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AGRICULTURE

Beyond food versus fuel

The most controversial aspect of biofuels is the perceived competition for farmland. Will advances in biofuels and agriculture send this trade-off speeding towards the history books?

BY DUNCAN GRAHAM-ROWE

When Ferrari's Formula 1 drivers nabbed first and second place in last year's Bahrain Grand Prix they had a little something extra in their fuel tanks — lignocellulosic, or 'second-generation' biofuel. Even the high-octane world of F1 racing has woken up to the reality of dwindling oil reserves and the threat of climate change. Since 2008, the rules have stated that at least 5.75% of all Formula 1 fuel must be derived from plants. But the fuel in Ferrari's tank is different. Made from the non-edible parts of plants, Ferrari's fuel additive demonstrates just one of the ways in which biofuels can meet our energy needs without reducing food production.

Recent rises in food prices are some of the sharpest since records began, according to the Food and Agriculture Organization (FAO) of the United Nations. These increases have been attributed to the growing use of 'first-generation' biofuels, derived from the edible parts of food crops such as sugar cane and corn (maize), for example, which are often blended with today's gasoline (petrol). With food riots becoming increasingly common in developing countries, many are concerned about how prudent — or ethical — it is for Western governments to be establishing ambitious targets for the uptake of biofuels. Is there a way forwards that does not rob the world's population of the food it needs?

In Ferrari's case, the answer is yes. The team's choice of biofuel is ethanol derived from straw, a waste product of agriculture. Developed by the Ottawa-based biotechnology company Iogen, the race car fuel is one example of how scientific advances are helping researchers avoid some of the problems of first-generation biofuels. If the new generation of fuels could be used in combination with improved land-use strategies and increased agricultural yields, they might vault us beyond the point where we are forced to choose between food and fuel.

ENERGY ISSUES

Using crops to make liquid fuel is not a recent idea. As far back as the nineteenth century, Rudolf Diesel designed his eponymous engine to run on vegetable oil or peanut oil. And Brazil has mandated the addition of sugar-cane-derived ethanol to its fuel since 1929. However, it is only in the past decade, with mounting fears about energy security and climate change and with the relentless escalation in energy consumption, that biofuels have begun to take a more central role in global energy policy.

The haste to develop such fuels has led to tensions over land use. In Malaysia, for example, policies encouraging the use and production of palm-oil-based biodiesel have resulted in large swathes of Borneo's jungle being replaced by palm plantations. And, where edible crops such as corn are being used to make fuel, significant chunks of the global harvest are now diverted from food production into biorefineries. In 2007, the United States planted a record 92.9 million acres (about 375,000 square kilometres) of corn, but one-third of it was used to produce ethanol. This diversion, it has been argued, has led to unprecedented rises in

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the price of corn, which spiked 73% towards the end of 2010. Early this year, the FAO reported that its index of food prices was the highest in the index's 20-year history.

Pick apart the data, however, and it becomes clear that biofuels are only part of the equation. According to the 2008 World Bank report *A Note on rising food prices*, although biofuels are the most important factor, there is good evidence to suggest that other factors, such as stock market speculation and extreme climatic events, have helped to drive up the price of food since 2002. The rising cost of petroleum should also not be overlooked, because this has a direct impact on food prices, says Ottoline Leyser, a plant geneticist at the University of Cambridge, UK. Leyser, who was also a co-author of a recent report on biofuels by the London-based Nuffield Council on Bioethics, points out that it takes a lot of energy — mainly in the form of fossil fuels — to harvest, process and transport food.

To give biofuel critics their due, food price is not their only concern. According to Angela Karp, scientific director of the Centre for Bioenergy and Climate Change at the Harpenden-based Rothampsted Research, the largest agricultural research centre in the UK, first-generation biofuels also tend to require intensive inputs, such as water and nitrogen, and this has an impact on their greenhouse gas emissions. Although most biofuels weren't developed specifically to address rising carbon dioxide levels, it is nonetheless expected they will help alleviate the problem. However, biofuels often show only minimal reductions in greenhouse gases compared with their fossil fuel equivalents, according to a life-cycle analysis by Nigel Mortimer, former chair of sustainable energy development at Sheffield Hallam University, UK, who now works at Stocksfield-based North Energy, a renewable energy and sustainability consultancy. And research by Kenneth Stone, an agricultural engineer at the US Agricultural Research Service's branch in Florence, South Carolina, suggests that if the US Department of Energy's biofuel target for 2030 is met using corn-derived ethanol only, agricultural water use could increase six-fold.

One of the trickiest problems arising from the competition between biofuels and food production is land use. Ideally, biofuel crops would be grown on marginal land that has a low carbon stock, leaving the higher quality soil for food production, says Ian Crute, chief scientist at the Kenilworth-based Agriculture and Horticulture Development Board. But, in reality, the profitability of energy crops has caused farmers to shift production from food crops to fuel crops, creating a ripple effect, says Olivier Dubois, coordinator of the FAO's Bioenergy Group in Rome. "Food crops still have to be produced somewhere," he says. And that means finding additional land and converting it for agricultural use.

