SUGGESTIONS FOR IMPROVING CELLULOSIC BIOMASS REFINING

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Summary

The economics of biofuels hinge on inexpensive fermentable sugars. Hydrolysis of the carbohydrates in biomass to their sugars should lead to a profitable, environmentally-benign new fermentation industry while having a significant contribution to overall consumption of energy. Several aspects of feedstock selection, steam economy, acid hydrolysis, and excessive dilution that have had insufficient attention are addressed here.

1. Introduction

Inexpensive sugars are the key to economical production of alcohol fuels from biomass. Sucrose from beets or sugarcane and glucose from the hydrolysis of starchy plants are being fermented to fuel ethanol in ever increasing amounts, but competing uses such as human and animal food insure that raw material costs will continue to rise. Furthermore, energy content of fuel ethanol as currently manufactured is not much more than the energy expenditures to grow, harvest, transport, and refine the biomass, and to distribute the product. Processes for making ethanol from extracts of sugarcane and from fermentation of corn or other grains employ reasonably mature technologies that will not be discussed here [see also– *Biorefineries*, and *Technology and Economics of Fuel Ethanol Production from Sugarcane*]. Cellulose is much more abundant than other plant carbohydrates and has the potential to remain relatively inexpensive while providing fermentable sugars. The lignin in cellulosic biomass can fuel the biomass refinery [see also– *Lignocellulose Biorefinery*] and can be converted to byproducts that command high prices but have small markets compared to those for liquid fuels. Certainly, liquid fuels from cellulosic biomass will play ever increasing roles in the world's energy picture. Some approaches to improving biomass refining are presented here. No claim is made that these suggestions have not been advanced by others.

2. Processing of cellulosic biomass

Key characteristics for a feedstock for biomass refining are yearly productivity, moisture content, and composition. Crops that grow slowly make poor use of agricultural lands. Because high moisture content wastes transportation energy, the feedstocks that have been assigned high priority are relatively dry. Nevertheless, the great productivities of some wet plants may counterbalance handling costs if refineries are near the areas for their cultivation. Typical harvest times are in Table 1.

Crop	Harvest time
Trees	Several years
Corn	yearly
Sugarcane	Two crops per year in some nations
Grasses	Can be cut several times per year
Floating plants	Six days
Algae	One day

Table 1: Harvest times for candidate plants

The sucrose in sugarcane and the easily hydrolyzed starch in corn are the reasons why these crops are attractive to ethanol producers. Sorghum and various other grains are also fermented to ethanol. Cellulosic feedstocks with negligible sugar or starch content require processing that is much more complicated than simple extraction. For order of magnitude considerations of challenges, opportunities, and pitfalls, representative numbers for wood are not much different from those for other biomass: 43% cellulose, 19 % xylan, 4 % mannan, 0.8 % arabinan, 0.2% galactan, 4.6 % acetate, 28 % lignin, 1 % ash, and 48 % moisture.

Wood. Hybrid trees can be harvested every two or three years. Fresh wood is about 50 per cent water. Burning fresh wood sacrifices the energy required to vaporize the water, and drier wood from such sources as scrap wood and demolition wastes is a better fuel. A major advantage of substituting wood for coal or petroleum in a power plant is its very low content of sulfur thus greatly minimizing the release or sulfur oxides. Expert opinion based on a working shift to load, convey, and unload trucks is that trees should not be hauled from more than 100 miles (161 km). A storage lot to hold a few days supply for a large refinery would cover an area equivalent to 2 or 3 football fields with the feedstock rising 3 or 4 meters high.

Wood is hydrolyzed to the sugars from cellulose and hemicellulose following subdivision to allow penetration of cellulase enzymes or acid, and the most promising pretreatments also reduce the crystallinity of cellulose to facilitate the hydrolysis.

Corn Stover. The residue after corn is harvested has a valuable use when left on the soil to combat erosion. Diverting it to biomass refining has questionable economics because its price will rise as demand increases and a substitute for its erosion control may be expensive. While corn stover should not be dismissed as a feedstock, it does not appear to be near the top of the list of attractive candidates.

Sugarcane residues. The leaves of sugarcane are burned before harvest to kill pests such as scorpions and snakes that would endanger the workers. Schemes for collecting the leaves to use as fuel would add much to the yield of energy. Selective breeding has produced sugarcane with more leaves. The main useful residue currently is bagasse, leftover after squeezing cane to extract its sucrose. Sugar producers burn wet bagasse to power their factories, and the combustion energy is sufficient for their needs. The bagasse could be dried using flue gases to increase its heating value greatly. Adding a cellulosic section to a factory that makes ethanol from sugarcane makes sense because the leaves and bagasses that are close by can supply both cellulose and combustion energy, and the distillery section could use almost identical technology for product recovery.

Grasses. Several crops per year are taken by cutting grasses. Moisture content of fresh grass is higher than that of trees, so transportation is more expensive on a dry weight basis.

Municipal wastes, manure, and sewage sludges. Mixed municipal solid waste is messy stuff and includes metals, batteries, and plastics. Sorting is required to separate the paper component for hydrolysis to fermentable sugars. It makes a great deal of sense to accept disposal credits, byproduct credits, and to use the paper as biomass. However, the economics are not convincingly profitable, and there is not enough total waste to approach the amount needed for full substitution of motor fuel.

While it may not be attractive to invest in making ethanol from solid waste, it would enhance the economics of a refinery to blend solid waste with the main feedstock of the factory. Small amounts of solid waste would not markedly change the processes. In other words, solid wastes can have only a minor impact on energy needs, but accepting them would reduce environmental problems and defray costs of their disposal [see also– *Socio-economic strategies for sustainability*].

