BIOFUELS: WHAT IMPACT ON CROP PROTECTION AND SEEDS NOW?

Part 3: Innovation in crop production, protection and utilisation

In the October and December 2008 issues of Outlooks on Pest Management the first two parts of this article reviewed the current status of the biofuels industry and the potential demand for crop feedstocks over the next 25 years or more. In this final article in the series, Alan Baylis, Nuvistix Innovation, reports on the involvement of crop protection and seeds companies, their current areas of research, and reviews the challenges and potential opportunities for the industry.

Keywords: Biodiesel, bioethanol, biofuels, crops, feedstocks

Introduction

In the first years of this century governments in the US and Europe, followed by many others, moved quickly to support the development of a biofuels industry (Baylis, 2008a). A precedent had already been set thirty years earlier in Brazil with the use of sugarcane to produce ethanol as an alternative liquid transport fuel. Longer term concerns over the reliance of the world economy on oil and shorter term fears about security of supply, together with pressures to reduce greenhouse gas emissions, and desires to support rural economies led to policies aimed at promoting the growth of bioethanol and biodiesel as vehicle fuels.

The impact of biofuels on the crop protection and seeds industry has already been significant in various ways in just a few short years. This has been because the major crop feedstocks for biofuels are grown in highly developed agricultural systems which are already the main markets for crop protection products and proprietary seeds (Baylis, 2008b). Corn (maize) and wheat in the US and Europe, respectively, are being grown for ethanol production, and soybeans in the US are a biodiesel feedstock.

In addition, the other major biofuel feedstocks, sugarcane for ethanol and oilseed rape (canola) for biodiesel, are strategically important crops for the industry, albeit of lower value. The area of sugarcane harvested in Brazil has been forecast to double and production to increase 250% over the next decade or so. Oilseed rape is a strategic crop because of its place as a break crop in wheat rotations in Europe and Canada. Other markets may be important locally or for specific products, eg oil palm in South East Asia is expanding as a biodiesel feedstock.

Huge areas of fertile cropland are needed for biofuels to make any significant contribution, so, especially because of the already pressing need to produce more food, increasing yield has been re-emphasised as an important target, regardless of crop or territory. Crop yields and initiatives aimed at increasing these will be considered in the following discussion, before reviewing some of the activities of the major industry players in the Americas, Europe and Asia. Finally, some of the more indirect impacts of the push for biofuels will be noted.

Crop yields

When the price of food commodities soared throughout the course of 2007, biofuels took much of the blame in the media, although in reality only some 2% of the world's grain harvest is presently used as biofuel feedstock (EREC, 2008). 'Unwanted' surplus crop production in the West over the past 20-30 years encouraged interest in biofuels. Now, biofuels themselves are focusing attention on higher crop yields as land use for food, feed, fibre, fuel and environmental resources becomes a global issue. Innovations in crop protection and biotechnology to increase yield are eagerly sought after to raise yields, not only on the most productive land, but perhaps more usefully on land which does not grow good crops, whether through poor soil, drought, or lack of technical knowledge or infrastructure.

Wheat provides an interesting example. Although plant breeders have claimed consistent year-on-year advances of 1% in yield as new varieties are introduced, ie about 1 tonne/ha per decade recently, arguably, on-farm national average yields of leading producing countries are plateauing (Figure 1).

Although advances in yield have been truly spectacular, assumptions about the availability of wheat feedstock to meet bioethanol targets rely on still higher yields (EC, 2007). To meet all needs in 2020, the EU wheat harvest will need to

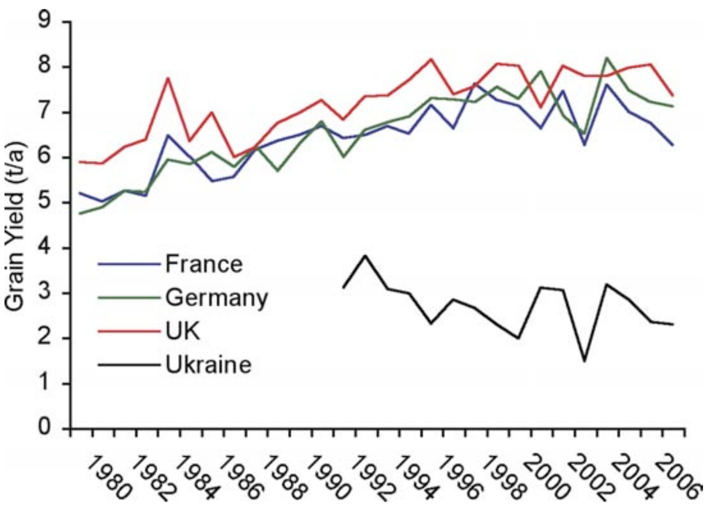

Figure 1: **Yield trends in wheat harvested in major European producing countries and the Ukraine. National averages since 1980 (FAOSTAT).**