"Large-scale, second-generation biofuels will take five to ten years."

Land-use issues are not just restricted to crops: livestock has a big impact. According to research published by Bruce Dale, a chemical engineer at Michigan State University's Biomass Conversion Research Laboratory in East Lansing, more than 80% of US agricultural production goes into animal feed. Global increase in meat consumption is one of the main driving forces behind high food prices. As Leyser says, "It's spectacularly wasteful."

And with the inexorable growth of the global population, additional land is set to become increasingly scarce. By 2050, the world's population is expected to exceed 9 billion people. According to the FAO's 2009 report *How to feed the world in 2050*, this means we'll need to feed 2.3 billion more people. Moreover, because of the steady increase in meat consumption and average calorie intake, the amount of food needed to meet this demand will be disproportionately larger than the 34% increase in population (see 'Growing challenges'). "We need 70% additional food by 2050," says Dubois.

Even before this point, the US Energy Information Administration predicts that there will be additional demand for land coming from the energy sector. By 2035, the energy consumption in developing countries is set to rise by 84%, and nearly one-third of this additional fuel is expected to come from biofuels.

Land for both food and fuel production will become scarce unless farming practices change. The global amount of arable land could, in theory, double over the next four decades. But the FAO predicts that the net increase is more likely to be just 5%, because developed countries more commonly convert arable land to accommodate urban expansion. So to raise agricultural productivity, crop yields will have to increase, says Dubois.

Trends over the past half century are not encouraging, however: although average global productivity is increasing, the annual rate of growth has declined from 3.2% in 1960 to 1.5% in 2000. Crute sees a silver lining: productivity is still increasing — and, he says, there is plenty of room for improvement. One way is to close the yield gap between countries. For example, large parts of Africa are underutilized, mainly because they lack infrastructure. If farmers can't get their product to market, then they will grow only what they need to feed their family, says Crute. Growing biofuels in these regions has a big chance of making a positive impact on both infra structure and agricultural output (see 'A new hope for Afica', page S20).

Genetic modification might also help improve agricultural productivity, and not just by generating crops that are more pest resistant —a modification in use today. "On the horizon is drought tolerant maize," which can survive harsher conditions and requires less water, says Crute. Salt tolerance can be incorporated too. With such crops, more land would be viable, and plants could flourish in regions where rising sea levels have increased the salinity of the water table. Furthermore, certain crops, such as corn, have much more efficient photosynthesis mechanisms than wheat or rice, says Crute. These highly productive mechanisms could be 'borrowed' from one plant species and incorporated into others.

GETTY IMAGES

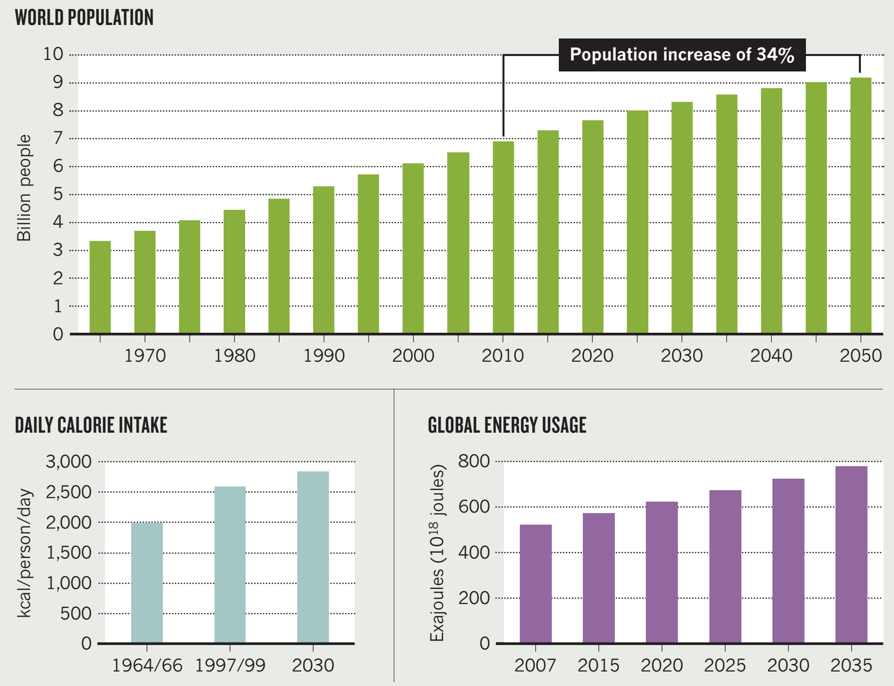
Willow trees planted to supply a biofuel power station in Lockerbie, Scotland, United Kingdom.