Feedstocks with an unfavorable ratio of carbohydrates to lignin are unsuitable for making ethanol. Manure and sewage sludges are enriched in lignin and other molecules that are not easily metabolized because the carbohydrates that are the best starting materials for conversion to ethanol or other fermentation products are mostly consumed during passage through the digestive tract or by microorganisms in the sewage treatment system. Manure stored in piles has the fraction of carbohydrates depleted fairly quickly. The most popular technology for deriving methane from these feedstocks is slow, and there are obnoxious, wet wastes that incur costs for final disposal [see also– *Recycling Livestock Excretes in Integrated Farming Systems*, and – *Biogas as Renewable Energy from Organic Waste*]. While methane is easily collected, a byproduct is carbon dioxide that must be removed before the gas is acceptable in pipelines.

Algae and aquatic plants. The potential of these plants has been reviewed by Sheehan and coworkers in 1998. Aquatic plants contain a low percentage of solid mater in relation to their water content. Processing near the growing areas is mandatory when transportation costs are considered. There are several major problems for plantations of algae. One is the cost of ponds because flat land and abundant water are required. These are also factors for prime agricultural lands, not to mention proximity to waterways as a main attraction for recreational lands. Much more valuable competing uses for the land means that capital investment for growing algae will be high. Another problem is harvesting because concentrations are low. Large quantities of water are handled to concentrate algae with microstrainers, devices that employ a small liquid head to prevent compacting and clogging on the filter medium. The microstrainer input suspension is a pale green and the output stream is a bold green. However, the output stream requires further concentration despite this intermediate step. Centrifuges make no sense because of the high energy to develop rotational velocities of so much water for so little product.

Algae grow at maximum rates only when illuminated well. Scums of algae growing on the surface of a body of water and not thick enough to constitute high productivity per unit of area, and systems now being studied use suspensions of algae. Those algae that are remote from the light source are masked by the others; agitation is required to bring them to the surface even though they can float when attached to the oxygen that they evolve by photosynthesis. Outdoor ponds of algae get relatively poor illumination when the sun's angle is acute. Floating plants such as water hyacinth are relatively easy to collect. Water hyacinth projects above the water surface and gathers sunlight well at all times of the day. This plant is a world-wide nuisance that must be removed from navigable waters. It covers streams and lakes and restricts oxygen supply to organisms in those bodies of water. Credits for its removal and disposal would help a biomass refinery, but the challenges are formidable for handling a wet plant to the stage where it can be hydrolyzed to sugar solutions not too dilute for fermentation.

Macrocystis is giant kelp that belongs to the algae family. It could grow in the oceans where vast areas might cost little. Kelp does not grow back when cut; it must be replanted. Current proposals feature divers attaching each new plant to an underwater grid of supports. It is unimaginable that this replanting method can become part of a practical biomass scheme. Furthermore, the upper regions of the oceans have low nutrient concentrations; pumping water more rich in nutrients from the depths of the ocean would require enormous capital expense. Kelp will be dismissed here with no more discussion.

3. Typical Processes

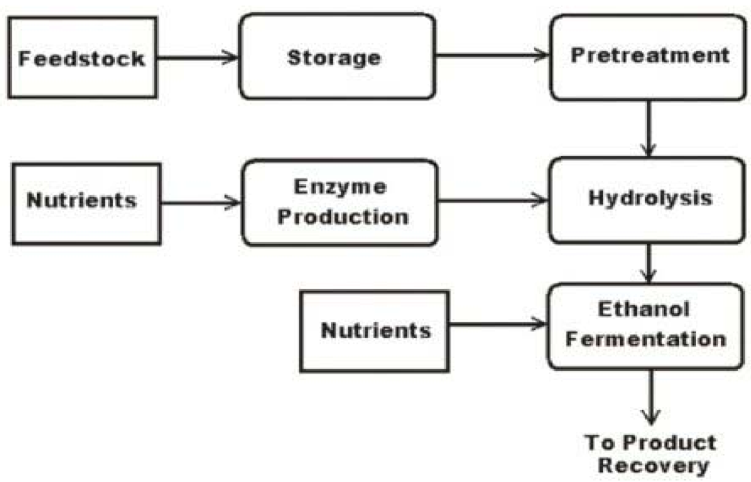

Figure 1a. Steps in a Biomass Refinery Using Enzymatic Hydrolysis

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Biographical Sketch

Henry Bungay has the degree Bachelor of Chemical Engineering from Cornell University and a PhD in biochemistry from Syracuse University. His industrial experience was as a biochemical engineer with Eli Lilly and Company (Indianapolis) and as Vice President-Technical Director at Worthington Biochemical Corporation (Freehold, NJ). He served as Program Manager at the National Science Foundation, as Program Manager at ERDA (now part of the U.S. Department of Energy), and was Resident Energy Fellow at the New York State Energy Research and Development Authority. He was a faculty member at Virginia Polytechnic Institute and Clemson University before joining to Rensselaer Polytechnic Institute. He coordinated a U.S./U.S.S.R. cooperative program for enzyme technology and has visited India, Brazil, and Indonesia as part of National Academy of Sciences teams on biomass energy. Assignments for UNIDO took him to Bulgaria and to the Republic of the Philippines. His honors include the James Van Lanen Distinguished Service Award and the Marvin Johnson Award from the Microbial and Biochemical Technology Division of the American Chemical Society. He was chairman of that division and has also served ACS as Speaker to Local Sections throughout the United States. He is a Fellow of the American Institute of Chemical Engineers. He has over 200 publications and has authored five books including ENERGY, THE BIOMASS OPTIONS that received an award as best technical book from the American Association of Publishers.