increase to around 187 million tonnes. This is over 50 million tonnes more than were harvested in 2007. This figure includes an extra 17 million tonnes for food and 38 million tonnes for animal feed and sufficient feedstock to meet the 2020 target of 10% replacement of transport fossil fuels with biofuels. Even with land coming out of set-aside, less than one third of the extra supply could come from more wheat hectares, so most must come from higher yields.

Figure 1 also shows yield data for the Ukraine – the 'bread basket' of Eastern Europe and indicates where extra yield may perhaps be most readily gained. Success here may come from better harvesting, transport and storage logistics as much as anything – the Ukraine grows about 6 million ha of wheat, three times as much as the UK.

In the US, yield will also be key to realising longer term forecasts for biofuel production from biomass. The US 'Billion Ton' report (Perlack *et al*, 2005) which considered potential sources of biomass for biofuels in 2030 assumed that the yield of corn would increase by 50%. The yield trend in US corn is robustly upwards (Figure 2), and reaching average yields of 12-14 tonnes/ha in 20 years looks credible, yet still may need to accelerate on-farm.

Biotechnology solutions to higher yields are anticipated in genetic modification of crops to use water and nitrogen fertilizer more efficiently. Most of the leading seed companies are working in these areas. For instance, Monsanto has moved its drought tolerance trait into the final stages of development (Monsanto, 2009). The company claims that some 85% of US corn suffers some degree of drought stress, although the timing will be critical to affecting yield. Corn hybrids with the trait have shown yield increases of up to 10% under drought through the ability to continue effective photosynthesis. Nitrogen-use-efficiency traits are further behind in R&D pipelines. Pioneer (DuPont) note that its research is at the proof of concept stage and anticipates a product within 10 years.

Chemicals for yield enhancement, once known as plant growth regulators (PGRs), but now plant stress protectors, are also back in favour. Syngenta's R&D pipeline includes *Invinsa* (1-methylcyclopropene) scheduled for launch in 2009/10 to increase yields of major field crops such as corn, soybeans, cotton, wheat and rice (Syngenta, 2007, 2008). Sales are forecast to be up to $500 million. First triazole and later strobilurin fungicides have often been observed to increase cereal yields in the apparent absence of disease. Now BASF has been successfully promoting the use of its fungicide pyraclostrobin (F500) on corn, a crop usually not recognised as being troubled by diseases, to increase yield by increasing resistance to heat and drought stress (BASF, 2009).

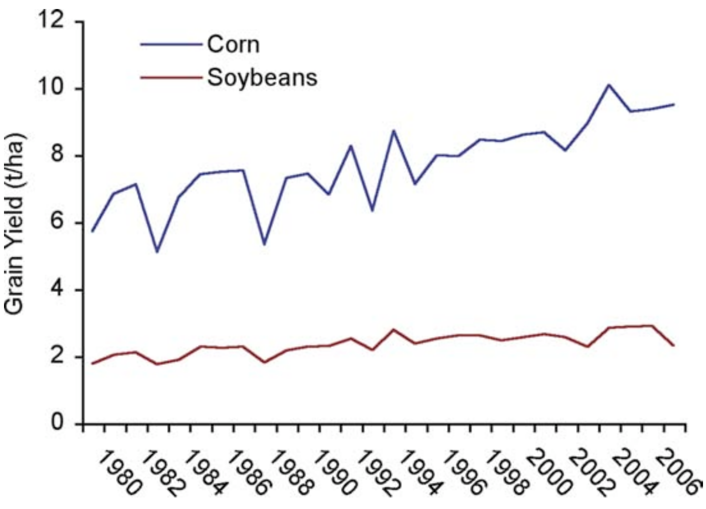

Figure 2: **Yield trends in corn and soybeans harvested in the US. National averages since 1980 (FAOSTAT).**

