation, with little remaining for aviation – even though the European Commission, working with Airbus and leading European airlines, has developed a roadmap for producing 2 million tons of sustainable aviation biofuels a year by 2020.[3]

Some airlines are stepping into the void to help jump-start production, either by signing contracts to purchase aviation biofuels or by making direct investments in new refineries.

United Airlines, for instance, signed a contract with AltAir Fuels in June 2013 to buy 15 million gallons of renewable jet fuel over a three-year period. That's not even a rounding error on United's annual consumption of four billion gallons of jet fuel. But it is half the planned annual output of a facility AltAir is scheduled to complete this year near Los Angeles International Airport. The company cut capital costs by retrofitting an existing petroleum refinery and installing Honeywell UOP's green jet fuel equipment to process non-edible oils and agricultural waste.

"It will take time before we have substantial quantities of fuel available," says Angela Foster-Rice, United's managing director of global environmental affairs. "We would very much like to partner with AltAir further if this works while exploring other options."

### *"AIRLINES HAVE TO COME TO THE PARTY"*

British Airways, meanwhile, decided it needed to send a signal to potential biofuel investors by putting its own capital on the line. In April of this year, the airline announced it would both invest in the construction of the GreenSky London biofuel refinery to be built by U.S. company Solena as well as purchase the facility's entire production of bio-jet fuel when the project goes online in 2017. The 11-year contract to buy 13.4 million gallons of biofuel annually is worth $550 million and will account for 2 percent of British Airways aviation fuel consumption, according to Counsell, the airline's environment chief.

GreenSky will convert 575,000 metric tons of landfill waste annually into biofuel in a process

*The global airline industry has committed to becoming carbon-neutral by 2020, with a 50 percent reduction in greenhouse gas emissions by 2050.*

*Some airlines are stepping into the void to help jump-start production, either by signing contracts to purchase aviation biofuels or by making direct investments in new refineries.*


*Staff of the China Eastern Airlines in front of an airplane using biofuel shortly before the plane's successful trial flight on April 24, 2013 in Shanghai, China / ChinaFotoPress*


*Qantas chief executive Alan Joyce holding vials of biofuel during a media conference at Sydney airport preceding Australia's first flight powered by sustainable aviation fuel on April 23, 2012 / Greg Wood, Getty Images*

Solena calls Integrated Biomass-Gas to Liquids. In a "Gasification Island," plasma torches generate temperatures of $3,500^{\circ}$ C to reduce garbage and other urban waste to their molecular compounds to create a biosynthetic gas. The gas leaves the device and is sent to a conditioning chamber to cool to $300^{\circ}$ C and remove particulate matter and acidic gases. A Fischer-Tropsch process converts the gas into long-chain hydrocarbons. The crude is then refined into bio-jet fuel or biodiesel.

Given the years-long lead time to persuade farmers to grow a new non-edible agricultural feedstock and the continuing uncertainty over their sustainability, Counsell says British Airways is focusing on a virtually inexhaustible feedstock available immediately: garbage.

He notes that the United Kingdom generates about 200 million metric tonnes of trash a year. Just within a 25-mile radius of the planned plant, there's 10 million tonnes of landfill waste available. "If this works, we can build half a dozen more of these plants and we could meet 10 percent of our fuel demand," says Counsell. "In the U.K. there's an abundant source of waste so this is the obvious path for us to take."

The airline is also exploring the potential of other biofuels, such as algae. Ultimately, British Airways believes it can obtain 30 percent of its jet fuel from biofuels by 2050.

But if airlines are to hit their sustainability targets, then they need to step up and take the lead in investing in the first biofuel projects, argues Counsell. "I think it's necessary for airlines to invest in high capital-intensive projects like this one," he says. "You're going to need a range of investors, so I think airlines are going to have to come to the party and provide some of that investment capital."

*"You're going to need a range of investors, airlines are going to have to come to the party and provide some of that investment capital."*

*JONATHON COUNSELL, HEAD OF ENVIRONMENT FOR BRITISH AIRWAYS.*

Foster-Rice of United says such investment is something the airline would consider, though it would be a departure for the company. United, based in Chicago, is part of a consortium that is investigating the potential of a host of feedstocks, from municipal waste to corn stover – the inedible remains of a corn harvest – which is plentiful in the Midwest.

## *NO SILVER (OR GREEN) BULLET*

Work continues, meanwhile, on more exotic biofuels like algae. Sapphire Energy is operating a biorefinery on 80 acres of New Mexico desert called the Green Crude Farm. In long oblong ponds filled with brackish water, algae is fed a diet of carbon dioxide, and sunlight and oil is harvested from the resulting pond scum. The pilot project is only producing about 1.5 million gallons of oil a year, and the company doesn't expect production to reach commercial sale until 2018. It also still needs to obtain regulatory certification for its oil for use as ground transportation and jet fuel.

The revival of jatropha as a feedstock for aviation biofuel is also under way. Although jatropha lost popularity in biofuels circles over the last decade after investors found it bore too few oil-rich seeds, the San Diego-based company SGB has used genetic engineering to breed unusually high-yielding jatropha strains for use in biofuels (See "From Bio to Fuel," front inside cover).

Among SGB's clients is JetBio, a consortium of Airbus, BP and the Inter-American Development Bank that seeks to foster development of aviation biofuels. "The demand is huge — every single airline would like to be flying on biofuel today," Rafael Davidsohn Abud, JetBio's managing partner, told me. "We've been very pleased with what SGB has done with jatropha."

And the search continues for new non-food-crop plants that could be grown to feed airlines' appetite for biofuels. In the Middle East, for instance, a group that includes Boeing and Honeywell is supporting a project to grow the halophyte *Salicornia bigelovii*, a native, saltwater-tolerant scrub that thrives in coastal deserts. "It's another crop that can be grown in adverse situations and bring land that normally is not producing any type of crop and make it available for fuel," says Honeywell's May.

In other words, there won't be any single silver – or green – bullet when it comes to aviation biofuels. Rather, it's likely that, at least in the short term, a variety of feedstocks will be used to supply jet fuel in the regions where they're most suited for cultivation. In Brazil, that could be jatropha or sugarcane-based biofuels. The U.S. and Europe will probably rely on a mix of municipal waste and biomass like agricultural waste. Algae will be grown in a variety of hot, sunny regions with access to carbon dioxide. Boeing has signed an agreement with South African Airlines to explore the use of municipal waste for biofuels and to encourage smaller farmers to grow feedstocks.

That makes both logistical and environmental sense. In the U.S., a handful of airports account for most aviation traffic and thus it's logical to obtain locally sourced biofuel when possible to avoid the cost of transporting it by tanker. An existing pipeline in Los Angeles, for instance, will send green jet fuel from AltAir's refinery to United's facility at Los Angeles International Airport.

## *FROM GREENHOUSE GAS TO BIOFUEL*

The most widely available feedstock for a low-carbon jet fuel happens to be a fossil fuel – methane from natural gas. A San Francisco Bay Area startup called Siluria Technologies is commercializing a process called oxidative coupling of methane developed by MIT professor Angela Belcher that allows methane to be converted to biofuels without using the expensive and energy-intensive Fischer-Tropsch process. Instead, a catalyst grown as a nanowire, directed by a genetically modified virus, does the work. The result is a biofuel with half the carbon footprint of petroleum-derived jet fuel, according to chief executive Edward Dineen.

A Siluria pilot project near San Francisco Bay can produce about a quarter to a third of a barrel of gasoline a day. Methane or ethylene gas flows into a reactor containing the catalyst, and gasoline flows out the other end. On the day I visited the project, Eric Sher, Siluria's vice president for research and development, hands me a bottle filled with a clear liquid. I take a sniff – pure petrol.

With additional processing, methane could be refined into aviation fuel. But Dineen is in no


*A British airways jet / Getty istock. British airways is exploring algal biofuel and using municipal waste as feedstock to produce drop-in jet fuel.*


*Top photo: Camelina, a member of the mustard family, is a popular feedstock for drop-in jet biofuel/Credt: Biomass Hub. Bottom: Airport workers filling the tank of an Airbus with biofuel in preparation for its flight from Paris to Toulouse in October 2013 / Credit: ERIC CABANIS/AFP/ Getty Images*

hurry to pursue that market. At least not yet. "Aviation fuel is a lower-priced product and you're selling to the airlines, which are always under profit pressures," he says. Nevertheless, he has had discussions with some airlines. "I think down the road we'll probably make aviation fuel."

In the near term, the most abundant current source of aviation biofuel is something already being made in the hundreds of millions of gallons: green diesel. In January, Boeing announced that one of its chemists, James Kinder, discovered that green diesel – typically made from biomass or waste oils and fat – was perfectly suited for use as jet fuel. Unlike biodiesel – the stuff you may see pumped into a 30-year-old Mercedes sporting "Biodiesel: No War Required" bumper stickers – green diesel has a different molecular structure that allows it to pack an energy density that actually exceeds that of petroleum-based jet fuel.

Better yet, green diesel refining capacity stands at about 800 million gallons a year. A single refinery operated by Diamond Green Diesel in Louisiana, for instance, is now producing 130 million gallons a year.

"We had been looking at a number of years at different pathways for biofuels and we decided what's out there now and can those be modified to meet our needs," says Julie Felgar, managing director of commercial airplanes environmental strategy and integration at Boeing. "It was one of those kind of things that was right in front our faces, and we wondered why we or others didn't see it earlier. It's a case where you can be too innovative sometimes in looking for solutions."

Use of green diesel for jet fuel awaits regulatory approval, but Felgar and other industry insiders believe there's a secret weapon to launch the aviation biofuels industry – the Department of Defense.

The U.S. military is the biggest single buyer of fuel on the planet and is eager to substitute homegrown biofuels for imported oil – if the price is right. The Navy has bought small quantities of biofuel and has plans to invest in biofuel production by issuing grants to manufacturers. Wallace Tyner of Purdue has analyzed the effectiveness of contracts versus direct investment and found that a fixed purchase agreement is more effective at stimulating biofuels production and investment. "A contract reduces the risk to investors a hell of a lot more," he says.

