Feedstocks for Biofuels
James N. Seiber, August 5, 2008

Switchgrass, energy cane, used cooking oil, Salicornia, barley straw, municipal solid waste—getting confused by all the feedstocks being looked at for biofuels and bioenergy? Actually, the U.S. and world will need everything that can be mustered if the global demand for energy—estimated to be 720 Quads per year in 2035 vs 430 at present—is to be satisfied. China, India, and other 'developing nations' are ramping up quickly in energy consumption. China will likely pass Western Europe in the next year or so, and equal the U.S. by 2035. Biomass conversion to biofuels and other forms of useable energy is just one of the possibilities for expanding the energy 'pipeline' in the coming years. Solar, wind, and nuclear are also being implemented or are under discussion along with expanded exploration for, and development of coal, oil and natural gas 'fossil fuels'. Renewables and other alternatives were among the topics discussed at the recent Latin American Chemical Congress (FLAQ) held in San Juan, Puerto Rico July 27-31, 2008. The Congress included a 1-day Symposium organized by the American Chemical Society on Biofuels and Bio-based Products Chemistry and Environmental Impacts that featured speakers from Brazil, Puerto Rico, Europe, and the United States.

Feedstocks are the Key

Dependable sources of inexpensive biomass to serve as a feedstock are a prerequisite for sustainable bioenergy production. Today's feedstocks include sugars from sugarcane, sugar beets, and sweet sorghum, along with starch from corn and wheat, and vegetable oil from soybeans or palm as preferred sources for conversion to bioethanol and biodiesel—the liquid transportation biofuels of choice. But these sources combine to produce just 3 % (7.5 billion gallons) of today's transportation fuel requirement in the U.S. and with expansion just 10-12 % of its estimated consumption for 2022. The U.S. Energy Independence and Security Act of 2007 requires the annual use of 36 billion gallons of renewable fuel by 2022. Europe has similar lofty goals—20% of its transportation fuel must come from renewable sources by 2020 (vs 3% today). Brazil is doing better, currently providing % of its transportation fuel needs from sugarcane-derived bioethanol and soy-derived diesel. But Brazil has been working toward this enviable position for some time, expanding its production of sugarcane and soybeans, developing infrastructure for transporting and processing these feedstocks, and by implementing national standards for flex-fuel vehicles (ie, those that can run on either petroleum or biobased sources of liquid fuels, including various blends). Worldwide, there are signs that global demand may be attenuated somewhat by the advent of more fuel efficient vehicles, conservation, and escalating fuel costs, but the longer range prospects are for sustained economic growth in China, India, Eastern Europe, and South and Central America and more and more energy consumption.

The Cellulosic Route

Looking beyond corn starch and sugarcane sugar—the 'low-lying fruit' among fermentation feedstocks—has become a major challenge and economic competition. Much of the research and development effort is focused on 'cellulosic ethanol', or bioethanol produced from the cellulosic structure (largely plant cell walls) of herbaceous grasses and crop and forestry residues. Among the leading possibilities for feedstocks are 'energy crops' that are cultivated

only or primarily for conversion to energy. Switchgrass, a perennial prarie grass native to North America, is undergoing significant R&D aimed at genetic improvement by both conventional breeding and biotechnology. The U.S. departments of agriculture (USDA) and energy (DOE) have teamed up to sequence the gene structure of switchgrass along with another grass, Brachypodium distachon, which can serve as an experimental model for other grassy 'energy' species including miscanthes, reed canary grass, and sweet sorghum. Targets for genetic improvement include increasing the biomass yield, increasing the cellulose to lignin ratio, expanding the range for crop cultivation, and building in mechanisms for hastening the breakdown of the plants biomass at or near the time of harvest, so that the pretreatment steps which now must precede fermentation or other means of conversion to biofuels can be reduced or even eliminated.

Corn, sugarcane, alfalfa, and sweet sorghum are here-and-now crops that can be modified to improve characteristics as cellulosic feedstocks, providing starch, sugar, and cellulosic material for conversion to energy. Sugarcane bagasse, the residue after sugar is extracted from sugarcane, and corn stover, the rest of the corn plant after harvest of the starch-containing kernels (wheat, rice and barley straw are somewhat analogous to corn stover for purposes of energy feedstocks) are currently favored as feedstocks for cellulosic conversion because they are in abundant supply and are often aggregated as a result of harvest or milling operations. In the case of cereal straw residues like rice and wheat, open burning while still in the field—a long standing practice to remove them from the fields prior to the next season's planting—is no longer allowed in many parts of the world because of air quality including visibility deterioration. Using this 'surplus' biomass for producing energy is attractive, to growers, to energy producers, and to environmentalists.