Sugarcane is currently the most economically attractive feedstock for ethanol (Assis *et al*, 2007). Being vegetative, increasing yield presents different challenges in sugarcane. Figure 3 shows that yields of sugarcane in Brazil have increased, on average, steadily by about 50% over the past 25 years. In November 2008, it was announced that Monsanto had acquired two leading sugarcane R&D companies in Brazil (Rasera da Silva, 2006). CanaVialis is the leading private sugar cane breeder and applied genomics company Alellyx specialises in traits for the crop. Monsanto had earlier established agreements with both companies over the development of glyphosate tolerant and Bt insect resistant GM sugarcane in Brazil. Of particular interest for future cellulosic bioethanol production is the development of high fibre or '*energy cane*'. While varieties bred for sugar content yield 70-120 tonnes/ha, high fibre varieties promise to yield approaching 250 tonnes/ha, potentially doubling the yield of ethanol over conventional varieties. Improving drought tolerance is also a target. This would allow production to move out of the higher rainfall Sao Paulo area into the drier Cerrado.

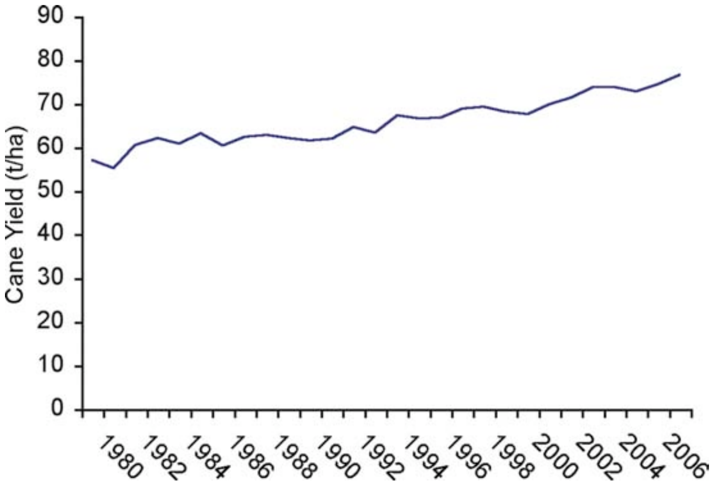

Figure 3: **Yield trends in sugarcane harvested in Brazil. National averages since 1980 (FAOSTAT).**

Oilseed rape is the major feedstock for biodiesel in Europe (Garafalo, 2006). Meeting the increased demand in Europe will not be helped by the fact that national average yields have increased little over the past 25 years, and they are quite variable (Figure 4). In the UK, average yields from variety testing trials have increased from 3.3 to 4.2 tonnes/ha over the same period, and a potential yield of nearly 8 tonnes/ha is believed to be achievable. Several speakers at a session at the BCPC Plant Protection Congress in 2007 discussed problems with oilseed rape in relation to shorter rotations to accommodate greater production for the biodiesel market. Under the best agronomic practice oilseed

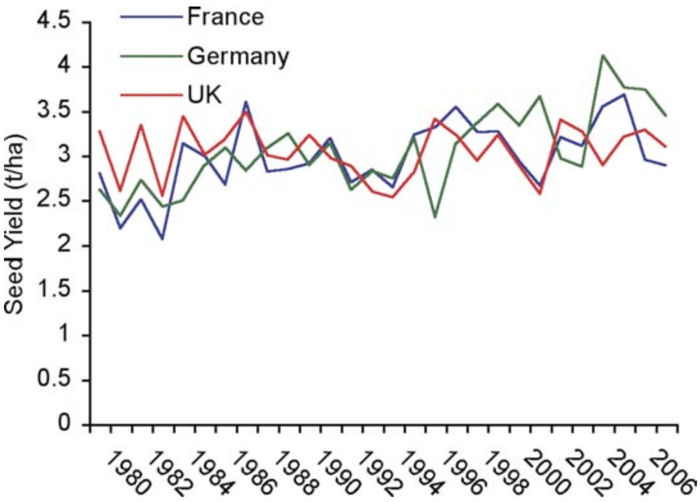

Figure 4: **Yield trends in oilseed rape harvested in major European producing countries. National averages since 1980 (FAOSTAT).**