Notes Felgar: "The Navy can use green diesel in their ships and ground fleets. They can drive production capacity and spur investment in other pathways. When policymakers put in place incentives that work well, the industry will take off."

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COVER PACKAGE

BY STEVE PIETSCH, PH.D.

# FLEX FUEL VEHICLES IN THE UNITED STATES:

# WHY ARE WE LAGGING BEHIND BRAZIL?

**Despite the danger posed by greenhouse gases from transportation, the United States is largely ignoring one of the lowest cost options to combat it: flexible fuel vehicles (FFVs).**

Why do we have so few of these "green" vehicles? After all, flex fuel vehicles are permitted to operate on higher ethanol blends than the current standard of E10 (10 percent ethanol blended with gasoline). Sure, they are gasoline engine vehicles, but they've been modified to operate smoothly on any mixture from straight gasoline and E10 up to E85 (a blend of 85 percent ethanol and 15 percent gasoline).

In addition, modifying a conventional auto to make a flex fuel vehicle is inexpensive. FFV technology is estimated to cost roughly $100 per vehicle at the time of manufacture.[1] What's more, retrofit kits are available for many cars for about $400. Another piece of good news is that FFVs will work even better with bio-butanol, the next emerging advanced biofuel (See article on page 22).

*Nonetheless, FFVs currently make up only 3 to 6 percent of the total U.S. light vehicle fleet of about 250 million vehicles, compared to more than 80 percent of the vehicles in Brazil.* E85 has captured less than 1 percent of the U.S. gasoline fuel market, and the Energy Information Administration estimates that in 2011, only 1 million of the approximately 10 million ethanol flex fuel vehicles in the U.S. actually used E85.[2]

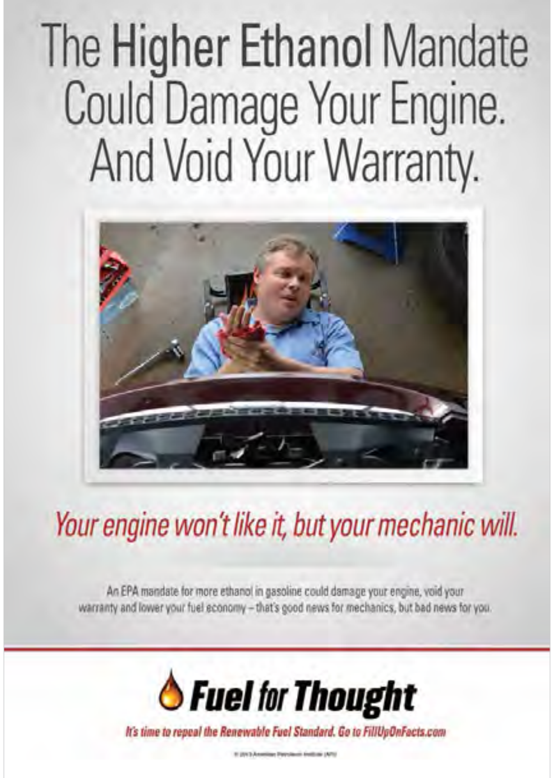
## *FUEL FOR THOUGHT*

Rather than pushing for more flex fuel vehicles, however, oil company associations have launched a public relations blitz against advanced biofuels. The American Petroleum Institute (API), a trade association for the fossil fuels industry, has rolled out a multimedia "fuel for thought" campaign warning consumers about alleged engine damage from E15 and other high ethanol renewable fuels and urging them to ask Congress to repeal the Renewable Fuel Standard.[3]

One of the API's first "fuel for thought" ads featured a car mechanic who tells viewers that ethanol is bad for cars. He quotes the American Automobile Association as saying that "too much ethanol could cause engine damage not covered by warranty." As he slides back under the car's engine sup-

*WEB EXCLUSIVES*

*For our web exclusive on "Making Things a Little Greener: Flex Fuel Drivers at the Pump," see www.bioenergyconnection.org*




*The American Petroleum Institute has put out a series of print, radio, and television ads seeking to repeal the Renewable Fuel Standard and charging that any ethanol blend greater than E10 would damage car engines/API*

posedly harmed by renewable fuels, the mechanic adds with satisfaction that ethanol is good for *him*.[4] Critics have attacked the ad as false and misleading: the AAA did not endorse the ad, and it also supports the use of ethanol and alternative fuels. And although higher-ethanol fuel is not suitable for all vehicles, it is suitable for FFVs and some newer vehicles.

Of course, there are multiple reasons – including misguided government incentives and lack of market pull – why there are so few FFVs in the United States. Most galling are the lack of incentives for manufacturers to produce compact car FFVs. Instead, government standards serve as incentives for carmakers to keep producing large, fuel-inefficient SUVs, sedans, and pickup trucks. This is because EPA rules allow automakers to use a contorted formula involving high ethanol fuels to dramatically overestimate the fuel efficiency of FFVs in calculating their fleets' corporate average fuel economy.

Because the gas mileage of SUVs and other oversized vehicles is so poor, carmakers get the biggest bang for their buck by making their least fuel-efficient vehicles into FFVs. As one *Consumer Reports* writer noted, his 2008 Chevrolet Tahoe test vehicle – which had a federal Corporate Average Fuel Economy (CAFE) fuel efficiency rating of 16 miles per gallon on its window sticker – was credited under CAFE rules with a rating of 27 miles per gallon, because it can run on E85.[5] In this fashion, General Motors obtains a 70 percent artificial boost on the vehicle's miles per gallon rating – all for an investment of about $100.

*More troubling, the EPA "incentive" allows carmakers to meet fuel-efficiency standards while retrofitting a relatively tiny number of gas-guzzling vehicles.* So, even though FFVs have been available in the U.S. since the 1980s, only 25 percent of new vehicles sold in 2014 will be flex fuel. [6] But as flawed as the CAFE credit may be, EPA's plans to substantially reduce it in 2015 and 2016 do not bode well for the future of FFVs. According to Texas-based consulting engineer Thomas Hogan, "Finding an FFV vehicle in the 2035 auto population might be as rare as finding a Dodo bird swimming in your backyard pool."

## PRICE IT AND THEY WILL COME

The lack of incentives for carmakers is not just a business issue, but a very real obstacle in the fight against global warming. Transportation accounts for 28 percent of all energy consumption in the U.S., and it remains almost exclusively the domain of fossil fuel-driven gasoline and diesel vehicles.[7, 8]

Even though the Department of Energy estimates that enough bio-ethanol could be produced to satisfy 30 percent of gasoline demand, penetration of alternative fuel is small, with ethanol accounting for 4 percent of all energy used in transport.[9] Ninety-two percent of transportation energy comes from petroleum, with 3 percent from natural gas and 1 percent from electricity. Perhaps not surprisingly, transportation accounted for 32 percent of all $CO_2$ greenhouse gas emissions in the most recent survey in the United States.[10]

Despite these potential gains, fuel ethanol consumption has stalled. This is largely because the Environmental Protection Agency originally limited the amount of ethanol that could be blended into gasoline to 10 percent by volume, due to concerns about ethanol damage to the engines of older vehicles. This so-called "blend wall" means that the U.S. gasoline market can only accept 12 to 13 million gallons per year of ethanol, which is about what corn ethanol producers are currently able to produce. This leaves no real market for an

*Former Brazilian president Luiz Ignacio Lula da Silva in flex fuel vehicle, 2007 / Getty Images*

increase in regular ethanol production or more advanced biofuels.

Two recently released studies suggest that FFVs and E85 can solve the short-term blend wall problem and ensure the growth of renewable fuels.

If 80 percent of the existing FFV fleet used E85, it would increase ethanol demand sufficiently to consume the available supply, overcoming the glut caused by the E10 blend wall, according to a study from Iowa State University.[11] It argues that the key driver is appropriate pricing of E85. A separate study by Philip Verleger, former visiting fellow at the Peterson Institute for International Economics, has shown that lowering the price of E85 can dramatically spur acceptance by FFV owners.[12]

Small wonder that consumers are paying attention. "In many locations today, a gallon of E85 is priced at least $1 less than regular E10," says Bob Dinneen, president and CEO of the Renewable Fuels Association. "These dynamics explain why we recently saw E85 purchases in Minnesota double in just one month."

### A CHICKEN-AND-EGG DILEMMA

Another overlooked driver for increased ethanol use is the increasing U.S. fuel economy standards – that is, standards for more efficient fuels. On March 7, 2012, President Obama made fuel efficiency and alternative fuel vehicles, including flex fuel vehicles, staples of his energy policy. This was accompanied by increasingly stringent CAFE standards – 54.5 miles to the gallon by 2025 - and investments in alternative fuel vehicles and fuel infrastructure.

Leading independent automotive technology firm Ricardo reports that nearly 3 out of every 4 vehicles will require a higher-octane fuel in the future to meet these standards. The demand for high-octane fuel has already strained our existing refining infrastructure, and the strain will only grow by 2025. How could the demand best be met? By high-octane biofuels such as ethanol and butanol. For this reason alone, having fleets of FFVs that can burn these at high blend ratios will be critical in the next 10 to 12 years.

This brings us to a chicken-and-egg dilemma: Automakers resist bearing the slightly higher cost to produce FFVs because there is not a market demand for them, and the developers of advanced biofuels cannot count on the rapid emergence of a vehicle fleet to provide a large-scale market for their products. Changing the incentives and mandates for automakers to offer FFVs across all their models would be the easiest and least expensive way to achieve the benefits of increasing biofuel use. Producing FFVs now to pave the market for the introduction of advanced biofuels at scale, experts say, is clearly the best choice.

In addition, increasing fuel efficiency while requiring the broad introduction of FFVs could dramatically reduce greenhouse gas emissions from transport over the next 10 to 20 years.[13] This will be particularly true when the commercial-scale production of advanced biofuels takes off in the United States. As the advocacy group American Coalition for Ethanol puts it, "While automakers and other engine manufacturers may need to make adjustments to accommodate this new fuel, they benefit by making a product that operates on the fuels of the future."

