Bio or bust?

The economic and ecological cost of biofuels

Last month, oil prices reached US$100 per barrel for the second time—the first time was in late 2007. Just a few weeks before, in early December, most representatives at the United Nations' Climate Change Conference in Bali pledged to reduce emissions of carbon dioxide further, and set new targets and limits to be implemented when the Kyoto Protocol ends in 2012. Caught between rising prices of crude oil and natural gas, and their commitment to stop global climate change by cutting the emission of greenhouse gases, many countries are now investing in the development and use of alternative and renewable energy sources to avoid their economies going 'bust'.

…the growing demand for biofuel […] has raised concerns about the long-term economic, environmental and social viability of alternative fuels

Biofuels—bioethanol and biodiesel derived from plants—seem to be an elegant solution to this dilemma because they decrease dependency on fossil fuels and only return recently sequestered carbon dioxide to the atmosphere. The governments of many industrialized and developing countries are therefore creating and expanding policies and research programmes to increase the production and use of biofuels. Nevertheless, the growing demand for biofuel to be produced from crops previously used for food has raised concerns about the long-term economic, environmental and social viability of alternative fuels. In August 2007, the United States Department of Agriculture (USDA) sponsored a global conference, 'Agricultural Biofuels: Research and Economics' at the University of Minnesota (Minneapolis, MN, USA) to discuss these issues. Clearly, the current standards of technology and agricultural output are not sufficient to replace fossil fuels entirely. This challenge can ultimately only be met by new scientific and technological solutions that allow an increase in the production of biofuels without having a negative impact on the environment or food supply.

Theoretically, biofuels could be produced from any organic material, but most current biofuels are so-called first-generation fuels based on food crops: ethanol is produced by fermenting starch or sugar—mainly from sugar cane or corn—and biodiesel is made from the oily seeds of plants such as rape, coconut or soya beans. Many other plants can be used to produce fuels, but their use depends on several factors, including yield, agricultural practices and environmental considerations, as well as international trade agreements.

However, scientists and engineers are already forging ahead with second- and third-generation biofuels. Second-generation biofuels are derived from cellulose by enzymatic conversion and fermentation. These processes expand the possible sources of fuel to non-edible plants and plant parts, including grass, wood and agricultural residues, such as corn stover or sugar cane bagasse. According to Kevin Hicks, a crop conversion science and engineering research leader at the USDA's Agricultural Research Service (Wyndmore, PA, USA), third-generation biofuels are broadly defined as new- and hybrid-processing technologies that convert organic materials. Yet, techniques such as consolidated bioprocessing—organisms that break down any given biomass to produce biofuels with no added enzymes or pretreatment—synthetic biology or the direct thermal conversion of organic material into liquid, are all largely in their infancy. The aim is to speed up the natural processes that turn organic material into oil or coal over millions of years. "If you left a plant in the ground for 300 million years [fossil fuels are] what you would get out, so it is like taking the plant out of the ground 300 million years earlier," explained Melvyn Askew, a fellow at the Central Science Laboratory in York, UK.

As most methods of producing second- and third-generation fuels are still unavailable, countries that use biofuels generally rely on various first-generation fuels depending on the domestic climate and agricultural resources. "The economics of first-generation biofuels is very much location-specific," commented Masami Kojima, Lead Energy Specialist at the World Bank (Washington, DC, USA). "For economic development, there is a preference for countries to utilize crops that can be grown domestically and import when their own production cannot meet the demand." Most of the five billion gallons of ethanol used in the USA come from domestically grown maize—rather than the sugar-cane-derived ethanol from Brazil's comparable five billion gallon production—although sugar cane yields approximately three times more energy than maize: 157.5 GJ/hectare compared with 52.5 GJ/hectare, respectively. Europe, which produces approximately 8% of global biodiesel, largely capitalizes on its domestically grown rapeseed, whereas China, India, Egypt, Tanzania and Kenya are expanding their production of jatropha to produce fuel. "Jatropha will come along because it grows [easily] in areas, there is environmental benefit, and people don't eat it," Askew said.