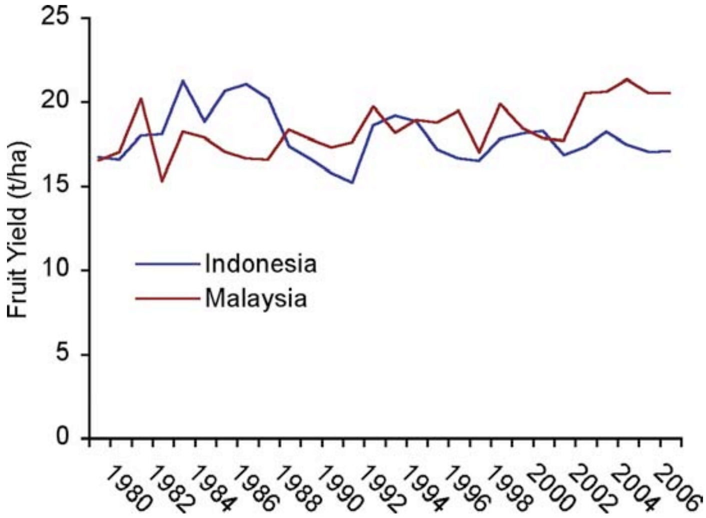

Figure 6: **Yield trends in oil palm harvested in Indonesia and Malaysia. National averages since 1980 (FAOSTAT).**

rape would be grown one year in four. Expansion in cropped area, however, has meant that crops grown in more intensive rotations of one rape crop every three years increased from just 8% of crops in 1990 to 23% in 2003. Infection from soil-borne diseases is a particular risk in tight rotations and currently available fungicides are not very effective in high disease pressure years. Club root (*Plasmodiophora brassicae*) has been noted to be increasing alarmingly. Heavy infestations have been recorded as reducing yield by 50%. As spores remain viable for 20 years it is a long term problem. No fungicides are registered for club root control in the EU, and only one variety is resistant. Short rotations also favour *Sclerotinia*.

Tropical crops and marginal land

Much of the opposition to biofuels has been directed at the expansion of tropical crops, particularly oil palm, at the expense of forest and marshland. In Malaysia and especially Indonesia, this expansion has indeed been dramatic (Figure 5). However, little progress has been made in increasing the average yield of oil palm in these countries (Figure 6).

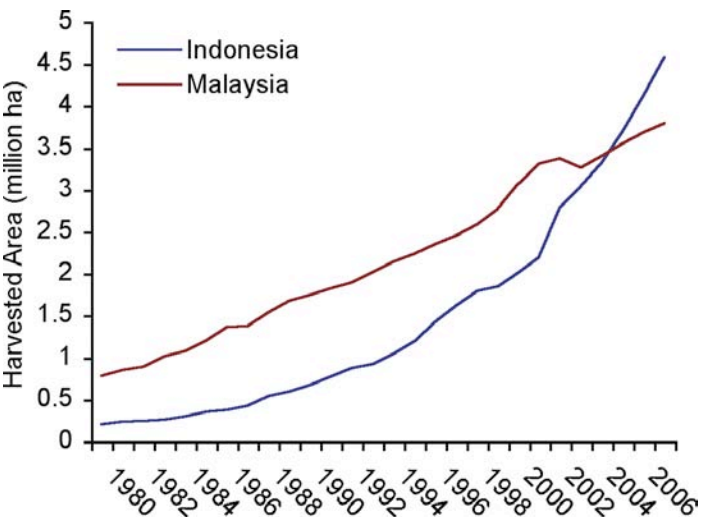

Figure 5: **Areas of oil palm grown in Indonesia and Malaysia since 1980 (FAOSTAT).**

Issues of growing biofuel feedstocks on land that would otherwise be used for food production and the effect of inputs on net energy balance has prompted interest in crops which have a reputation for being able to produce good yields on marginal land with low inputs of fertilizers and pesticides. In early 2008, Bayer announced that the company would work with Archer Daniels Midland and Daimler to explore the potential for using jatropha (*Jatropha curcas*) as a feedstock for biodiesel (Bayer, 2009). Jatropha is a small tropical tree which bears fruit containing large seeds with 30-40% oil content. The plant is noted for its high water-use efficiency and plantations are being developed in many tropical countries, especially India. The oil comprises a high proportion of unsaturated fatty acids, unlike palm oil, which makes for a biodiesel product with a lower freezing point, less likely to form waxes in fuel lines at low temperatures. However, jatropha was originally noted as a medicinal plant – because of the presence of various toxins – and the oil was known as '*oleum infernale*'. The meal left after oil extraction cannot be used as animal feed due to the presence of toxins including curcin, a protein similar to ricin from the castor oil plant, and phorbol esters. Nevertheless, as with the breeding-out of erucic acid and glucosinolates from oilseed rape, there may be potential to improve jatropha in this respect.