*"Finding an FFV vehicle in the 2035 auto population might be as rare as finding a Dodo bird swimming in your backyard pool."*

*THOMAS HOGAN, TEXAS-BASED CONSULTING ENGINEER*

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*OTHER FEATURES*

# SWEETENING THE BIOFUEL SECTOR: THE HISTORY OF SUGARCANE ETHANOL IN BRAZIL

Sugar crystals image / Credit: Getty Images/Kristin Duvall

## The evolution of the biofuel's R&D, science, and technology

By José Goldemberg, Ph.D., and Luiz A. Horta Nogueira, Ph.D.

**Nearly 500 years ago, the Portuguese introduced sugarcane to Brazilian agriculture. Soon Brazil became the world's largest exporter of sugar – a crop so lucrative and in demand that it surpassed the income from gold mines in colonial times and was known as "white gold."[1] Ethanol from leftover molasses – a byproduct of the sugar milling process – was first used to make alcoholic beverages. Today, sugarcane is sweetening the Brazilian economy in yet another way. Brazil is the world's largest sugarcane ethanol producer and home to one of the most important renewable energy programs in the world.**

In Brazil, no light vehicle has run on pure gasoline for decades.

> More than 80 percent of the Brazilian fleet of light vehicles (27.5 million cars in 2011) are flex fuel,

capable of using any blend of ethanol and gasoline, while the rest of the fleet uses gasoline with 18 to 25 percent of anhydrous ethanol. Brazil's biorefineries produce the organic equivalent of 930,000 barrels of oil per day, taking into account both liquid biofuel plants and cogenerated electricity.[2] The sugarcane sector in Brazil employs 70,000 sugarcane farmers and has an annual economic output of $50 billion,* providing 1.34 million direct jobs and accounting for 16 percent of the domestic supply of energy.[3,4] But today the ethanol industry is facing new challenges, including dwindling investment in sugarcane ethanol (See "Brazil at a Crossroads," our web exclusive). As the industry tries to regain its footing, a look at the past may help show the way forward.

**Ethanol has helped fuel motorized transport in Brazil since 1903. In demonstration tests in 1925, Model Ts using ethanol rambled through different regions of the country.**

Ford Model T adapted by INT for demonstrations of ethanol use in 1925

Since the early days, ethanol has helped fuel motorized transport in Brazil. In 1903, Brazil's First National Congress on Industrial Applications of Alcohol recommended the development of infrastructure to produce automotive ethanol.[5] While Henry Ford was promoting ethanol in the U.S., the Brazilian National Technology Institute was conducting vehicle tests aimed at substituting imported gasoline with a domestic fuel.[6] In demonstration tests, Ford Model Ts using ethanol rambled through different regions of the country in 1925.

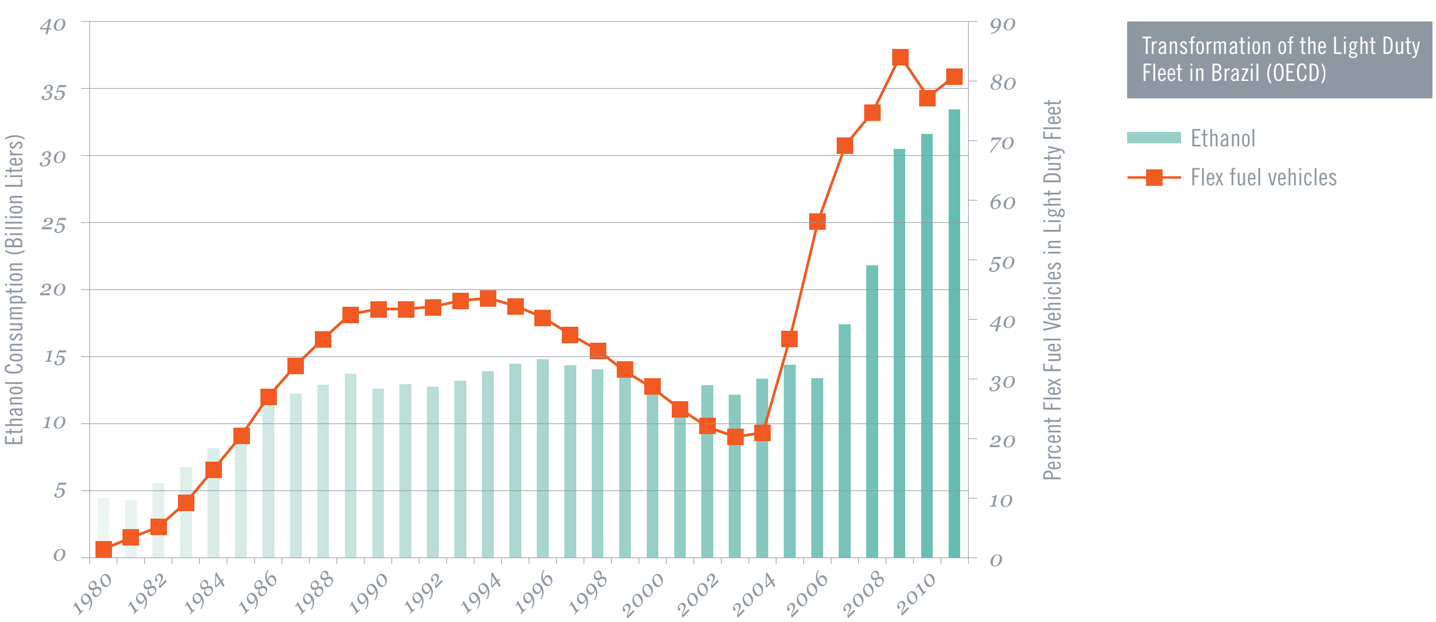
In 1931 the Brazilian government took a big step forward by implementing a compulsory blend of at least 5 percent anhydrous ethanol in gasoline (a mandate known as Decree 19.717). The move aimed to reduce dependence on petroleum-derived fuels and take advantage of excess production in the sugar industry. Initially, the mandate was applied only to imported gasoline, but later it was also extended to gasoline made in Brazilian refineries with imported oil. Over the years, the ethanol content varied depending on biofuel availability and sugar prices.

The oil shock of 1973, which increased Brazil's foreign debt and spiked inflation, inspired a newfound interest in ethanol. The government launched the National Alcohol Program in 1975, and the country became committed to reducing its dependence on imported oil, a commitment with many consequences. The government started spurring ethanol production by controlling prices. For example, the newly created National Alcohol Commission (CNA) set price parity between ethanol and raw sugar. Benefiting from this support, ethanol production increased from 580 million liters in 1975 to 3.676 billion liters in 1979, surpassing the target established for that year by 15 percent.

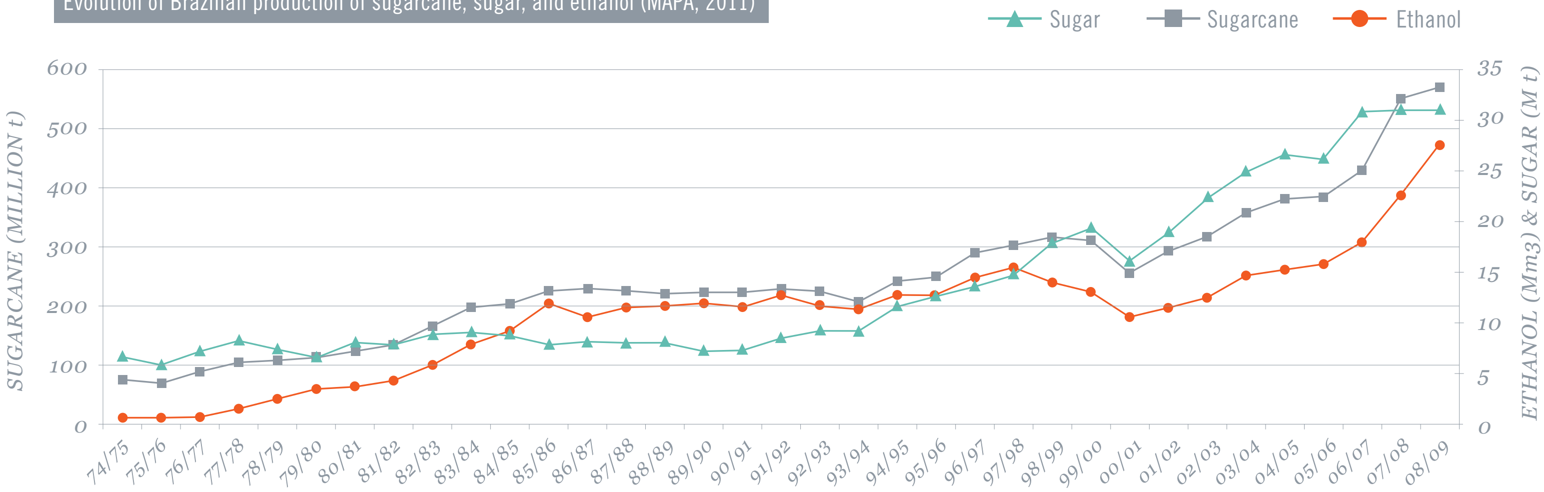
In 1979, with the oil crisis worsening and prices reaching new levels, the ethanol program gained new strength, and ethanol played an increasingly important role as a transportation fuel. At that time, imported oil was around 85 percent, accounting for 32 percent of all Brazilian imports, a burden to the national economy that justified the ambitious goal of producing 10.7 billion liters of ethanol in 1985. To this end, the federal government increased its support for alcohol production by creating the National Alcohol Council and the National Executive Commission for Alcohol, respectively, to oversee and implement the program. Under this scenario, ethanol production reached 11.7 billion liters in 1985, exceeding the planned goal by 8 percent.

**The oil shock of 1973 inspired a newfound interest in ethanol. The Brazilian government launched the National Alcohol Program in 1975 to help reduce dependence on foreign oil.**

Around 1985, support of ethanol started to fade in the face



Evolution of Brazilian production of sugarcane, sugar, and ethanol (MAPA, 2011)




of falling crude oil prices and strengthening sugar prices. The government scaled back incentives in 1986, ushering in a period of stagnation for the ethanol agroindustry. The absence of specific policies and government attention to support ethanol production led to sporadic supply shortages in 1989. As supply dried up, the government had to turn to emergency measures, such as reducing the level of ethanol in gasoline, using gasoline-methanol mixes as a substitute for ethanol, and even importing ethanol from other countries.

