Prospects for the New Bioeconomy

By

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Outline

1. Where are we today?
    a. Ethanol from corn starch and sugar cane as mature technologies

2. The New Biology of Genomics
    a. Role of co-products (e.g. DDGS, bagasse)
    b. Life Cycle Analysis

3. Possibilities for the Future
    a. Biorefinery of the future, including dedicated energy crops

What are the Possibilities for the New Bioeconomy?

This paper will discuss the state of current bioenergy platforms, the impact of the new biology of genomics on biomass conversion and the biorefinery of the future. A biorefinery is herein defined as a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum.

In order to discuss what the future may hold when it comes to the bioeconomy, it is important to examine where we are today with respect to the current bioenergy platforms. Both dry and wet mill ethanol production from corn starch (U.S.) and ethanol production from sugarcane (Brazil) are regarded as essentially mature technologies for producing bio-ethanol. Currently, dry-grind ethanol plants produce the majority of fuel ethanol (ca. 60%) in the U.S. Given concerns regarding net energy balance and the food vs. fuel debate, ethanol production from corn is expected to level off (von Braun, 2007). However, some incremental increases in energy efficiency of these processes can be expected as co-product utilization (e.g. distillers grains and bagasse) is incorporated into next generation plants. Currently, distiller's grains from corn ethanol production is used as animal feed, while most of the bagasse from sugar cane production is burned for power generation.

Seven million metric tons of distillers grains (DDGS) is expected to be produced in the U.S. by the end of this year. Some experts are predicting that DDGS production in the U.S. will reach up to 15 million metric tons in a few years. In addition to starch, distillers grains contains fiber, which is composed of cellulose, xylan and arabinan. If these co-products were further hydrolyzed and converted into liquid fuels or other bio-products, the efficiency and profitability of these plants would be expected to improve even further. In order to accomplish this, technologies have to be developed for de-construction and enzyme treatment of the fiber component present in DDGS. Members of The Midwest Consortium for Biobased Products recently completed a comprehensive study on the utilization of DDGS that will be published in a special edition of Bioresource Technology. As part of this study, the fermentation of DDGS hydrolysates to biobutanol by the solvent-producing clostridia was examined (Ezeji and Blaschek, 2008).

An outline of the potential steps for pre-treatment and conversion of DDGS to simple 5 and 6 carbon sugars and fermentation to value added products such as acetone, butanol and ethanol can be seen in Figure 1.

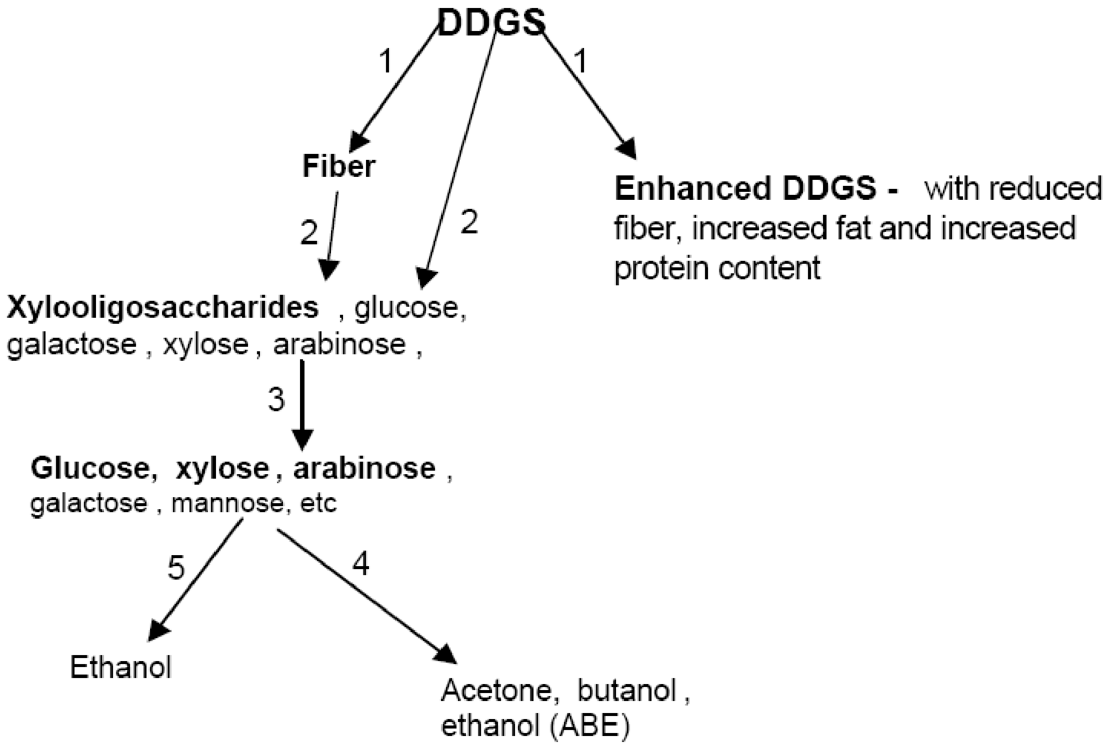


Figure 1. Pre-treatment and conversion of DDGS to value added products. Symbols: 1 elusieve process (Srinivasan et al., 2005), 2 electrolyzed water pretreatment (Wang et al., 2004); 3 enzymatic hydrolysis; 4 ABE fermentation by solventogenic clostridia (Ezeji et al, 2004); 5 ethanol fermentation by E.coli FBR 5.