Other companies are also working on crops for more marginal land. Tropical sugar beet is new feedstock for bioethanol production in India being developed by Syngenta. Although it has a similar yield of sugar to sugarcane, the beet's water requirement is substantially less. Not only can it be grown in drier climates, but because it is faster growing, tropical sugar beet can be followed by another crop in the same year making it an attractive crop for Indian farmers.

Feedstock processing opportunities

The main crop feedstock for biofuels in North America is overwhelmingly corn, with more than 30% of the 2009 harvest forecast to be used to make bioethanol from grain starch (Westcott, 2007). Syngenta intends to introduce GM

Corn Amylase hybrids in 2009 (Syngenta, 2008). These express high levels of improved alpha-amylase enzymes that catalyse the hydrolysis of starch to sugars, a key first step in fermentation to ethanol. The novel alpha-amylases, more heat stable and pH tolerant, will cut costs in biorefineries. An alternative use of this technology could be to add soya meal containing improved enzymes as an additive to the pretreatment step in which feedstock is prepared for fermentation (Link, 2008). However, engineering enzymes to survive the harsh conditions from steam and sulfuric acid is a tough target. Syngenta expects that the benefits from *Corn Amylase* may include savings in energy inputs and costs, reduced water and chemical usage and increased ethanol output per bushel.

In future, 'second generation' technology will allow the use of crop residues (stover) to make 'cellulosic ethanol'. Again, in the US most of this will come from corn, although there will be many other sources of biomass from animal manure to urban construction waste. Enhanced enzyme systems could improve the efficiency of conversion of biomass to ethanol. Lignified cell walls mean that biomass needs to be subjected to some form of pretreatment necessary to make cellulose more physically accessible to subsequent steps in ethanol manufacture. Non-enzymic methods involve physical treatments such as steam explosion and chemical treatment with acid, alkali or organic solvents, and the whole method needs to be specific to particular feedstocks to optimise efficiency and energy use (Graf & Koehler, 2000). Syngenta aims to commercialise *Hi-ethanol* corn hybrids expressing multiple cellulase enzymes sometime after 2011 (Syngenta, 2008). At the appropriate time these will switch-on to digest the complex cellulose and hemicellulose in the cell wall (Link, 2008). Finally, fermentation could be improved by the development of novel microorganisms. Efficient fermentation is only achieved if both hexose sugars from cellulose and pentoses from hemicellulose are utilised. Traditional yeasts naturally ferment only hexoses. Strains of GM *Zymomonas mobilis* have been created which are not only capable of utilising both five- and six-carbon sugars, but also have much faster activity. This results in greater efficiency and cost savings critical to the success of second generation cellulosic ethanol (EREE, 2001).

Energy crops

In anticipation of second generation biofuel technologies using biomass feedstocks become more economical, several dedicated perennial energy crops are being explored. These include switchgrass (*Panicum virgatum*), reed canary grass (*Phalaris arundinacea),* willow (*Salix* spp.), poplar (*Poplus* spp.) and miscanthus (*Miscanthus giganteus*). New crops ultimately bring new pests and disease, and challenges for weed control by appropriately selective herbicides. At present, areas down to such crops are very small, but in future could rival those of the current major food crops in some regions. Perlack *et al* (2005) estimated that switchgrass could be grown on 22 million ha in the US by 2030. DuPont now has a local registration for the use of nicosulfuron herbicide in switchgrass in Tennessee, USA (DuPont, 2008). Nicosulfuron, primarily a corn herbicide, controls seedlings of species including *Echinochloa* spp. and *Digitaria* spp. and larger Johnsongrass (*Sorghum halepense*) post-emergence in switchgrass. Although switchgrass varieties are resistant to most pests and diseases, weed competition during establishment can be a major constraint on productivity (Vogel & Masters, 1998).

