The Economist

The future of biofuels

The post-alcohol world

Biofuels are back. This time they might even work

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MAKE something people want to buy at a price they can afford. Hardly a revolutionary business strategy, but one that the American biofuels industry has, to date, eschewed. Now a new wave of companies think that they have the technology to change the game and make unsubsidised profits. If they can do so reliably, and on a large scale, biofuels may have a lot more success in freeing the world from fossil fuels than they have had until now.

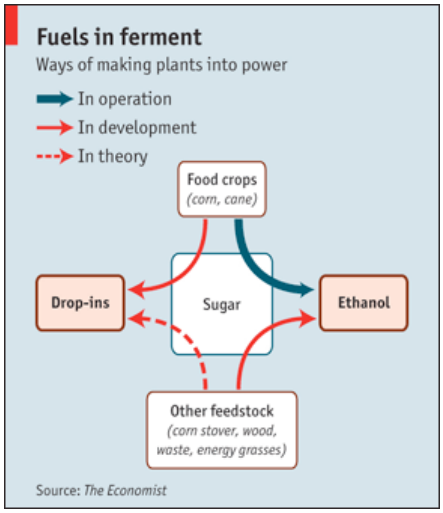
The original 1970s appeal of biofuels was the opportunity to stick up a finger or two, depending on the local bodily idiom, to the oil sheikhs. Over time, the opportunity to fight global warming added to the original energy-security appeal. Make petrol out of plants in a sufficiently clever way and you can drive around with no net emissions of carbon dioxide as well as no net payments to the mad, the bad and the greedy. A great idea all round, then.

Sadly, in America, it did not work out like that. First, the fuel was not petrol. Instead, it was ethanol, which stores less energy per litre, tends to absorb water and is corrosive; people will use it only if it is cheap or if you force them to through mandatory blending. In Brazil, which turned to biofuels after the 1970s oil shocks, the price of ethanol eventually became low enough for the fuel to find a market, thanks to highly productive sugar plantations and distilleries powered by the pulp left when that sugar was extracted from its cane. As a result Brazil is now a biofuels superpower. North American ethanol is mostly made from corn (maize), which is less efficient, and often produced in distilleries powered by coal; it is thus neither as cheap nor as environmentally benign. But American agribusiness, which knows a good thing when it sees one, used its political clout to arrange subsidies and tariffs that made corn-ethanol profitable and that kept out the alternative from Brazil.

This still left the problem: using corn limits the size of the industry and pits it against the interests of people who want food. Boosters claimed that cellulose, from which the stalks,

leaves and wood of plants are made, could if suitably treated become a substitute for the starch in corn. Both starch and cellulose consist of sugar molecules, linked together in different ways, and sugar is what fermentation feeds on. But cellulosic biofuel has so far failed, on an epic scale, to deliver. At the moment, only a handful of factories around the world produce biofuel from cellulose. And that fuel is still ethanol.

This is what companies working on a new generation of biofuels want to change. Instead of ethanol, they plan to make hydrocarbons, molecules chemically much more similar to those that already power planes, trains and automobiles. These will, they say, be "drop-in" fuels, any quantity of which can be put into the appropriate fuel tanks and pipelines with no fuss whatsoever. For that reason alone, they are worth more than ethanol.



Appropriately designed drop-in fuels can substitute for diesel and aviation fuel, which ethanol cannot. That increases the size of the potential market. They also have advantages on the production side. Because crude oils from different places have different chemical compositions, containing some molecules engines won't like, oil refineries today need to do a lot of careful tweaking. The same applies to the production of biodiesel from plant oils. Genetically engineered bugs making hydrocarbons more or less from scratch could guarantee consistent quality without the hassle, thus perhaps commanding a premium with no extra effort. Meanwhile the feedstock could be nice and cheap: Brazilian sugar. Tariffs that block Brazilian ethanol from northern markets do not apply to drop-in hydrocarbons.

Scale models

If this approach works, it will not only be beneficial in its own right—modestly reducing greenhouse-gas emissions while making money for its investors—it will also provide a lasting market incentive to scientists to devise better ways of turning cellulose into sugar. This gives the prospects for this generation of biofuels a plausibility that was missing from its predecessors. The drop-in firms are starting to come out of the laboratory, float themselves on the stockmarket, team up with oil companies and build their first factories. The dice, in other words, are rolling.