Ironies abounded. Not only was ethanol supposed to help Brazil wean itself from imported fuel, it was supposed to be a near limitless resource. The national advertising campaign said it directly: "Use what you need because there will be no shortage." The shortages shook the confidence of Brazilian consumers, which then led to the inevitable fall in sales of pure-ethanol-powered cars. Having accounted for 85 percent of new car sales in 1985, sales of ethanol-powered vehicles represented only 11.4 percent in 1990.[7]

Yet even during the period of reduced government interest on the ethanol, independent analysts recommended maintaining the program. They proposed scaling back production but ensuring continuity, not only for social and environmental reasons but also for economic benefits: At $30 a barrel, productivity gains had made ethanol competitive with crude oil. The State responded: In a process of liberalization, old agencies were closed, and the Inter-ministerial Sugar and Alcohol Council, the National Energy Policy Council, and the National Agency for Petroleum, Natural Gas and Biofuels were created. This institutional reshaping revived the industry and helped Brazil regain its place as a world leader in ethanol. After controlling the price of ethanol for decades, the government moved towards free-market pricing in the sugar-alcohol sector in 1991, progressively removing subsidies and implementing a new regulatory framework to organize the relationships between sugarcane producers, ethanol producers, and fuel distributors. Since then, ethanol has been traded freely between producers and distributors. The only feature that remained of the original supporting scheme was the differential tax on hydrated ethanol and ethanol vehicles, an attempt to make hydrated ethanol more attractive to consumers.

In 2003 a new line of cars with flex fuel engines appeared in the Brazilian market, to great customer acclaim. Car owners had the option of using gasoline (with 25 percent anhydrous ethanol), hydrated ethanol, or both. As a result, hydrated ethanol made a comeback in the domestic market. This opened new possibilities for the expansion of the sugarcane industry in Brazil as well as the international market for anhydrous ethanol.

It is important to note that growth in ethanol production was not due solely to expanded cultivation but also to significant gains in productivity and efficiency. Between 1975 and 2005, productivity per acre increased 3.5 percent each year on average.[8] As a result of this advance, the area currently dedicated to the production of sugarcane for energy is about 3.6 times smaller than the area that would be required at the productivity levels observed in the 1970s.[9]

The expansion of the Brazilian ethanol agroindustry stalled again in 2008, essentially because the government had artificially lowered the price of gasoline, making ethanol much less competitive in comparison. Motivated by inflation control, the Brazilian government (which holds the control of Petrobras, the main oil products supplier) has held the gasoline price at approximately $70 a barrel for the last 5 years, significantly below of the international parity prices formerly adopted.

Taxes have historically represented more than 40 percent of the final price of gasoline, but the Federal government has been grad-

Top: Sugarcane stalks after harvest / Credit: Dreamstime; Bottom: Native trees nursery at the São Manoel Sugar Mill, in central São Paulo. The company planted 200,000 native trees in 2012 as part of a reforestation program / Credit: EBI

ually reducing its tax in recent years. In June 2012, the main Federal tax on gasoline was set to zero. Currently, the gasoline price at gas stations is approximately 30 percent below the value that would be expected if taxes were applied. Because the Brazilian fleet is predominantly flex fuel, increased gasoline blending has decreased demand for ethanol. As a result, ethanol production in 2010 was 30 percent less than in 2008. In 2012, until November, Brazil exported 2.88 billion liters of cane ethanol and imported 219,970 liters of corn ethanol. Up to now, the Brazilian government has taken little effective action to change this situation, which highlights the relevance of public policies in the framework of bioenergy.

It's worth noting that ethanol isn't the only sugar-based source of energy. Electricity produced by combustion of bagasse, the excess plant material left over from sugar extraction, generates significant renewable electricity in Brazil. There are currently in operation 370 cogeneration systems in sugar and ethanol mills, with an installed capacity of 8,900 megawatts (MW) – 7.2 percent of total electricity generation capacity in the country. These generated 25 terawatt-hours (TWh) – or 25 billion units of energy – in 2012, 4.5 percent of the total domestic electricity generation. The potential for production of bioelectricity is still limited since only 129 plants (30 percent of 432 plants) are interconnected, allowing them to sell their surplus electricity to the grid.[10]

The bioenergy agroindustry in Brazil also creates much more employment than other energy industries and requires less investment per job created. About 10.9 jobs per ton of oil equivalent produced are created by the ethanol agroindustry, while the oil and natural gas industry creates approximately 0.47 jobs per ton of oil equivalent produced. In other words, the ethanol industry creates about 23 times more jobs per unit of energy than oil or natural gas.[11]

Jobs created in the sugarcane industry, according to several indicators (wages, educational profile, level of formalization, seasonality, and so on) are better than those observed in typical agricultural activities. For example, about 80 percent of sugarcane workers have a formal contract, twice the national average for agricultural workers.[12] The steady trend of mechanization of sugarcane harvesting has partially reduced the number of workers, but it has also increased the wages paid to employees.

Critics of the sugarcane ethanol industry have alleged that sugarcane ethanol drives up food prices and causes deforestation. Such consequences strike an intuitive chord in people and, if true, would call into question the long-term sustainability of this biofuel. So far, the evidence supports neither allegation. An examination of the food crisis of 2008-2012—a period of high prices and relative scarcity—indicates multiple causes, among them, rapid expansion of demand in Asian countries, increased oil prices, global financial instability, and climatic problems. No significant correlation between staple food prices and ethanol production has been demonstrated. In fact, the development of marginal areas for bioenergy production can reduce hunger and food availability.[13]

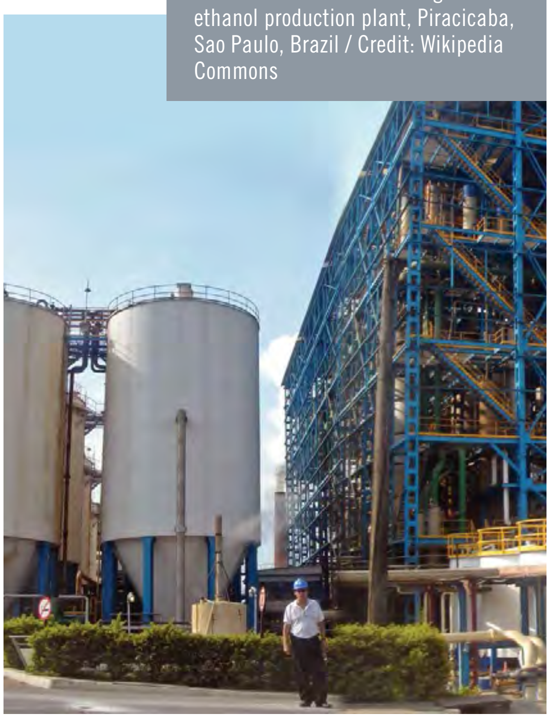
Likewise, the process of deforestation in the Brazilian rain forest cannot be simplistically associated with ethanol production. To store sugar in its stem, sugarcane requires a dry and relatively cold season that is not existent in the Amazon region. The more feasible areas for expanding sugarcane culture in Brazil are closer to the south-central part of the country, several thousand kilometers from the Amazon. Agricultural and environmental organizations in Brazil are adopting agro-ecological zoning—using maps of soil, climate and rainfall, topography and land use in classifying and defining the areas of highest potential yield while respecting environmental regulations and areas that should be preserved—to ensure that sensitive lands aren't lost to sugarcane fields.[14] According to estimates, there are about 65.0 Mha suitable for expanding sugarcane. This land is currently occupied by low-productivity pastures without native vegetation.[15] Detailed studies in Brazil suggest that the sugarcane crop has little to do with the deforestation of the rainforest.

By all measures, the Brazilian ethanol program has made huge strides during the last decades, showing strong signs of sustainability. There is still room for improving bioenergy production – increasing electricity production from bagasse, precision agriculture, advances in sugarcane breeding, vinasse biodigestion and biogas, and use of lignocelullosic residues, to name a few.

Public policies played a decisive role in the past in creating a strong biofuel industry in Brazil by reducing risks and encouraging investment and innovation. Today, the Brazilian ethanol agroindustry depends on a fair playing field in its competition with gasoline. The government has stepped in before to revitalize the ethanol industry. And once again, it may be government action and support that determine the future of this vital and historic industry.

Detailed studies in Brazil suggest that the sugarcane crop has little to do with the deforestation of the Amazon rainforest.

Photo below: Costa Pinto sugar/ethanol production plant, Piracicaba, Sao Paulo, Brazil / Credit: Wikipedia Commons



*WEB EXCLUSIVES*

*Get the latest on Brazil's ethanol challenges in our web exclusive: "Brazil: Bioenergy Powerhouse at a Crossroads," by Chris Woolston, M.S., on www.bioenergyconnection.org*

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# Vonnie Estes: A Passion for Sustainability

Vonnie Estes

Education:

BS, Horticulture, New Mexico State University

MS, Plant pathology, University of California, Davis

Business training: Berkeley, Harvard, Stanford, Wharton

Executive history: Monsanto, Syngenta, DuPont Cellulosic Ethanol, Codexis, GranBio

*The U.S. managing director of GranBio talks about the company's goals in a shifting RFS environment, her love of agriculture, and women in biofuels*

One of the leading female executives in the biofuels industry, Vonnie Estes started her career in agricultural biotech, working on ways to grow food more sustainably. She became enthusiastic about cellulosic biofuels more than a decade ago after making her first visit to Brazil.

Estes has worked as a top executive in global chemicals companies for more than 20 years, leading teams to identify commercial opportunities in the U.S., Latin America, Asia, and Europe. Among other positions, she served as vice president of commercial development for DuPont's cellulosic ethanol division and as vice president of strategic planning and technology at Codexis, which offers custom enzyme and biocatalyst services to industries from pharma to biofuels.

Today she is the U.S. managing director of GranBio, a privately held Brazilian company that recently completed a cellulosic ethanol plant expected to produce 22 million gallons per year. Estes talked with writer Katherine Griffin recently about GranBio and the state of the cellulosic energy market.