Ethanol production from corn is reaching maximal production levels, and it is anticipated that cellulosic ethanol will play a bigger role in order to supply a target of 30% of U.S. gasoline demand by 2030. While ethanol from corn is suggested by most investigators to be slightly net energy positive, ethanol production from cellulose allows for an improved net energy balance and greenhouse gas emissions are significantly reduced. Work carried out at Argonne National Labs by May Wu and colleagues suggests that the production of higher alcohols such as bio-butanol from biomass will help to improve the overall picture for greenhouse gas avoidance (Figure 2; Wu et al., 2007)

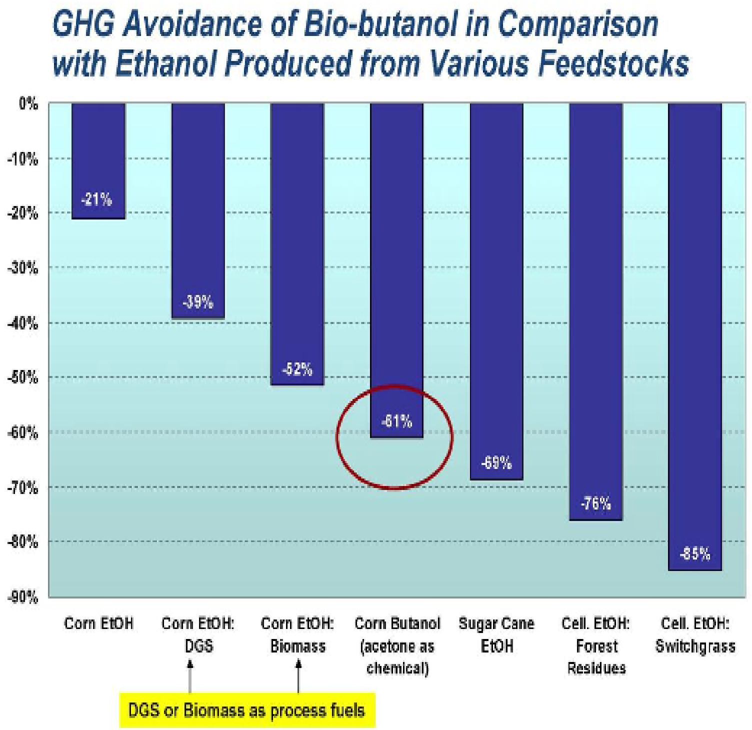


Figure 2. Greenhouse gas avoidance by utilization of various feedstocks and production of different biofuels.

Butanol as a second generation liquid fuel offers significant advantages over ethanol as seen in Figure 3. An overview of recent developments in the genetics and downstream processing of bio-butanol was recently reported (Ezeji et al., 2007). The development of an integrated system for biobutanol production and removal may have a significant impact on commercialization of this process using the solvent producing clostridia.

- Higher energy content than ethanol
- Can be stored humid conditions unlike ethanol
  - lack of solubility with water (higher flash point and lower vapor pressure)
- Can be used in internal combustion and diesel engines; less corrosive
- Can be shipped through existing pipelines
- Replacement for gasoline or as a chemical

Figure 3. Advantages of bio-butanol as a second generation liquid fuel.

The challenge on the sugar platform side of the conceptual biorefinery will be to scale up technologies for cell wall deconstruction to the point where they become practical on a commercial scale. While it is feasible to produce sugars from lignocellulosic biomass, the concern relates mostly to the production of inhibitors of fermentation (e.g. furfurals, acetic acid, coumaric acid, etc.) that are produced during the pre-treatment process (Ezeji et al., 2007).

It appears that in addition to economics, and specifically the price of petroleum, sustainable environmental aspects are driving the push to the use of alternative feedstocks such as corn stover, switchgrass, *Miscanthus* and tropical maize or sweet sorghum. The economics of perennials are particularly favorable given that *Miscanthus* is expected to yield 15 tons of biomass/acre as compared to corn which has a yield of 160 bushels (about 4 tons) per acre. At a level of 50% removal, corn stover alone is expected to provide 90M tons of fermentable sugars for conversion to fuels and chemicals without negatively impacting soil fertility. While some modifications may have to be made to current harvesting equipment, corn stover is readily available, it is largely unused, and therefore requires little additional investment or resources to produce it.

