



## Editorial

### Future of bioethanol...

Fermentation-derived bioethanol has received a great deal of attention as a potentially renewable biofuel and fuel additive. Nearly all the bioethanol in use today is produced from edible crops, mainly sugarcane, corn, and wheat. Production of bioethanol especially from corn and wheat has reduced their supply for food. This has been the source of much conflict as corn and wheat are staple food in parts of Africa and other regions. Bioethanol derived from abundant lignocellulosic materials, or lignoethanol, will certainly circumvent the food versus fuel dilemma and has the potential to be less expensive than ethanol currently sourced from food crops. This has been recognized for decades, but despite much investment over a long period, hurdles remain to commercialization of lignoethanol. Commercialization may be feasible in the near term, but the timelines are uncertain. Attempts are underway to obtain ethanol from starch produced in microalgae, the primitive microscopic aquatic plants that tend to be more productive than terrestrial crops. This has been shown to be technically possible, but is expensive and has its own problems. At the moment, lignoethanol holds the most promise as a renewable fuel that is unlikely to impact supplies of food and feed.

Lignoethanol is a second generation biofuel relative to ethanol obtained via fermentation of sugars sourced from sugarcane and starchy food crops. Lignoethanol is produced via essentially the same fermentation technology as is now used in making ethanol from cane molasses, corn, and wheat. The only difference is the source of the sugars. The sugars used in making lignoethanol come from the readily available and cheap lignocellulosic materials that have almost no food applications. The cellulose and hemicellulose polymers in the lignocellulosic biomass provide the sugars for lignoethanol. Unfortunately, cost-effective production of fermentable sugars from lignocellulosic biomass remains a challenge.

As lignocellulose is difficult to deconstruct into its constituent sugars, the biomass needs to be extensively pretreated to first remove the lignin and then hydrolyze the cellulose and hemicellulose to fermentable sugars. A variety of pretreatments have been developed and continue to be improved. Nevertheless, pretreatment processes contribute nearly 20% to the final cost of the lignoethanol. A universal pretreatment process does not exist, as the amenability of lignocellulosic feedstock to a given pretreatment varies with the source of the feedstock. Different biomass feedstocks require different pretreatments. Seasonal variability in supply of biomass results in variability in feedstock for a given pretreatment process and this also affects the overall performance of the production operation. A suitable pretreatment must not only be cheap, but it must have a low energy demand and an acceptable environmental impact. Furthermore, the pretreatment must allow a near complete recovery of the fermentable sugars initially present in the biomass feedstock and it must not produce inhibitory products that may interfere with the microorganisms involved in the downstream fermentation.

The future of bioethanol is very much intertwined with genetic and metabolic engineering. Genetic and metabolic engineering of nonfood crops, for example, can greatly improve the biomass feedstock productivity and ease of deconstruction. Cost of production of the biomass and the resource requirements for producing it may be reduced. Capabilities of the enzymes for hydrolyzing cellulose can be enhanced and their cost of production can be reduced by genetic engineering of producer microorganisms and molecular engineering of the enzymes themselves. Furthermore, the conversion of the

sugars to ethanol and its rate of production may be enhanced by genetic and metabolic engineering of microbial species. Attention to improving the production and capability of cellulose hydrolytic enzymes is important as these enzymes contribute more than 50% to the cost of producing the sugars from the biomass. Recycling of cellulolytic enzymes is impractical. To reduce costs, the enzymes must be produced close to the biorefinery where biomass is deconstructed and subsequently fermented to bioethanol. The overall cost of production of bioethanol may be reduced by finding uses for the lignin byproduct of biomass deconstruction and for the microbial biomass generated in the fermentation process. The biomass deconstruction step may be made to yield other useful byproducts, depending on the specifics of the biomass being used.

The conventional lignoethanol processes use separate steps for saccharification of cellulose and fermentation of the resulting sugars. This allows the two steps to be carried out under conditions that are optimal for each. Other potential approaches mentioned in the literature include simultaneous saccharification and fermentation (SSF) at a fixed temperature and SSF with a variable temperature-time profile. Substantial scope exists for improving some of these schemes.

In principle, a microorganism may be isolated, or engineered, with the capabilities for simultaneous hydrolysis of cellulose and fermentation of the resulting sugars to ethanol. Alternatively, cocultures of two or more microorganisms may be used to achieve combined saccharification and fermentation. Both these approaches will reduce the need for intermediate purification steps and, therefore, may reduce costs. Such consolidated bioprocessing (CBP) remains to be proven in commercially viable operations.

In short, ethanol from food crops is not a desirable option in view of its adverse impact on supply of food and feed. Ethanol from lignocellulosics holds the greatest promise, but remains relatively expensive. Other sources of ethanol, microalgae for example, require extensive research for commercialization. Direct production of ethanol from carbon dioxide and water via photosynthesis in genetically modified microalgae is another plausible scheme, but is insufficiently developed for commercial implementation at present.

*Editors*

Keikhosro Karimi

*Department of Chemical Engineering, Isfahan University of Technology, Iran*

Yusuf Chisti

*School of Engineering, Massey University, New Zealand*

*Email Addresses: [karimi@cc.iut.ac.ir](mailto:karimi@cc.iut.ac.ir) (K. Karimi)  
[y.chisti@massey.ac.nz](mailto:y.chisti@massey.ac.nz) (Y. Chisti)*