**The new plant has gotten a lot of attention lately. Longer term, what is GranBio's mission?**

Bernardo Gradin, the company's founder, comes from the petrochemical industry. When he started the company in 2011, he was looking at building chemical plants based on biomass. No one was ready to build a plant. That's why he started on cellulosic ethanol. The plan is to invest $2 billion over the next eight years, to build 10 cellulosic ethanol plants like the one we've built in Brazil, and five chemical plants.

The drive is to make products that would normally be made from petrochemicals that will have a much smaller carbon footprint. Right now, we're using what's left over from the harvesting and processing of sugarcane. We are working on energy cane, which would be a very high-yielding biomass that we would plant in areas that have been overgrazed, so you're not taking away really good land that could be used for something else.

**How will GranBio's plans be affected if the EPA makes a drastic change to the cellulosic ethanol mandate?**

Certainly when we started building the plant—like everyone who was starting to build—we were expecting the high value from the RINs [renewable identification numbers]. And now if they keep the proposed value from the RVO [renewable volume obligations], we're all very concerned that that will hurt the market. Because that's what really drives innovation and willingness to invest in the technology.

For us specifically, we will still be able to count the fuel as an advanced biofuel and get the D5 advanced biofuel RIN. We just don't know if the D3, the cellulosic ethanol RIN, is going to have any value. We will bring the fuel into the U.S. anyway, to California. I'm spending lots of time right now in Sacramento getting the fuel registered to get the Low Carbon Fuel Standard value. That value, depending on the cost of carbon, will probably be higher than the D3 RIN value would be anyway.

**A number of companies hoping to produce cellulosic biofuel have failed to cross the so-called "Valley of Death"—the hazardous period when emerging companies face difficulties in raising expansion capital to build their products at commercial scale. Why do you think some prominent advanced biofuel companies have failed to cross that valley?**

The biggest problem is getting capital to build. Even plants with proven technologies, if they don't have 50 or more engineers to deploy to make the thing work and then they start running out of money—it's just hard. You need to try a bunch of different things. For some of the small biotech companies, there's a different skillset between getting the technology to work at lab scale and being an engineering company and building a plant.

One thing we've got to our advantage is that Bernardo's brother Miguel started another company, GranEnergia, at the same time as GranBio. That is our engineering procurement construction contractor. That's a huge advantage, to have your brother be the one to call when something is not going right.

**Kior's problems, in particular, have gotten a lot of attention. What have you learned from watching that story unfold?**

Kior was one of the companies that had venture capitalists involved early, and VCs are looking for short-term return. This is a long-term process. I'm not close enough to the technology to know what might have happened if they had had more time and money.

**Right now there appears to be great reluctance on Wall Street to invest in advanced biofuel equities, especially cellulosic biofuels. When and how do you think this situation may change?**

Right now, DuPont is building a plant. Abengoa, Enerkem, POET-DSM, Chemtex/BetaRenewables in Italy, and our plant all opened up in the second half of the year. When companies like DuPont build a plant and it runs, and POET, who knows ethanol, builds a plant and it runs, and billionaires like Guido for Chemtex and Bernardo for GranBio build their own plants and write the checks—if the plants are producing ethanol and it's working and it's economical and we have a good policy platform, Wall Street will follow.

Policy risk is still the issue. We need a platform of policy to drive the investment. That will be a problem in the U.S. because the EPA is being so cautious. It's heartbreaking to me that we are on the brink of being successful and we are having the policy rug pulled out from under us. A lot of it is environmental backsliding. We've seen for decades that when the economy is not going well, people forget that they care about the environment.

*Top: Vonnie Estes climbing Mt. Shasta, a volcano in Northern California; Bottom: Estes joking with colleagues at a sugar mill in Brazil*

**In Brazil, 87 percent of the autos and trucks are flex fuel vehicles. What does the U.S. need to do to make this a reality?**

I don't see that happening in the U.S. We've had such a fight trying to get to 15 percent ethanol. With old cars, because ethanol is a solvent, there have been problems with hoses in some of the tubes. With new cars, the car companies are unwilling to give a warranty to run more than 10 percent ethanol. Is that because of the oil company lobby? I don't know. In the U.S. we have more cars, more people, more powerful lobbyists for the oil companies. We might get to 15 percent. And there may be be a niche market for E85 (fuel that is 85 percent ethanol).

**Are biofuels the best way to affect greenhouse gases in transportation?**

Today it is because there are not a lot of other alternatives. Especially in California, if the Air Resources Board (ARB) could snap its fingers and make the whole fleet electric, that would be their choice. But they have to look at everything; there are issues with batteries . . . We will probably get there and there will be more electric cars, trucks, and planes. But for the next couple of decades, this is where we can have the effect. Especially second generation biofuels.

**Globally, it sounds like California is an important part of the picture.**

What's great about California's Low Carbon Fuel Standard is that you do a life-cycle analysis and they give you a carbon intensity score. It depends on how much carbon you displaced. They don't care how you did it. They're not picking and choosing technologies. They have a model and whatever comes out, that's what you get. We are working really closely with the

ARB now because we are the first foreign-produced sale of ethanol that's gone through. I have a lot of respect for the guys at the ARB. They are wanting to do what is right, because everything they do is setting precedents for everyone coming after.

**What are some of the biggest myths about bioenergy among the general public?**

Corn ethanol has gotten a bad reputation with the fuel-versus-food argument. I think that's overblown. There is plenty of corn in Iowa. It's not taking food out of people's mouths. But is that the best use of fertile land?

There haven't been enough cellulosic ethanol plants running for the public to understand what it can be. The four that will come online are being built in rural areas and they will produce jobs, they will produce less carbon and they'll use residue that's on the ground that otherwise would have been burned. As that story gets out, we will have a better understanding.

*Estes in the U.S. division of GranBio in the San Francisco Bay Area / Photos courtesy of Vonnie Estes*

**What drew you to the field of bioenergy, and GranBio in particular?**

I started in agricultural biotech. My question was, what can we do to use food biotech to be better for the environment? That's where I spent most of my career. Then I started working for a company in San Diego, looking at some enzyme technology and what we might do with it. That was at the very beginning of the biofuel industry, in 2002. I started going to Brazil, to see what we could do with the biomass lying around. At that time, it was the corn ethanol boom. I was thinking okay, fine, but what else can we do that may be a little more sustainable? That's what drew me in. I love the agricultural part. I gave a talk in Philadelphia last week about what we're doing with feedstock in GranBio that is so different from what is being done elsewhere. It's great to talk about feedstock again. So different.

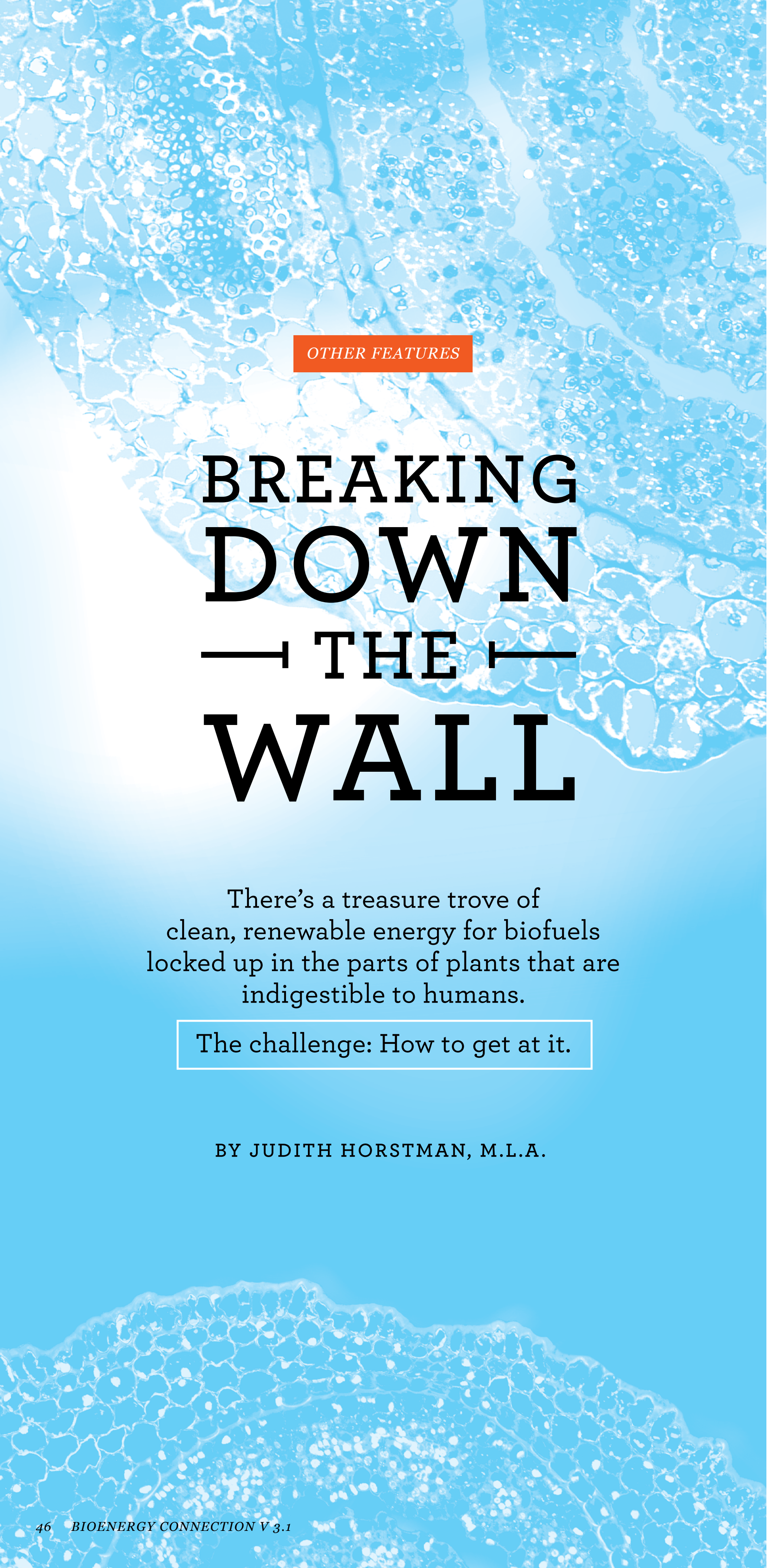
As for GranBio, there were so many reasons I wanted to work there. I had spent time in Brazil, and I really like the country, the people, and the culture. I had met officials there in my previous job. Bernardo and my boss are so wonderful and dedicated. And I had been working on cellulosic ethanol before the industry even existed. Colleagues have told me, "GranBio wasn't hiring a person, it was hiring a network."