One of the leaders of the drop-in drive is Alan Shaw, the boss of Codexis, a firm based in Redwood City, California, which makes specialised enzymes that perform tricky chemical conversions. In Dr Shaw's opinion, the industry's problem has not been bad products so much as a failure to think big.

Dr Shaw proposes to remedy that. In collaboration with Shell, an Anglo-Dutch oil company, and Cosan, Brazil's third-largest sugar producer, he plans to build a factory capable of producing 400m litres (2.5m barrels, or 105m gallons) of drop-in fuel every year. The other companies will provide money, reaction vessels and sugar. He will provide the enzymes and genetically engineered bacteria needed to make a drop-in fuel.

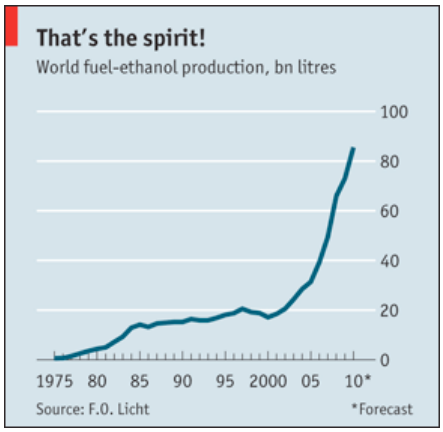
The project is part of a joint venture by Shell and Cosan; with a capacity of more than 2 billion litres a year, it is the world's largest biofuel operation, and it owns a 16.4% stake in Codexis. At the moment, the joint venture's business is based on fermenting cane sugar into

ethanol, but the new plant would start changing that. Codexis's enzymes and bacteria can turn sugar into molecules called straight-chain alkanes which have between 12 and 16 carbon atoms in them. Such alkanes are the main ingredients of diesel fuel.

In April Codexis became the first start-up involved in drop-in fuels to float itself on a stockmarket—which in this case was NASDAQ, America's main market for high-tech stocks. But it is not the last. Another firm that recently completed its NASDAQ flotation is Amyris, of Emeryville, which is also in the San Francisco Bay area. Amyris started off using large-scale genetic engineering, also known as synthetic biology, to create bugs that make a malaria drug. But now it, too, has a product that it claims is a drop-in biodiesel. And it, too, has hooked up with an oil company: Total, of France, which owns 17% of the firm.

Amyris's biodiesel is made of more complicated molecules than Codexis's (they are known, technically, as terpenes), and the firm employs genetically engineered yeast, rather than bacteria. But Brazilian sugar is again used as the raw material. Amyris has formed a joint venture with Santelisa Vale, Brazil's second-largest sugar company, and is busy refitting some of that firm's ethanol plants in order to make drop-in diesel.

The Codexis-Cosan-Shell partnership and the Amyris-Santelisa-Total one are the furthest along of the drop-in fuel businesses, but others are coming up on the rails. LS9, which is based in South San Francisco (a separate municipality that has a cluster of biotech companies), also uses bacteria to make straight-chain alkanes. It is converting a fermentation plant in Florida into a test facility to see if what works in the laboratory will work at scale. And Virent, based in Madison, Wisconsin, is making alkanes out of sugars using a chemical, rather than a biological, process.



Gevo, of Englewood, Colorado, which filed for flotation on NASDAQ in August, is planning to make another type of post-ethanol fuel: butanol. Like Codexis, it will use enzymes and genetically engineered bugs to do this; like Amyris and LS9, it will retrofit existing ethanol plants to keep the cost down. The aim is to turn out an annual 2 billion litres of butanol by 2014. BP, a British petroleum company, is building a butanol pilot plant to do this near Hull in the north of England and also has big ambitions for the fuel.