Sugarcane illustrates another quality which is important in using crops for fuel. It is a perennial crop in year-round warm climate areas such as Brazil, so a single planting can lead to year-after-year harvests of 5 years or more. This is a big advantage relative to corn, barley or wheat which must be planted annually. New varieties of sugarcane that are more cold tolerant could expand perennial sugarcane to areas such as the U.S. gulf coast. Cultivating sweet sorghum along with sugarcane is another strategy being explored to improve efficiency of production and processing. Sweet sorghum could be harvested at times outside the sugarcane harvest, extending the milling season by several weeks, and similarly extending the availability of sugar syrup or bagasse for bioenergy production.

Novel Feedstoks: MSW, Guayule, and Salicornia

Seasonality issue are important with crops grown for energy: most energy or fuel production facilities need a year-round supply of feedstock, yet most crops, like corn, wheat and barley, are seasonal. Geographic issues are important as well, since crops grown for energy may not be located where the bioenergy or biofuel needs are the greatest, eg along the eastern seaboard, in the gulf states, or along the west coast in the U.S. where much of the population resides. For both seasonality and geographic reasons, comingling agricultural biomass with Municipal Solid Waste (MSW) is attractive. MSW is composed largely of cellulose (from waste paper). In one strategy, the comingled feedstock is treated with a steam autoclave, reforming the MSW and agricultural cellulose base, subsequently removing recyclables like plastic and glass, and then

fermenting the bulk of the material to ethanol, or thermochemically treating it via gasification or pyrolysis to combustible fuels for transportation, heating, or generating electricity.

Concern over diversion of crop material which could be used for food or animal feed to energy is growing (the 'food vs fuel' debate). There are also environmental concerns over the sustainability of intense crop cultivation for energy purposes, including water use, pesticide and fertilizer use, and depletion of soil nutrients. These concerns have prompted a search for energy (and/or food crops) that can be grown on marginal lands—semi-arid, saline, etc. Salicornia, a halophyte or salt-tolerant plant that can be cultivated in hot climates such as Mexico's Sonoran desert, can be irrigated with sea water. Its biomass can be harvested for either bioenergy or for food or animal feed. And adding this crop to low-lying marginal lands such as in the delta of the Colorado River can make use of rising coastal water levels occasioned by global warming, plus it reduces atmospheric carbon dioxide, as does any plant, during the process of photosynthesis.

Guayule is another newcomer. Now under cultivation in the Mojave desert region of Arizona, guayule produces a superior rubber latex for biomedical, aircraft tire, and other high end uses. Extracting the latex leaves behind, just as with sugarcane and sugar, a residue bagasse which can make a good feedstock for conversion to bioenergy, biofuels, and/or other biobased products. From essentially native stands of guayule shrubs dispersed in the desert there are now over 5000 acres under cultivation and plans for many-fold expansion of production in the future.

From Promise to Production

The FLAQ Symposium covered other novel biomass sources which could be used for cellulosic ethanol or other biofuel, ranging from grape pomace and Scotch whiskey distillery wastes to dormitory food wastes on college campuses to wastes from forest thinning or paper pulping, animal manure, etc. But demonstration of sustainable cellulosic conversion to biofuels is still far off. It is estimated that there are some 50 such facilities under construction or planned for the U.S, but none is presently operating at more than pilot scale. The same is true of cellulosic-fed gasifiers, although thermal conversion by combustion is practiced widely, including in many agricultural operations to help meet demand for steam, electricity, and to run driers.

The next large step forward in bioenergy remains an elusive goal—conversion of cellulosic material, including hemicellulose, which is the primary structural material of the plant kingdom, first into fermentable sugars and then into bioethanol, other biofuels, or platform biobased chemicals such as lactic and succinic acid that can be converted further into solvents, paints, monomers and polymers, fibers, etc. It is the biobased co- products that can support the economics which will insure profitability of tomorrows biorefineries—producing a range of products that in the past were in large part or solely derived from petroleum.