**Biofuels Digest named you as among the top 100 people in the biofuels industry. There aren't many women on the list. Have you encountered sexism in the bioenergy field?**

That's a slippery slope. (Laughs.)

For me, starting out in agriculture, a lot of people were one or two generations away from being farmers, and they had wives or daughters who would work on the farm. It was a little sexist, but more, it was like, "We're all in it together."

Now that I'm touching the oil and gas industry, it's very different. There are fewer women. Biotech is very science-based and there are more women in science, but they tend to stay in the science part, not get into the business side. It's been hard. I miss having female colleagues. That is starting to change—there are more women in the field now.



OTHER FEATURES

# BREAKING DOWN THE WALL

There's a treasure trove of clean, renewable energy for biofuels locked up in the parts of plants that are indigestible to humans.

The challenge: How to get at it.

BY JUDITH HORSTMAN, M.L.A.

Every Labor Day for several years, long distance runner Rod Mackie would compete in a road race that went past a canning factory garbage dump just outside Hoopeston, Il. As a microbiologist at the University of Illinois at Urbana-Champaign, he couldn't help noticing a smelly, bubbling, porridge-like leachate that was oozing up from the ground.

Intrigued, he finally stopped after a race in 1993 to take a sample of what turned out to contain a versatile bacterium later named *Caldanaerobius polysaccharolyticus* – a heat-loving microbe that may be valuable in making enzymes for biofuel production.

Professor Mackie, a gut microbiologist, wasn't thinking about biofuel when he took the sample. He was looking for what he calls a "hot Beano" – heat-resistant enzymes to break down certain indigestible components of gas-producing foods like beans.

But his college also happened to have a fund for plant cell wall degradation and biofuel research. "As we were working with this particular bug, we knew it had a vast array of enzyme activities," he said. That started them thinking about what was in that bacterium's genome. It turned out to have a lot of enzymes capable of breaking down insoluble polysaccharides in plant cell walls—the first step in making second-generation biofuel.[1]

*Credit: Image provided by Mayandi Sivaguru, Anatoli Lygin, and Dean Riechers of the Dean Riechers Lab, IGB Core Facilities*

### A MIGHTY FORTRESS IS A PLANT

That serendipitous bit of bioprospecting (see sidebar, p. 50) highlights the new ways researchers are mining nature for tools in the quest for a commercially viable advanced biofuel – a sustainable alternative to our dwindling fossil fuels.

There's a wealth of bioenergy locked up in lignocellulose – the structural part of plant leaves, roots and stems. For most of human history, combustion of lignocellulose in the form of wood was the main source of energy. Approximately 10 percent of all human energy use today is still derived by combustion of lignocellulose, yet it is estimated only about 2 percent of the earth's annual supply is utilized by humans.[2]

The problem in using lignocellulose for biofuels is getting at it. That's because plants have evolved fortress-like cell walls over 450 million years, both to hold themselves upright and move water and protect themselves from disease and predators.

These cell walls are composed of lignocellulose, made up of three types of polymers – cellulose, hemicellulose, and lignin – that are knitted into a complex polymer matrix surrounding the plant cells. The cell walls make each cell rigid, allowing plants to grow upright (see illustration).

Because it is so difficult to decompose, lignin that is produced as a byproduct of advanced biofuel production is usually burned to provide heat and electricity for the overall biofuel production process.

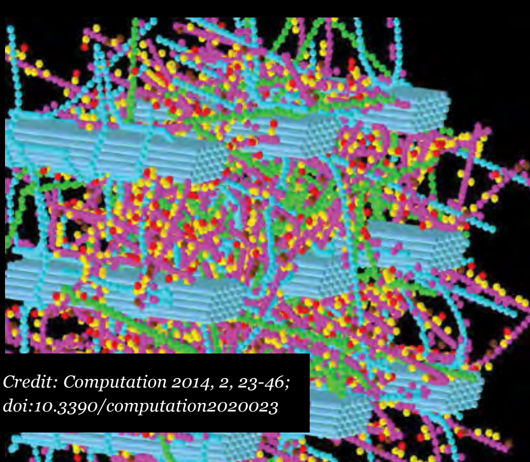
To make ethanol and other liquid fuels from lignocellulose, the most common approach is to use enzymes to break up the polysaccharides into free sugars and then use microorganisms to ferment the sugars to ethanol or other fuels (such as butanol, another type of alcohol). Most of the methods in these steps of biofuel production come directly from the brewing industry, in which the sugars in grains or grapes are fermented to the alcohol in beer and wine. In fact,

**THERE'S A TREASURE TROVE OF BIOENERGY** locked up in lignocellulose – the structural part of plant leaves, roots and stems. For most of human history, combustion of lignocellulose in the form of wood was the main source of energy.

**THE PROBLEM IN USING LIGNOCELLULOSE FOR BIOFUELS** is getting at it. That's because plants have evolved fortress-like cell walls over 450 million years, both to hold themselves upright and move water and protect themselves from disease and predators.

### COMPONENTS OF THE PLANT CELL WALL

The most abundant component in plant cell walls is cellulose, which comprises about half of the overall mass. At the molecular scale, cellulose microfibrils resemble long ropes composed of chains of glucose molecules (polysaccharides) that wrap around the plant cells to make them stiff. Cellulose is familiar to most people because it is the main component of cotton and paper and is the most abundant organic material on the surface of the earth.



*Credit: Computation 2014, 2, 23-46; doi:10.3390/computation2020023*

Hemicellulose, which is less well known, is composed of other sugars such as xylose and arabinose and coats the cellulose microfibrils to prevent them from sticking to each other. (In fact, paper is made by separating hemicellulose and lignin from cellulose so that the cellulose molecules adhere to each other without the need for any glue.)

Then there is lignin, which is composed of cross-linked phenolic compounds that stubbornly resist breakdown. It accounts for about one-fifth of lignocellulose. Not only is lignin a major component of coal (lignite) and soil, its molecular structure is somewhat similar to the PET plastic commonly used in water bottles. Like plastics, lignin is a very durable material that is not readily decomposed by biological processes.

so called "first generation" biofuels from corn or sugarcane are essentially 200 proof bourbon and rum.

Unlike first generation biofuels, which are made from sucrose or easily degraded starch, the main challenge in making liquid fuels from lignocellulose is in breaking up the polysaccharides that comprise cellulose and hemicellulose into free sugars. At present, plant biomass is usually "pretreated" with an acid or base that partially disrupts the plant cell wall structure so that enzymes can penetrate the biomass and depolymerize the polysaccharides to unlock the sugars – a process some scientists have dubbed "deconstruction."

It's a time-consuming and difficult process, thwarting nature's barricade. Depolymerization is the biggest challenge and the most expensive step in creating biofuel from plants, accounting for more than 50 percent of the costs, says Blake Simmons, Ph.D, Chief Science and Technology Officer and Vice-President of Deconstruction at the Joint Bioenergy Institute in Berkeley[3].

> MOST OF THE METHODS IN THESE STEPS OF BIOFUEL PRODUCTION come directly from the brewing industry in which the sugars in grains or grapes are fermented to the alcohol in beer and wine. In fact, so called "first generation" biofuels from corn or sugarcane are essentially 200 proof bourbon and rum.

> THE SPECIAL TOOLKITS OF ENZYMES PRODUCED BY CERTAIN MICROBES HOLD OUT PROMISE for renewable ways to unlock sugars from biomass. Mackie's garbage bug is one of many such specialized microbes discovered around the globe, from hot springs in Nevada, Iceland, and Yellowstone Park to backyard compost piles. Just as miners once prospected for gold in streams and rivers, scientists go on bioprospecting expeditions to look for these microbes, part of a class known as extremophiles, or "lovers of extremes."

## LOOKING FOR SUSTAINABLE SOLUTIONS

At first glance, it seems strange that it is difficult to deconstruct the plant cell wall because it is a process that happens naturally on a massive scale. The earth's ecosystems constantly produce plant biomass that eventually dies and is decomposed by a variety of organisms. Termites, cows and other ruminants, and other creatures consume some of the biomass, though they all rely on a consortium of microorganisms in their guts to break down the polysaccharides to sugars that they can then metabolize. And recently, Energy Biosciences Institute deputy director Isaac Cann and his colleagues at the University of Illinois discovered that some of the best microbial candidates for this process may actually reside in the human lower intestine.[4]

Other biomass is decomposed by free-living microorganisms such as filamentous fungi, which depolymerize the lignocellulose and consume the sugars and, in some cases, the lignin. Small wonder that one of the fundamental ideas underlying much of the research on advanced biofuels is deceptively simple: by understanding the processes used in nature to decompose biomass, we may be able to adapt some aspects of those processes in our goals of producing liquid fuels and chemicals.

"We've created entire industries to try to do something that bacteria (and fungi) have been doing naturally for millions of years," says Paul Gilna, Ph.D, director of the Department of Energy's Bioenergy Science Center in Oak Ridge, Tenn.[5]

Although scientists are exploring methods for decomposing biomass with high temperature processes or strong acids, the idea of adapting natural bioconversion processes is attractive because they are nonpolluting and renewable.

"We can do amazing things with technology, but very often it's highly energy expensive," said Timo Schuerg, Ph.D., a postdoctoral researcher who is studying the secrets of plant deconstruction by fungi at the Energy Biosciences Institute. "We need to look deep into nature and try to understand its sustainable solutions. We need to ask, how is nature doing it? That is the only way for us to achieve sustainability."