Clearly, the current standards of technology and agricultural output are not sufficient to replace fossil fuels entirely

Joseph Keriko, Director of the Institute of Energy and Environmental Technology at Jomo Kenyatta University of Agriculture and Technology in Juja, Kenya, explained that the World Bank gave Kenya US$30,000 in 2001 for the rehabilitation of yellow oleander as a cash crop in order to spur economic development. Although the plant is native to Peru and not Kenya, it grows well in Kenya, is drought tolerant and requires little care even when grown

 ©2008 EUROPEAN MOLECULAR BIOLOGY ORGANIZATION

in dry areas. Kenya is now exploring the plant's potential to produce biodiesel from its oily seeds. "Pilot research equipment are being designed and fabricated in our engineering workshop, which could be the basis for the development of a plant in the future," Keriko said.

The use of biofuels still requires financial incentives for producers and consumers alike. Many countries thus support biofuel production through government tax credits and subsidies. "Both the EU and Brazil started as [the USA] did with subsidies for ethanol and other renewable fuels," explained Wallace Tyner from Purdue University's Department of Agricultural Economics (West Lafayette, IN, USA). US producers receive tax credits of US$0.51 per gallon of ethanol and US$1.00 per gallon of biodiesel. Brazil granted a tax credit of approximately US$1.14 in 2005 with tax reduction incentives ranging from 32% to 100% depending on the fuel source and use; Germany currently encourages the use of biodiesel by levying lower taxes compared with normal diesel. Concurrently, various countries have subjected biofuels to import tariffs to protect domestic producers. The US has had a tariff of US$0.54 per gallon for imports that do not fall under the North American Free Trade Agreement (NAFTA) and the Caribbean trade agreement, whereas the European Union charges US$0.98 per gallon.

However, far more important than tariffs and subsidies are usage targets to encourage the production and use of biofuels further. "Brazil has only an ethanol mandate (standard) of 25% and the EU countries are also quickly switching from subsidies to mandates," Tyner said. Current targets range from 2% to 3% in New Zealand and Japan, to 25% in Brazil. In the long term, the EU plans to set a target of 5.75% by 2010 and 10% by 2020; Japan has set a target of 20% by 2030; and Canada of 5% ethanol by 2010 and 2% biodiesel by 2012. In the USA, the largest consumer of fuel on the planet, President George W. Bush's ambitious initiative for a renewable and alternative fuel standard aims for a 20% reduction in gasoline usage during the next 10 years. The first goal aims at 7.5 billion gallons of renewable fuel by 2012. Through a combination of increasing the use of alternative fuels to 35 billion gallons and improved fuel economy standards for cars, sport utility vehicles and light trucks, the USA plans to reach the 20% target in 2017.

According to Tyner, one of the main motivations for governments to switch from subsidies to renewable fuel standards (RFS) is to reduce costs. "[A] strong RFS would mean a subsidy is not necessary for biofuels to be economically viable, [although in the USA] the industry will certainly lobby to keep the subsidy and add the RFS," he explained. "The RFS says a gasoline supplier must procure a certain per cent of their product from renewable national resources and in the Senate Bill, it is about 15%." According to Luca Montanarella, a scientific officer from the European Commission (Brussels, Belgium), the EU targets are on a voluntary basis and

©2008 EUROPEAN MOLECULAR BIOLOGY ORGANIZATION

the commission has not planned specific sanctions if these are not met by 2010. In any case, it is not clear yet whether countries will actually be able to meet these standards. "The goals are established, but it depends on the evolution of technology [...] and if certain feedstocks become economically viable," commented Jerry Loos, information officer from the Nebraska Energy Office (Lincoln, NE, USA).

Yet, as the production of and demand for biofuels increase, so do concerns about rising food prices and the environmental impact of expanding agriculture. Earlier in 2007, the rising price of corn imported from the USA triggered protests in Mexico, and the United Nations' Food and Agricultural Organization (Rome, Italy) expressed concerns that globally rising food prices could create social unrest in developing countries (FAO, 2007).