THE NEXT GENERATION

On the other side of the equation from improved farming practices, advanced biofuels could overcome many of the issues that have brought bioethanol and biodiesel into

GROWING CHALLENGES

Between now and 2050 the world's population is predicted to increase to more than 9 billion people. Each person will also be consuming more calories per day and using more energy to power their lives. Food and fuel supplies will need to massively increase to meet these needs.



SOURCE: POPULATION DIVISION OF THE DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS OF THE UNITED NATIONS SECRETARIAT, 2007.

contention with food production. By using the entire plant and not just the edible parts, vastly different types of biomass become available as starting materials, or feedstock. There is a lot more energy stored in the rest of the plant than the grain, but it's harder to get at, says geneticist Chris Somerville, who directs the Energy Biosciences Institute at the University of California, Berkeley. Consequently, this process is currently much more expensive than the production of corn ethanol (see 'A chewy problem', page S12).

To create Ferrari's straw-based fuel, Iogen uses an enzyme from the 'jungle rot' fungus *Trichoderma reesei*. The fungus deploys this enzyme to extract nutrients from trees, by digesting lignin, one of the main components of lignocellulose, the woody part of plants. But the search is on to find more efficient enzymes. Enzymes for corn-ethanol processing are highly efficient and cost only about 2 US cents per US gallon, says Somerville. Enzymes that break down lignocellulose cost about 13–25 US cents per litre and that's where the challenge lies. At the Energy Biosciences Institute, "we would like to reduce that cost by about half," he says.

It might be possible to genetically engineer plants with lignin that is easier to break down, but this is a long way off, says Somerville. A more promising idea is to use selective breeding or genetic analysis to identify plants that are high in energy. Charles Wyman, a chemical and environmental engineer at the University of California, Riverside, studied 47 variants of the poplar tree to determine which were most willing to give up sugar from their lignin — and what made that possible. In March 2011, his team reported that the sugar yield could range from as low as 28% up to 92% of the theoretical maximum, depending not only on the lignin content but also on its structure.

So, if these technologies can be perfected and the costs of processing the waste parts of plants (or residues) can be reduced, this should sidestep the food versus fuel issue. For example, grain from corn could be harvested for food, while the rest of the plant could be rendered into fuel.

Although elegant in principle, this dual-use approach is dauntingly complicated to put into practice, says Dubois. "It's seen as a win–win solution, but competing use of residues is a big issue. They're needed as a cheap form of organic fertilizer."

In 2009, research by Guy Lafond, an agronomist with Agriculture and Agri-Food Canada in Indian Head, showed that if more than 40% of straw was removed from land and not ploughed back, the quality of the soil declined. Iogen's demonstration facility produced an average of 256,000 litres of ethanol per year since it opened in 2004, despite having an annual capacity of more than 1.9 million litres. Iogen attributes this shortfall to the fact it is a test facility and so does not operate continuously. But if Shell, which part owns the company, were to start producing ethanol from straw on a commercial scale, this would require 20–30 tonnes of straw per day as a feedstock, and that might put strains on supply.

"The main emphasis will come not from dual use but dedicated crops," Leyser predicts. By 'dedicated' she means using fast-growing plant species that are harvested entirely for biofuel production. To avoid the energy crops vying with food crops for land use, she says, will require careful selection of species. Fast-growing species of willow or poplar trees, for example, can be grown on polluted soil, which also helps to reduce soil contamination. These trees convert carbon dioxide into biomass more rapidly than most other plants — a trait that should translate into high biomass yields. Perennial grasses such as *Miscanthus* and switchgrass (*Panicum virgatum*) are perhaps even better candidates. These plants use little water and store nutrients in their roots, which remain in the soil for the next year's crop. "What you harvest is very nutrient poor, which means almost no fertilizer is needed," says Leyser. Perennial grasses can also be grown on land that is unsuitable for arable crops. Indeed, says Somerville, waste lands could be transformed into bioethanol energy fields using drought-tolerant plants such as agave, one species of which is used to make tequila.

Dubois says that second-generation biofuels "have their drawbacks". They still require land, and even plants that need minimal input will compete with food crops for some resources. And first-generation bioethanol has a head start of more than half a century. "Large-scale, second-generation biofuel production will take five to ten years," he says.

That process has begun. The oil company BP is building a US$400 million cellulosic ethanol plant in Highlands County. The facility will use a high-energy sugar cane, known as 'energy cane', as well as switchgrass or *Miscanthus* from the area, to generate about 136 million litres of fuel a year, which by the US Department of Energy's definition would make it a commercial-scale biorefinery. This may sound like a lot, but it is trivial compared with the 1.3 million litres of gasoline per day that Somerville says his local oil refinery produces.

Although they may take some time, advanced generations of biofuels are on their way. Regardless of whether it is a second-generation biofuel that ends up in our fuel tanks — and the tanks of Formula 1 racing cars — or a third- or fourth-generation that comes in its wake, biofuels will have an important role in meeting the world's energy needs. And through technology, careful land management and considered use of resources, they should allow us to have our fuel and eat it. ■

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