## NATURE'S OWN DECONSTRUCTORS: MICROBES

The special toolkits of enzymes produced by certain microbes hold out promise for renewable ways to unlock sugars from biomass. Mackie's garbage bug is one of many such specialized microbes discovered around the globe, from hot springs in Nevada, Iceland, and Yellowstone Park to backyard compost piles. Just as miners once prospected for gold in streams and rivers, scientists go on bioprospecting expeditions to look for these microbes, part of a class known as extremophiles, or "lovers of extremes." (See sidebar on page 50.)

Of course, no enzyme can do the job alone. Although plant cell walls usually have two main types of polysaccharides, the sugars that comprise the polymers are linked together in many different ways. Since each enzyme usually breaks just one type of sugar-sugar chemical bond, many different enzymes are needed to unlock the sugars in lignocellulose.

And when it comes to biofuel production, certain types of enzymes are more equal than others. Heat-loving (thermophilic) microbes and their enzymes, active at temperatures as high as 200 ºF that kill just about anything else, are especially well-suit-

*Dr. Louise Glass of the University of California at Berkeley (left); Drs. Isaac Cann (middle) and Rod Mackie (right) of the University of Illinois at Urbana-Champaign*

ed for a process that often involves extreme heat during pretreatment.[6]

Because different microorganisms have adapted to decomposing different types of biomass in everything from acid lakes to boiling geysers, they produce enzymes with many different properties. Scientists are exploring the properties of enzymes produced by microbes in different ecological niches in the hope of finding the enzymes that can withstand the extreme heat, acidity, and other harsh conditions in the industrial process to create biofuel and other products. Among the most coveted: Enzymes that are durable, heat-tolerant, have an acceptable Ph range, and are not inhibited by the other biocompounds in the process.

According to Douglas Clark, Ph.D, Chair of Chemical and Biomolecular Engineering at UC Berkeley and a principal investigator at the Energy Biosciences Institute, harnessing these microbes and their enzymes could allow biofuel producers to reduce the energy required to cool biofuel reactors. And because thermophilic enzymes are usually more stable – and chemical reactions are accelerated by temperature – it may take fewer of them to get the job done. “If we can use fewer enzymes, that would be a major breakthrough because it would reduce the cost,” Clark says, noting that enzymes are expensive.[7]

Scientists are searching for promising candidates with the tools of advanced imaging and DNA sequencing, used to study how microbes break down cellulose and hemicellulose into simple sugars. In one EBI project, using high throughput DNA sequencing, Mackie, Clark and other EBI researchers have discovered more than 27,000 carbohydrate-degrading enzymes in the rumen fermentation compartment of the cow stomach.[8]

Potentially useful enzymes have also been found in the guts of termites[9] and tiny wood-eating marine pests called gribbles.[10] “We are awash in biodiversity,” notes Chris Somerville, director of the EBI. “Finding the best enzymes among so many candidates is an overwhelming task.”

## A FUTURE WITH FUNGI

Bacteria are not the only microbes eating biomass. Fungi have evolved over millions of years, to become one of nature’s best – and most prolific—plant cell wall deconstructors.

“Fungi are the real experts in breaking down cellulose,” said Schuerg. If we didn’t have fungi, he adds, “we would have a big problem with cellulose waste”—all the leftovers from trees, grass, and harvests would be overwhelming.

At the CBS-KNAW Fungal Diversity Centre in the Netherlands, researchers are genetically barcoding the complete collection of more than 75,000 fungal strains, which are publicly available for use in bioenergy and other research areas.

“People keep looking for a super cocktail, usually from one fungal strain, that will do all the work,” says CBS scientist Dr. Ronald de Vries. “But the enzyme mixture that fungi produce tends to change over time as they degrade biomass, while in contrast commercial cocktails are static in their composition. To achieve the same efficiency as the fungi, the cocktail will probably need to be spiked with specific enzymes during the saccharification process."

"Also, a fungus in nature has no aim to fully degrade biomass," de Vries points out. "What it wants to do is find a food source, propagate itself, and try to stay alive. There is not a single fungus in the world that is truly dedicated to fully degrading biomass. But that's what we want it to do. So if we can identify the complex strategy by which it decides what to break down, and be able to combine the strategies of several fungi in our commercial process, we'll be closer to that goal."[11]

An ocean away at UC Berkeley, Schuerg is working on a model filamentous fungus, *Neurospora crassa,* a fluffy orange fungus often seen growing on trees after a fire. Valued by scientists for the ease of its genetics, biochemistry and molecular biology, it's seen as potential game-changer for bioenergy. Schuerg is investigating how it makes cellulases (enzymes that can chop up cellulose). "For biofuel we need a huge amount of enzymes," he says. "They are still pretty costly, so it's a bottleneck in biofuel production."

Fungal geneticist Louise Glass, Ph.D., Chair of Plant and Microbial Biology at UC Berkeley, has acclaimed *N. crassa's* virtues in a lecture called "Neurospora crassa: Portrait of a Fabulous Fungus." (Indeed, several postdocs spoke of the fungus with deep affection, with one comparing it to a beloved "lab pet.") Along with UC Berkeley Professor Jamie Cate, Ph.D., of the Molecular and Cell Biology Department, she and other researchers at the EBI have taken genes from the grass-eating fungi and inserted them into yeast, creating strains that are able to use sugars that are normally not metabolized. Another goal is to engineer the fungus to overproduce target cellulase enzymes at will. She has explained that what the researchers hope to produce in *N. crassa* is a blueprint for making inexpensive designer cocktails of plant cell wall-degrading enzymes.

Today's technology not only relies on the production of large amounts of enzymes - enzyme cocktails even need to be tailored to the many kinds of feedstock, which are "vastly different" in different parts of the world, said J. Philipp Benz, a postdoctoral researcher at UC Berkeley. In fact, "the composition of lignocellulose is very different even in different parts of one plant," he said. "The enzymes will have to work with similar efficiency on all of these."

(Continued on page 52)

## HOT SPOTS: BIOPROSPECTING FOR BIOFUEL'S MYSTERY BUGS

BY PETER JARET, M.A.

As the threat of global climate change intensifies, the astonishing organisms known as extremophiles may help us find practical alternatives to fossil fuels. The microbes of greatest interest to biofuels production are thermophiles – organisms that thrive at high temperatures. In fact, scientists "bioprospect" for them in hot springs and other extreme environments around the globe.

"The interesting thing is that extremophiles don't simply tolerate extreme conditions. They require them," says Michael W. Adams, Ph.D., professor of biochemistry and molecular biology at the University of Georgia. Organisms that require heat are particularly useful for many applications in the bioeconomy, including detergents, biotechnology, paper manufacturing, and breaking down cellulose in biomass for fuel and chemical synthesis.

Raising the temperature in biofuels production can speed the process and improve efficiency. That's why finding organisms and enzymes that operate at super-high temperatures could be especially useful, says Adams. "The conditions that hyperthermophiles require – temperatures as high as the boiling point of water – essentially eliminate all other organisms, so there's almost no need to worry about contamination in the production process," he explains.

Rajesh Sani, Ph.D., is an associate professor at the South Dakota School of Mines and Technology. He is also among the bioprospectors combing the world's "hot spots" for microbes that break down cellulose. Rather than prospecting in hot springs – a favored haven for thermophiles – Sani and colleagues have gone underground, collecting microbes 4,000 feet down a South Dakota mine shaft. "Even in January, when it may be snowing outside, the temperature down there is about 40 degrees C," he says.

Meanwhile, scientists like Christopher Rao, Ph.D., and his team are engineering strains of thermophiles capable of producing fuel molecules. Rao, an associate professor of chemical and biomolecular engineering at the University of Illinois at Urbana-Champaign and a principal investigator at EBI, has introduced genes into the thermophile *Geobacillus glucosidans* so that it makes ethanol molecules.

"What we do is prevent the microbe from making what it wants to make (organic acids) and get them to make what we want (ethanol molecules). To do so, we first have to delete, or knock out, the microbes' native genes, then add genes to the organisms," says Rao.

All this is pretty challenging in an organism that is 30 to 120 times smaller than the diameter of a human hair, especially because there are no standard techniques to draw on. "The technology for inserting genes into yeast was developed about 30 years ago, but those techniques don't really exist for these [microbes]," says Rao. "It's also complicated because bacteria exchange genes with one another and they're not species-specific – in biology, we'd say they have sex with one another." His lab uses a process called conjugation for manipulating the *Geobacillus* strain and has successfully "tricked" the thermophiles into producing ethanol and other fuel-like molecules.

Meanwhile, bioprospectors continue to search the planet for organisms that might help produce biofuels cheaply and efficiently. They've found complex organisms thriving in places no one would have expected. Here are some of the most promising:

### *CALDICELLULOSIRUPTOR BESCII*

WHERE FOUND: A freshwater volcanic spring in the Valley of Geysers on Russia's Kamchatka Peninsula.

WHAT IT LIKES: Temperatures around 78 °C.

CLAIM TO FAME: One of the most heat-loving bacteriums capable of breaking down cellulose, *C. bescii* can break down raw, unprocessed biomass. An enzyme in *C. bescii* has been shown to digest cellulose twice as fast as other known microbial enzymes. It also breaks down xylose, a component of plant cell walls that many commonly used biofuel microbes, like yeast, cannot use. Recently, the bacterium was tweaked at a University of Georgia laboratory to perform one-step conversion of lignocellulose into fermentable sugars for ethanol, cutting out the costly pretreatment processing.

FACTOID: First discovered in 1990, the bacterium was named after the BioEnergy Science Center ("BESC") at Oak Ridge, Tenn.

### *HABANAEROBIUM HYDROGENIFORMANS*

WHERE FOUND: Salty sludge at the bottom of Soap Lake, a mineral lake in Washington State.

WHAT IT LIKES: Extremely saline environments, at least 10 times saltier than sea water.

CLAIM TO FAME: *H. hydrogeniformans* is one of very few halophiles, or salt-loving microbes, that break down biomass efficiently enough to be useful for some applications of biofuels production. In addition to producing hydrogen from sugars in biomass, "it can also produce small amounts of electricity," said Melanie R. Mormile, Ph.D., a research professor at Missouri University of Science and Technology and a leading expert on the organism.