However, although economists in the US agree that the price of corn has had an impact on food prices overall, Marvin Duncan, Senior Agricultural Economist at the US Department of Argiculture's Office of Energy Policy and New Uses (Washington, DC), commented that, "the major impact so far is due to rapidly increasing oil prices." Indeed, Vernon Eidman, at the University of Minnesota's Department of Applied Economics (St Paul, MN, USA) calculated that a 30% increase in corn prices would translate into a 1.9% increase in food prices. Similarly, Askew commented that in Europe, there is a, "bit of friction with rapeseed […] there is no surplus and prices are going up."

Ultimately, market forces and the limited area available for agriculture will determine both the profitability and the volume of crops that are grown for first-generation biofuels. "There is no one I know of who feels the US can produce 30 billion gallons of ethanol from corn because we can't produce enough corn to supply the other markets for corn, such as feed, other food uses and exports," said Eidman. Duncan also pointed out that some corn-based ethanol plants have had to shut down temporarily owing to a lack of profitability, and that several planned plants are on hold, illustrating that the demand for corn for the food market supersedes that for the fuel market. "In the case of the increased agricultural commodity prices, the EU would like to establish if the increase is speculative or competition for land resources," Montanarella commented.

More worrying, however, is the possible environmental impact of expanding the cultivation of crops for first-generation biofuels. An expert panel convened by the US National Research Council, an arm of the National Academy of Sciences (Washington, DC, USA), issued a report in October 2007 which raised concerns that greater cultivation of crops to produce ethanol could harm water quality and leave some regions of the USA with water shortages (Schnoor *et al*, 2007). The study thus encourages efforts to monitor environmental impacts, such as the amount of pesticide and fertilizer used, and the development of cellulose-based ethanol, which could use less water.

Furthermore, there is a debate brewing about whether the expansion of crops for biofuels will actually increase the overall emission of greenhouse gases. In April 2007, Paul Adler from the USDA and colleagues published a study concluding that ethanol and biodiesel from corn rotations reduced emissions of greenhouse gases by approximately 40%, from reed canary grass by approximately 85%, and from switchgrass and hybrid poplar by approximately 115%. This included levels of nitrous oxide, the gas emitted in the largest amounts during the life cycle of biofuel crops (Adler *et al*, 2007). However, in August 2007, Paul Crutzen, an atmospheric chemist at the Max Planck Institute for Chemistry (Mainz, Germany) and the Scripps Institution of Oceanography (La Jolla, CA, USA) and the winner of the 1995 Nobel Prize for Chemistry together with Mario Molina and Frank Sherwood Rowland for their work on stratospheric ozone depletion, predicted a net increase in nitrous oxide emissions of 3–5% owing to the increased use of fertilizer (Crutzen *et al*, 2007). In any case, the debate is far from settled. "In our view, it is hard to judge the credibility of the studies because there are so many different assumptions that drive analyses without complete information," said Jeffrey Kueter, President of the George C. Marshall Institute (Washington, DC, USA). "Developing new biofuel technologies will drive future studies and what has been learned will be built into those studies."

As second- and third-generation biofuels promise to become more viable options both economically and environmentally, governments are already planning mandates and programmes to support their development. According to Tyner, the US Senate version of the RFS is calling for 36 billion gallons of biofuels with ethanol from first-generation corn capped at 15 billion and most of the remaining 21 billion gallons coming from cellulose-based processes. "We will maintain the corn base, but future growth will be cellulose," he said. Askew expects that, "[i]deally within ten years we will have synthetic biodiesel from low-grade biomass, such as waste, cabbage, grass and trees."

