Bioenergy and Agriculture: Promises and Challenges

2020 VISION FOR FOOD, AGRICULTURE, AND THE ENVIRONMENT

Bioenergy and Agricultural Research for Development

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Converting agriculture to produce energy as well as food has become an important and well-funded global research goal as petroleum reserves fall and fuel prices rise. But the use of crop biomass—both grain and other plant parts—as a raw material for bioenergy production may compete with food and feed supplies and remove valuable plant residues that help sustain soil productivity and structure and avoid erosion. Agricultural research can mitigate these trade-offs by enhancing the biomass traits of dual-purpose food crops, developing new biomass crops for marginal lands where there is less competition with food crops, and developing sustainable livestock management systems that are less dependent on biomass residuals for feeds. Agronomists will need to define the minimum thresholds of crop residues for sustainable production in particular farming systems, especially in low-yield rainfed systems (that produce less than 5–6 metric tons of grain and straw per hectare), and to establish the level of additional residues that may be removed for other purposes, including biofuel production. Enhanced root growth offers another avenue for maintaining soil organic matter. Agricultural research can also help improve the energy efficiency of biomass crops, enhancing their value as renewable energy sources with low net carbon emissions.

CROP-BREEDING OPTIONS TO ADDRESS BIOFUEL NEEDS

Agricultural biofuels are currently based on the generation of ethanol from sucrose or starch derived from vegetative biomass or grain, on biodiesel from the more direct use of vegetable oils and animal fats. Ethanol has a high octane rating and can be blended in low proportions with gasoline for direct use in normal internal combustion engines.

Further down the line, there is enormous potential to develop cellulose-based bioenergy systems. Plant biomass is an abundant and renewable source of hydrocarbons, and crops can generate more cellulose per hectare than sucrose or starch. Plant breeders should aim for high-density biomass production (for example, 15 tons per hectare in maize) rather than competing with crop residues or forest production for supplying materials to cellulosic biorefineries. Preliminary research shows significant genetic variation among maize and sorghum (brown midrib mutants) cultivars for cellulose and lignin content, suggesting that breeders can select for the increased quality of maize and sorghum stover for ethanol conversion. Breeders can also develop cultivars whose biomass lends itself readily to breakdown by fungi, improving ethanol production efficiency.

Breeders can increase cellulose or hemicellulose production by making photosynthesis or nitrogen metabolism more efficient, but they must also select for enhanced water- and nutrient-use efficiency under resource-conserving systems that provide an overall energy savings and cut emissions of carbon dioxide and pollutants. Growing biofuel crops on lands not suitable for food production—for example, those affected by drought, salt, or temperature stresses—would substantially reduce fuel–food competition.

One set of crops with great potential for ethanol production is sweet sorghum, which is similar to grain sorghum but features more rapid growth, higher biomass production, and wider adaptation. The dual-purpose nature of sweet sorghums—they produce both grain and sugar-rich stalks—offers new market opportunities for smallholder farmers and does not threaten food trade for sorghum. Because sweet sorghum requires less water and has a higher fermentable sugar content than sugarcane, which contains more crystallizable sugars, it is better suited for ethanol production than sugarcane or other sources, and sweet sorghum ethanol is cleaner than sugarcane ethanol, when mixed with gasoline.

THE ROLE OF BIOTECHNOLOGY

Reducing lignin in crop biomass will greatly improve biorefinery efficiencies. Genomics, proteomics, and metabolomics are being used to improve our understanding of and ability to manipulate the lignin biosynthesis pathway. For example, before processing, maize stover is currently pretreated to convert lignocellulose to sugars but transgenic technologies may provide *in planta* alternatives to pretreatment.

DNA markers are chromosomal "flags" that facilitate the discovery, understanding, and manipulation of genes. They may be used to accelerate breeding for reduced lignin biosynthesis and increased cellulose content, or enhanced bacterial digestion of plant cell walls. Care must be taken, however, because changes in lignin properties may reduce pest and disease resistance or alter stover nutritional value. Marker-assisted selection has already been used to improve the equally complex characteristic of oil concentration in maize kernels.

ALTERNATIVE CROP SPECIES WITH POTENTIAL FOR BIOFUEL PRODUCTION

Oil crops in South Asia. Many developing countries cannot afford to use edible oils as an energy source because they are already in short supply. Thus, non-edible oils from underresearched plants such as *Jatropha, Pongamia, Neem, Kusum*, and *Pilu* are being advocated. *Jatropha curcas* (ratanjot) and P*ongamia pinnata* (karanja) could be used to supplement traditional, highly polluting fuels and provide employment to landless and marginal people. Both *Pongamia* and *Jatropha* grow in low-rainfall areas and on problematic soils and wastelands in South Asia. They are easy to establish, are fast growing and hardy, and are not browsed by cattle and goats. *Pongamia* and *Jatropha* seeds contain 25 to 40 percent oil of a type that requires little or no engine modification, when blended after esterification with diesel in proportions as high as 20 percent. Additionally, the oilcake left after extraction of oil is rich in macro- and micronutrients, serving as an excellent organic fertilizer. More research is needed on developing these crops for biofuels.