FACTOID: The water at the bottom of Soap Lake, where *H. hydrogeniformans* was found, is so salty that it has the consistency of syrup. At the turn of the last century, Soap Lake was one of the most popular mineral spas in the country, prized for its purported healing powers.

### *PYROCOCCUS FURIOSUS*

WHERE FOUND: A shallow thermal vent off Volcano Island, Italy.

WHAT IT LIKES: Temperatures at 100 °C, the boiling point of water.

CLAIM TO FAME: *P. furiosus* is one of the most heat-loving thermophiles. Its enzymes are already used in biotechnology to copy DNA and produce diols (chemical compounds that contain two alcohols). It has cellulase that tolerates 100° C and is being studied as a possible way to turn atmospheric carbon dioxide into chemicals. Researchers at North Carolina State University and the University of Georgia are tinkering with this microbe in an effort to create liquid fuels directly from carbon dioxide.

FACTOID: The name *Pyrococcus furiosus* literally means "rushing fireball." It is one of the few organisms with enzymes containing tungsten, an element rarely found in biological molecules.

*WEB EXCLUSIVE*

*For more about extremophiles, see "Microbes Living on the Edge," on www.bioenergyconnection.org*

*Dr. Markus Pauly of UC Berkeley: Making plant sugars more accessible*

## BREEDING BETTER RAW MATERIAL

UC Berkeley plant and microbial biologist Markus Pauly, Ph.D., is taking another approach: helping nature create plants that are better suited for biofuel production through spontaneous mutagenesis or targeted genetic alteration.[12] Plant cell walls have had to become extremely good at resisting breakdown because "plants can't run," as Pauly puts it. ("Of course, that hasn't stopped them from surviving for millennia," he adds.)

Because the lignin in cell walls is a barrier to releasing sugars, one way to improve plant composition for biofuels is to reduce the amount of lignin that plants make, "but then the plant lies flat on the floor," says Pauly, who is a principal investigator at EBI. Recently, he said, researchers have been able to program plants to make modified lignins that are chemically easier to break, but still keep plants upright.

Pauly's approach is to make sugars more accessible, or to select for mutant plants that accumulate more sugar or polysaccharides. Working with corn, Pauly and collaborators randomly mutated seeds, screened the resulting plants for high levels of polysaccharides, and identified a new corn plant variety called Candyleaf 1 (or CAL1, for the University of California). The mutation inactivated a plant enzyme that naturally degrades hemicellulosic glucan, a type of polysaccharide found in leaves and stems. They ended up with a corn plant which yielded 30 percent more sugar after conversion of its lignocellulose.

Corn grain has long been used to make biofuels, as it can easily be converted to ethanol. But using grain for fuel is problematic and controversial. The new variety created by Pauly and his lab at EBI presents a win-win: only the corn stover, or waste leaves and stalk, is processed to fuel, while the kernels can be used as a food crop. Because CAL1 is a non-transgenic, induced mutation, similar to those occurring in nature, there is no problem with genetically modified food controversy or regulation. The process could be used with other food crop residues from rice, wheat and so on, he said, adding, "You take and use the kernels for food and take the leftovers for fuel."

## BREAKING DOWN THE RESEARCH WALLS

Although small amounts of lignocellulosic ethanol are now being produced, there is a general sense in the biofuels community that additional innovation is required in order to achieve the kind of efficiency and profitability that will stimulate expansion of lignocellulosic fuels from about 20 million gallons today to more than a billion gallons a year.

One of the hurdles is the huge variety of plants and plant structures scientists would like to use – all of which could need specialized deconstruction and extraction techniques. Simmons says the goal is "an omnivorous pretreatment technology" that can handle any range of feedstocks.

Startling progress is being made through cooperation among the many disciplines involved. Historically, as science progresses, it becomes more specialized and compartmentalized. "We're starting see these walls tumble," said Simmons. The synergy of sciences and specialties at many research and academic institutions has been breaking down departmental barriers between chemistry, biology, botany, economics, engineering, waste management and animal science, to name a few.

The type of cross-disciplinary research practiced at JBEI and the EBI "is a fundamental mind shift, and one of the greatest payoffs … is to bring together individuals from a wide range of backgrounds and disciplines to work on a common mission," said Simmons. "The search for renewable and sustainable biofuel is calling up a new generation of renaissance researchers who will have an impact in far-reaching fields."

*– Chris Woolston, M.S., Timo Schuerg, Ph.D, and J. Philipp Benz, Ph.D., contributed additional reporting to this article.*

*NEXT ISSUE: CHEMICAL DECONSTRUCTION OF BIOMASS*

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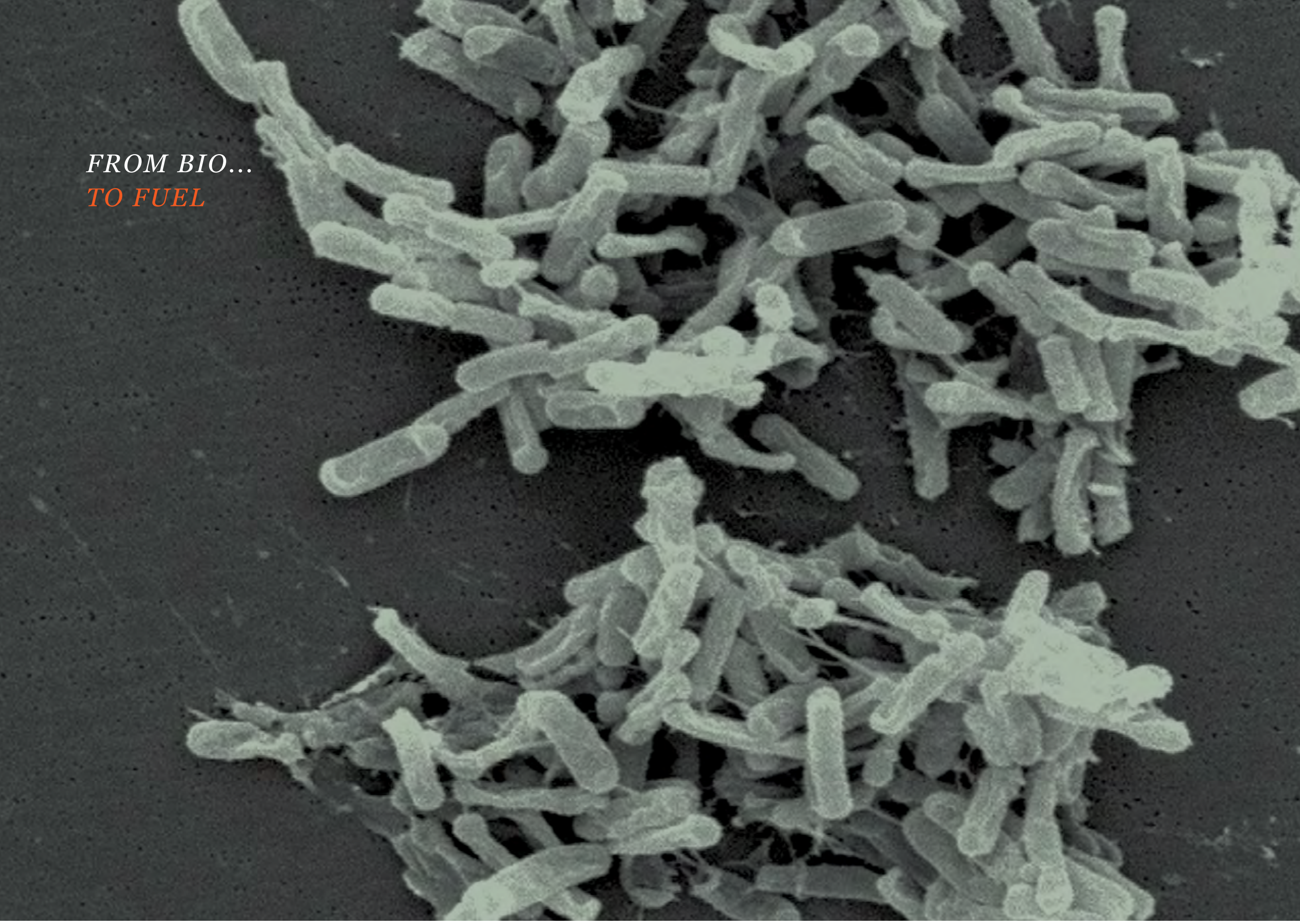

## *FROM BIO...*
## *TO FUEL*

*CLOSTRIDIUM:*
A BACTERIUM THAT CAN GROW JUST ABOUT ANYWHERE

### *WHAT IS IT?*

Clostridium is a genus of about 100 free-living bacteria and disease-causing agents (pathogens) that are capable of producing endospores. Individual cells are rod-shaped, from the Greek word *Kloster,* or spindle. The category includes several bacterium that have played a crucial role in biofuels for decades.

### *HOW DOES IT WORK?*

As early as 1916, scientists used it to produce biobutanol through a process called ABE fermentation – the airless conversion of carbohydrates by Clostridum strains into acetone, butanol, and ethanol.

### *WHY DOES IT MATTER?*

Commercial production of renewable butanol stopped as the petrochemical industry expanded, but over the past decade there's been renewed interest in biobutanol as a renewable drop-in transport fuel. Scientists are exploring Clostridium acetobutylicum for its remarkable ability to produce a range of metabolites (byproducts) useful to biofuel, as well as its exceptional diversity in the types of biomass it can grow on (everything from dairy and food waste to straw).

### *WHERE CAN I READ MORE?*

Check out the EBI paper *Engineering Clostridium Acetobutylicum for Production of Kerosene and Diesel Blendstock Precursors,* by S. Bormann, Z. C. Baer, S. Sreekumar, J. M. Kuchenreuther, F. Dean Toste, H. W. Blanch, and D. S. Clark, in *Metabolic Engineering,* 25: 124-130. doi: 10.1016/j.ymben.2014.07.003, July 22, 2014.

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HARVESTING CORN STOVER IN AN EMMETSBURG, IOWA FIELD

POET-DSM began producing cellulosic ethanol from the corn crop residue such as leaves, stalks, and corn cobs this fall at its plant in Emmetsburg, Iowa.

Photo courtesy of POET-DSM

For more information, contact poet.com/cellulosic

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