Like ethanol, butanol is an alcohol. That means each of its molecules contains an oxygen atom as well as the carbon and hydrogen found in an alkane. Butanol, however, has four carbon atoms in its molecules, whereas ethanol has two. That gives butanol more energy for a given mass and makes it more alkane-like in its properties; nor does it absorb water as readily as ethanol. Moreover, the production process for butanol is more efficient than the processes that produce alkanes; proportionately more of the energy from the feedstock (various crops for Gevo, wheat for BP) ends up in the final fuel. And BP will certainly be able to bring to the party the ambitious scale that Dr Shaw praises.

The last of the Bay-area drop-in contenders is, in many ways, the most intriguing. Solazyme, another firm based in South San Francisco, wants to use single-celled algae to make its fuel. This is not a new idea. Craig Venter, who led the privately financed version of the Human Genome Project, is trying it too, through his latest venture, Synthetic Genomics, in San Diego. Synthetic Genomics is backed by the biggest oil beast of them all, ExxonMobil—and several other firms have similar ideas, if not the same heavyweight backing. Solazyme's

approach is unusual, though. Instead of growing its algae in sunlit ponds it keeps them in the dark and feeds them with sugar.

At first sight this seems bonkers. The attraction of algae would seem to lie in the possibility that, since they photosynthesise, they could be engineered to contain the whole sunlight-to-fuel process in one genetically engineered package. Sunshine being free, this looked a brilliant idea. But looks can be deceptive. If you keep your algae in ponds the rays do not always strike them at the best angle and the algae sometimes shade one another if they are growing densely. Photobioreactors—complicated systems of transparent piping through which alga-rich water is pumped—overcome those problems, but they cost a lot and are hard to keep clean. Solazyme tried both of these approaches, and almost went bankrupt in the process. Then its founders, Jonathan Wolfson and Harrison Dillon, asked themselves whether it might not be cheaper to ignore the photosynthetic step, buy the sugar that photosynthesis produces instead, and concentrate on getting the algae to turn it into oil.

Which is what the firm now does. It also has a nice little earner in the form of a contract with the American navy. The navy intends that, by 2020, half the fuel it uses (over six billion litres a year, mainly diesel and jet fuel) will be from renewable sources. Over the past year Solazyme has been providing it with trial quantities of both from its production facilities in Pennsylvania and Iowa. The algal oils are not themselves good fuel; but a refinery in Houston takes care of that, producing shipshape alkanes of the sort the navy likes.

High-fibre diet

The success of all this obviously depends on the price of sugar, which is rising. Historically, the cost of making Brazilian ethanol has been about 26 cents a litre. Diesel will cost more, but petroleum-based diesel sells in America for 57 cents a litre before distribution costs and tax, so there should be room for profit. Nevertheless, if drop-in fuels are to become a truly big business they need a wider range of feedstocks.

Until recently, the assumption has been that cellulose would take over from sugar and starch as the feedstock for making biofuels. Making cellulose into sugar is technically possible, and many firms are working on that possibility. Some are using enzymes. Some are using micro-organisms. Still others have a hybrid approach, part biotechnological and part traditional chemistry. And some go for pure chemistry, breaking the cellulose down into a gaseous mixture of hydrogen and carbon monoxide before building it back up into something more useful.

The reason for this enthusiasm has been government mandates: America's Renewable Fuel Standard (RFS-2) and its European equivalent. On pain of fines, but with the carrot of subsidies, these require that a certain amount of renewable fuel be blended into petroleum-based fuels over the next decade or so. RFs-2 calls for a 10% blend of cellulosic fuel by 2022.

The targets in RFS-2, though, represent a huge climbdown. Its predecessor, RFS-1, called for 379m litres of cellulosic ethanol to be produced in 2010; RFS-2 mandates only 25m litres. The industry in fact has a capacity of about 70m litres today, according to the Biotechnology Industry Organisation (BIO), an American lobby group.

The reduced expectations reflect the fact that making fuel out of cellulose turns out to be hard and costly. Today's cellulosic ethanol is competitive with the petrol it is supposed to displace only when the price of crude oil reaches $120 a barrel. In Dr Shaw's view, a lot can

be done by scaling up (and using the appropriate enzymes, of course, which Codexis will be only too happy to sell you). And big plants will, indeed, bring the price down—probably not to the point where cellulosic ethanol can compete in a fair fight, but quite possibly to a level at which fuel companies will make or buy the stuff rather than pay fines for not doing so.