Crop protection issues in UK energy crops were discussed in a session at the BCPC Congress in 2007. A pest risk assessment on biomass crops in the UK by the Central Science Laboratory pointed to five potential serious pests of miscanthus. These were two species of aphids, two stem borers and a weevil. The same exercise identified 15 potentially serious pathogens: six rusts, five leaf spots/blotches, one downy mildew, one leaf scorch, one smut and one virus leaf streak. At Rothamsted, experience to date with miscanthus has been that fungal diseases have been few, although *Fusarium* caused a significant yield loss from lodging at one site. Outside the UK, miscanthus diseases include blights, rusts, ergot, downy mildew and smut. Pests have included the corn leaf aphid (*Rhopalosiphum maidis*) and the unusual *Melanaphis sorini*; the common rustic moth (*Mesapamea secalis*), the ghost moth (*Hepialus humuli*) and the cutworm larvae of noctuid moths. Willow and poplar are both very susceptible to rusts and breeding for resistance is in progress at Rothamsted. Rust resistant varieties released in the 1980s, saw their resistance break down within seven years. Of course, with perennial crops there is not the opportunity to re-establish using resistant varieties as easily as with annuals. Work at Long Ashton Research Station had shown some promise in using mixed genotypes to combat disease even when lines known to be susceptible were included in the mix. Pests of willow include defoliating beetles and aphids. Switchgrass grown at Rothamsted has been infected by sharp eyespot (*Rhizoctonia cerealis*). In the US, switchgrass diseases include *Phoma*, rusts, smuts, anthracnose and Panicum mosaic virus (PMV).

Conclusions

The impact of biofuels on the crop protection and seeds industry has been considerable, and will be much more so in future, if the wider implications are taken into account.

Strictly speaking, as only a tiny proportion of the area of world crops will ever be grown for fuel, the direct impact is small. This is confined to a few changes in the market notably due to:

- Expansion of existing crop markets due to larger areas, greater crop protection needs because of less frequent crop rotation, or due to increased inputs in response to any greater profitability
- New crops with new crop protection problems, scope for breeding new varieties of existing major crops, or new crops optimised as feedstocks
- Biotechnology solutions to be used in biofuel manufacturing

However, the biofuels opportunity seems to have been a significant stimulus to more general innovation in the industry. In addition, the food versus fuel debate has positioned yield as an imperative in the minds of stakeholders.

Innovation directly and indirectly stemming from biofuels has not only involved the use of chemicals and biotechnology. Industry leaders have been collaborating with partners in several formerly unfamiliar sectors to create new products and services. For example:

- DuPont has a partnership with BP to develop improved biofuels. The first product will be biobutanol. Produced from the same feedstocks as ethanol, biobutanol has a higher energy content, can be blended with petrol (gasoline) in higher proportions and has physico-chemical properties which allow it to be transported more easily.
- Monsanto has a joint venture with food processor and animal nutrition specialist Cargill called Renessen. The aim is to develop biorefinery technologies that will allow the efficient use of corn to provide starch as ethanol feedstock and protein, fibre and oil co-products for specific animal feeds, eg for ruminants and monogastrics.
- Monsanto has developed an ethanol supply chain programme called '*Processor Preferred*'. Corn hybrids with high starch contents can yield up to 4% more ethanol than average and those participating in the accreditation scheme are branded as '*Highly Fermentable Corn*'. Monsanto supplies analytical equipment and software to ethanol manufacturing plants to measure and track the ethanol production potential of delivered loads of corn. The programme also involves financial support for petrol (gas) stations to install pumps to supply ethanol blends and for farmers who want to buy flex-fuel vehicles capable of running on E85 (85% ethanol).

Finally, innovation will also impact on the industry from environmental concerns around biofuels. When cellulosic ethanol technology starts to use large quantities of straw and stover as feedstock, organic matter levels in soil will suffer. The importance of moving more cropland into no-till systems which conserve soil organic matter has been emphasised (Perlack *et al*, 2005). This will have particular impact on weeds and weed control systems. Also, several influential life cycle analyses have highlighted the sometimes disappointing net energy gains from biofuels because of the energy inputs in crop production as well as processing. Nitrogen fertiliser is a heavy user of energy and more nitrogen efficient crops will have lighter carbon footprints.

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