…market forces and the limited area available for agriculture will determine both the profitability and the volume of crops that are grown for first-generation biofuels

In addition, governments and industry are investing in second- and third-generation biofuels research. "The massive investment in pilot plants and research projects is typical because they don't hurt anyone and allow time to gain a better understanding of the issue," Montanarella said. The Bush farm bill proposal includes US$1.6 billion for renewable energy research, development and production, and US$2.1 billion of guaranteed loans for cellulose-based ethanol. The US Department of Energy will also invest up to US$385 million over four years for cellulose-based ethanol production. Within the EU, countries such as Sweden and Germany are among the largest supporters of second- and third-generation biofuels.

Yet, these efforts still face considerable technical hurdles. "No one knows yet if biochemical or thermochemical processing is better for making liquid from biomass," Hicks commented. Nevertheless, the number of pilot plants to test new processes is growing. Researchers from Tsinghua University in China are testing a solid-state fermenter for sweet sorghum in Mongolia to produce ethanol. Sweden has inaugurated two second-generation pilot plants to produce cellulose-based ethanol and synthesize gas for biofuel production. The German Karlsruhe Institute of Technology is developing a biomass-to-liquid pilot plant. The race to develop a viable cellulose-based processing plant has begun, Montanarella said, but he remains doubtful "that they would be the ultimate solution to produce biofuels."

 ©2008 EUROPEAN MOLECULAR BIOLOGY ORGANIZATION

The concerns about economic sustainability and environmental impact are still severe enough that the European parliament is considering a moratorium on biofuel processes because, "it's even hard to get the facts," according to Montanarella. Nevertheless, biofuels are creating new regional and niche markets, and spawning opportunities for international collaborations. In the early 1990s, the governors of 11 US states formed the Governors Ethanol Coalition (GEC), which includes the international partners Australia, Quebec, Thailand, Mexico, Sweden and Brazil. The GEC expects to receive funding from congress to target pilot markets with E85 flex fuel pumps modelled after a pilot programme in Minnesota. In fact, "the biggest bottleneck in the US is fuel at the filling stations," Loos commented, pointing to a lack of funding to put E85 pumps and storage equipment at existing gas stations. The E85 Fleet Toolkit is necessary to modify gasoline pumps and storage equipment to control fuel composition, and prevent equipment failure or contamination. Furthermore, the GEC will work to increase public awareness of the possibility of using alternative fuels. "There are already 5 million cars on the road that can use E85 and the owners don't even know," Loos said.

Although Europe and the USA are still the main consumers of fossil fuels, these developments are also set to benefit the rapidly growing economies of Asia as more people, particularly in China and India, are able to afford a car. International cooperation to increase and encourage research into biofuel production and use therefore benefits all countries because it helps to decrease the emission of greenhouse gases. Jorge Sanchez, Agricultural Attaché at the Embassy of the United States of America in Beijing, China, explained that the Chinese National Reform and Development Commission (Beijing, China) is developing policies, "for a country that can consume like a developed country, but still needs to closely foster the needs of the 800 million plus peasants living in China's country side." China is the second largest consumer of oil behind the USA and the third largest producer of first-generation biofuels behind the USA and Brazil. "[C]ooperation is an important way to significantly reduce fossil fuel consumption, promote the agricultural sector, and support rural development […] and both countries stand to benefit," Sanchez said.

REFERENCES

Adler PR, Del Grosso SJ, Parton WJ (2007) Life-cycle assessment of net greenhouse-gas flux for bioenergy cropping systems. *Ecol Appl* **17:** 675–691

Crutzen PJ, Mosier AR, Smith KA, Winiwarter W (2007) N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels. *Atmospheric Chemistry and Physics Discussions* **7:** 11191–11205

FAO (2007) *A Review of the Current State of Bioenergy Development in G8 +5 Countries*. Italy, Rome: United Nation's Food and Agricultural Organization

Schnoor JL, Doering III OC, Entekhabi D, Hiler EA, Huller TL, Tilman GD, Logan WS, Huddleston N, Stoever M (2007) *Water Implications of Biofuels Production in the United States*. Washington, DC, USA: The National Academy of Sciences

Laura Ruth

doi:10.1038/embor.2008.6

©2008 EUROPEAN MOLECULAR BIOLOGY ORGANIZATION