Phil New, the head of biofuels at BP, says his firm is determined to comply with RFS-2. To that end it is planning a plant in Florida that will have a capacity of 137m litres when it comes on stream in 2013. It is one of seven cellulosic-ethanol fermentation plants with annual capacities above 38m litres (that is, 10m gallons) which BIO says should be running by 2013, with a further seven making ethanol using syngas conversion. However, such claims are not that different from those made three years ago—which singularly failed to bear fruit.

Grassed up

If things work out better this time, it still leaves the question of where the cellulose is to come from. The answer is likely, in one form or another, to be grass.

Though they look very different, sugar cane and corn are both grasses. So is wheat, which is corn's counterpart as the starch source of choice in the EU. A simple way of garnering cellulose is to gather up the leftovers when these crops have been processed—bagasse from sugar cane, stover from corn and straw from wheat.

That is a start, but it will not be enough, Wood is a possibility, particularly if it is dealt with chemically, rather than biologically (much of the carbon in wood is in the form of lignin, a molecule that is even tougher than cellulose). But energy-rich grasses look like the best bet. Ceres, which is based in Thousand Oaks, California, has taken several species of fast-growing grass, notably switchgrass and sorghum, and supercharged them to grow even faster and put on more weight by using a mixture of selective breeding and genetic engineering. Part of America's prairies, the firm hopes, will revert to grassland and provide the cellulose that biofuels will need. The Energy Biosciences Institute that BP is funding at the University of Illinois, in Urbana-Champaign, is working on hybrid miscanthus, an ornamental grass that can produce truly remarkable yields.

If the price were right, such energy crops might take America a fair bit of the way to the "energy independence" that early proselytisers for biofuels crowed about. A study carried out last year by Sandia National Laboratories, an American government outfit, suggests that in theory 285 billion litres of cellulosic biofuel a year could be extracted from the country's agriculture and forestry without breaking too much sweat. That is 1.8 billion barrels, compared with American oil imports of 4.3 billion barrels in 2009. Europe's higher human-population density leaves less space for energy crops. But there is clearly some room for expansion in the Old World as well as the New.

Beyond the rich countries, capacity is greater still. In a fit of enthusiasm a few years ago Steven Chu, now America's energy secretary, floated the idea of a global glucose economy to replace oil. That is going a bit far. Brazil is a well-governed country, but other parts of the tropics, though endowed with sunshine and cheap land, are not always the sorts of places that the wise investor would pile into. And Brazil's blessings in terms of oodles of land that can grow cane with no irrigation are not widespread. Nevertheless, the country's success shows that international trade in biofuels is a possibility. If it brought economic development to less favoured lands, that would surely be welcome.

Drop in or drop out

Such a future, though, depends on cars continuing to be powered by liquid fuels. A large shift to electric cars would put the kibosh on the biofuel market as currently conceived by most of its supporters; but it would not necessarily kill the principle of using plants to convert sunlight into car-power. The goal of reducing emissions needs low-carbon generators to power the grid the electric cars draw juice from. Put the energy crops in generators instead of distilleries and off you go.

Richard Hamilton, the boss of Ceres, says he is indifferent as to whether his grasses end up in petrol tanks or power stations. Others think making them into electricity might be a better answer anyway. A study published last year by Elliott Campbell, of the University of California, Merced, and his colleagues suggested that turning crops into electricity, not fuel, would propel America's cars 80% farther and reduce greenhouse-gas emissions even more. Electrons are easy to transport and burning uses all of the fuel value of a plant—including that stored in the lignin which current processing methods find hard to deal with.

Dave Simonds

The electrification of cars, however the electricity might be generated, would be the end of the road for ethanol. But not necessarily for drop-ins. There is no realistic prospect for widespread electric air travel: the jet engines on aircraft need the high-energy density that only chemical fuels can provide. So if you want low-carbon flying, drop-in biofuels are the only game in town. And civil aviation alone is expected to use 250 billion litres of fuel this year, is growing fast and could pay a premium if its emissions were subject to a cap or a tax. Over the long run, the future for biofuels may be looking up.

Briefings2