North American wild grass. Switchgrass (*Panicum virgatum*), a perennial grass native to the North American prairies, could provide more than 100 billion gallons of biofuels per year, while allowing food, animal feed, and export demands for other crops to be met. Switchgrass can grow on lands incapable of supporting traditional food crops, with 1/8 the nitrogen runoff and 1/100 the soil erosion of conventional crops. Its deep root system adds organic matter to the soil, rather than depleting it. Breeding programs are aiming at least to double switchgrass yields (currently about 10 tons per hectare) and raise ethanol output from switchgrass to about 100 gallons per ton in the medium term.

Grasses in Europe. The *Miscanthus* genus (including giant Chinese grass, silver grass, silver banner grass, maiden grass, and eulalia grass) is receiving attention as a potential source of biomass for biofuels. Giant *Miscanthus* (*Miscanthus* x *giganteus*) is a hybrid grass that can grow four meters high. Given its rapid growth, low mineral content, and high biomass yield, some European farmers use *Miscanthus* to produce energy. The biomass from one hectare of *Miscanthus* can produce about 3,700 gallons of ethanol. Alternatively, after harvest *Miscanthus* can be burned to produce heat and power turbines or can be mixed with coal in equal amounts for use in coal-burning power plants without modifications. More research is needed in this area.

BIOFUELS AND CONSERVATION AGRICULTURE

Among other cellulose sources considered for ethanol production are the crop residues or straw from grain crops like maize and wheat. These residues are important for many farmers—particularly in rainfed areas—for use as animal fodder, cooking fuel, construction material, and soil amendments. In intensive agricultural systems, the residues can encumber field operations and are often burned, releasing large, sudden flushes of CO_2 into the atmosphere.

The removal of crop residues contributes to soil erosion and, through loss of soil organic matter, long-term degradation. These effects are exacerbated by continuous and extensive tillage, in itself energy consuming and polluting, leading to a gradual loss of crop productivity, even when irrigation and fertilization are increased. The solution is to combine appropriate conservation agriculture practices such as reduced or zero tillage with the retention of adequate levels of crop residues on the soil surface and diversified crop rotations.

Moreover, one of the most serious problems facing many farmers is their rapidly increasing fuel costs related to their high tillage production systems. Converting to reduced- or zero-tillage planting systems can dramatically reduce fuel costs for all crops. The use of sound conservation agriculture practices that emphasize zero tillage with rational residue management, thereby reducing overall fuel requirements, would be a win-win situation both for food and biofuel crop production. Research could help develop rational residue management approaches that could have the added benefit of reducing farmers' use of fuel.

INSTITUTIONAL ARRANGEMENTS FOR BIOFUEL RESEARCH

Biofuel production poses a major new challenge for crop improvement and the sustainable management of cropping systems. For farmers to respond to market changes, they need multipurpose crops combining food, feed, fiber, and biofuel traits. Basic research on crop biofuels may best be undertaken by upstream academic organizations and the private sector. On the other hand, trait-based mining of genetic resources may be the most appropriate niche for public genebanks, particularly those of research centers supported by the Consultative Group on International Agriculture (CGIAR). Clearly there are substantial financial incentives for private investment in developing new cultivars for biofuel production. Private investment, however, also threatens to result in the locking up of a large proportion of enabling technologies under various intellectual property protection mechanisms, as is already happening with, for example, critical enzymes in the biofuel production process.

The breeding of new cultivars for the biofuel market may open the opportunity for a whole new paradigm in public-private partnerships. Public research may focus on tapping potential plant genetic resources and initial trait genetic enhancement that will feed into either public or private breeding programs worldwide. International public organizations, such as the CGIAR, may serve as conduits of new knowledge and technology to small-scale farmers, particularly in resource-poor farming areas of the developing world. Clearly one of the most important roles of the CGIAR in this area will be to find mechanisms to ensure that smallholder farmers (particularly those in resource-poor areas) can benefit from this potentially lucrative new market without significant increasing their vulnerability. ■

For further reading see J. Hill et al., "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels," *Proceedings National Academy of Sciences*, USA (2006) 103: 11206–11210; A. J. Ragauskas et al., "The Path Forward for Biofuels and Biomaterials," *Science* (2006) 311: 484–489; C. C. Laurie et al., "The Genetic Architecture of Response to Long-Term Artificial Selection for Oil Concentration in the Maize Kernel," *Genetics* (2004) 168: 2141–2155; B. V. S. Reddy et al., "Sweet Sorghum: A Potential Alternate Raw Material for Bio-ethanol and Bio-energy," *International Sorghum and Millets Newsletter* (2005) 46: 79–86; C. Schubert, "Can Biofuels Finally Take Center Stage?" *Nature Biotechnology* (2006) 24: 777–784; M. Sticklen, "Plant Genetic Engineering to Improve Biomass Characteristics for Biofuels," *Current Opinion in Biotechnology* (2006) 17: 315–319; S. Wani et al. "Improved Livelihoods and Environmental Protection through Biodiesel Plantations in Asia," *Asian Biotechnology and Development Review* (2006) 8: 11–34.

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