Today, biomass provides about 3-4% of the energy in the U.S. It is anticipated that biomass could satisfy between 25 – 50% of the world’s demand for energy by the middle of the 21st Century. An examination of the bioenergy value chain from sunlight to bioproducts, suggests that a multidisciplinary approach is required in order to overcome limitations to making crop based resources become a viable alternative to petrochemical based systems for chemicals and energy (Figure 4). Because of the interdisciplinary nature of this field, efforts are underway to develop new bioenergy courses and curricula to respond to demand in this area (Blaschek et al., 2008).

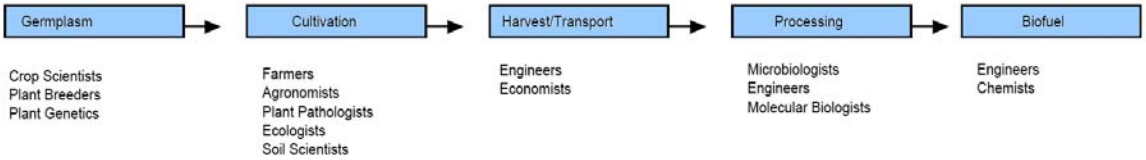


Figure 4. The bioenergy value chain and associated expertise needs.

The current limitations and bottlenecks in the production of second generation biofuels based on lignocellulosics include improvements in the efficiency of bioconversion of plant fibers to value added products and the efficient recovery of these high value products (Figure 5). Biological conversion involves utilization of both 5 and 6 carbon sugars by various microbes such as yeast and bacteria. *Saccharomyces cerevisae* is currently being engineered to ferment arabinose, *Zymomonas mobilis* to ferment xylose and arabinose and the solventogenic clostridia to simultaneously saccharify and ferment.

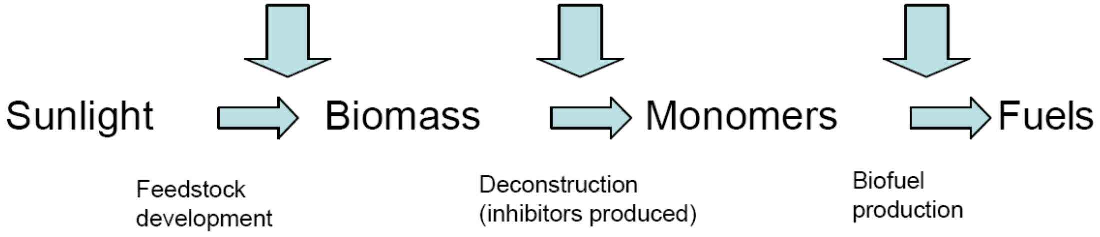


Figure 5. Roadmap and bottlenecks to biofuel production.

Because of the need for multi-disciplinary expertise, the utilization of plant and microbial genomic-based approaches leading to translational bioengineering and process scale up has been compared by some to the “Apollo Project.” The “New Biology of Genomics” allows for the application and integration of systems biology and metabolic engineering of fermentation pathways to overcome technical barriers in the production of biofuels from lignocellulosic substrates.

An approach for the development of new plant biomass sources involves examination of maize germplasm collections for particular cell wall characteristics and compositions. One way to do this is to screen germplasm collections for cell wall characteristics such as lignin content. Given its recalcitrance, the selection of maize lines with low lignin content would be expected to allow for improved fermentation processes. In addition to examination of lignocellulose as a potential feedstock, tropical maize or “sugar corn” offers a potential short term feedstock solution. According to work recently carried out at the University of Illinois, sugar corn requires low nitrogen input, can be grown in temperate climates and contains high concentrations of sucrose, glucose and fructose. Just like sugarcane, the sugars in tropical maize can be directly fermented in the absence of pre-treatment and enzyme treatment, making this feedstock potentially very interesting as a near term alternative for production of fuels and chemicals (www.bioenergy.uiuc.edu).

The “New Biology” of genomics also allows for examination of gene function and expression. This will allow for the development of road maps for construction of new plant and microbial strains with characteristics that are tailor-made for production of a particular biorefinery-based product. This technology will result in improved economics and efficiencies and allow for direct competition of bioproducts for feedstock chemicals currently produced by the petrochemical industry.

Some current examples of biorefinery activities include the investigation by Dupont and BP of bio-butanol, an advanced 4-carbon biofuel, the production of 1,3 propanediol as a polymer platform, the construction of a commercial scale biorefinery to produce polylactide polymers, the announcement by ADM of pilot scale testing of corn fiber as a substrate for bioproducts and the commercial scale production of ethanol from wheat straw by Iogen. This is only the beginning of the possibilities for the biorefinery of the future. It is anticipated that there will be both a sugar-based and a syngas-based platform that will allow for conversion of various feedstocks (including plant materials and waste products) to numerous chemicals and fuels. The Biorefinery of the future is expected to be similar in magnitude and be able produce a variety of products quite similar to today's mature and vertically-integrated petrochemical refinery (Figure 6).

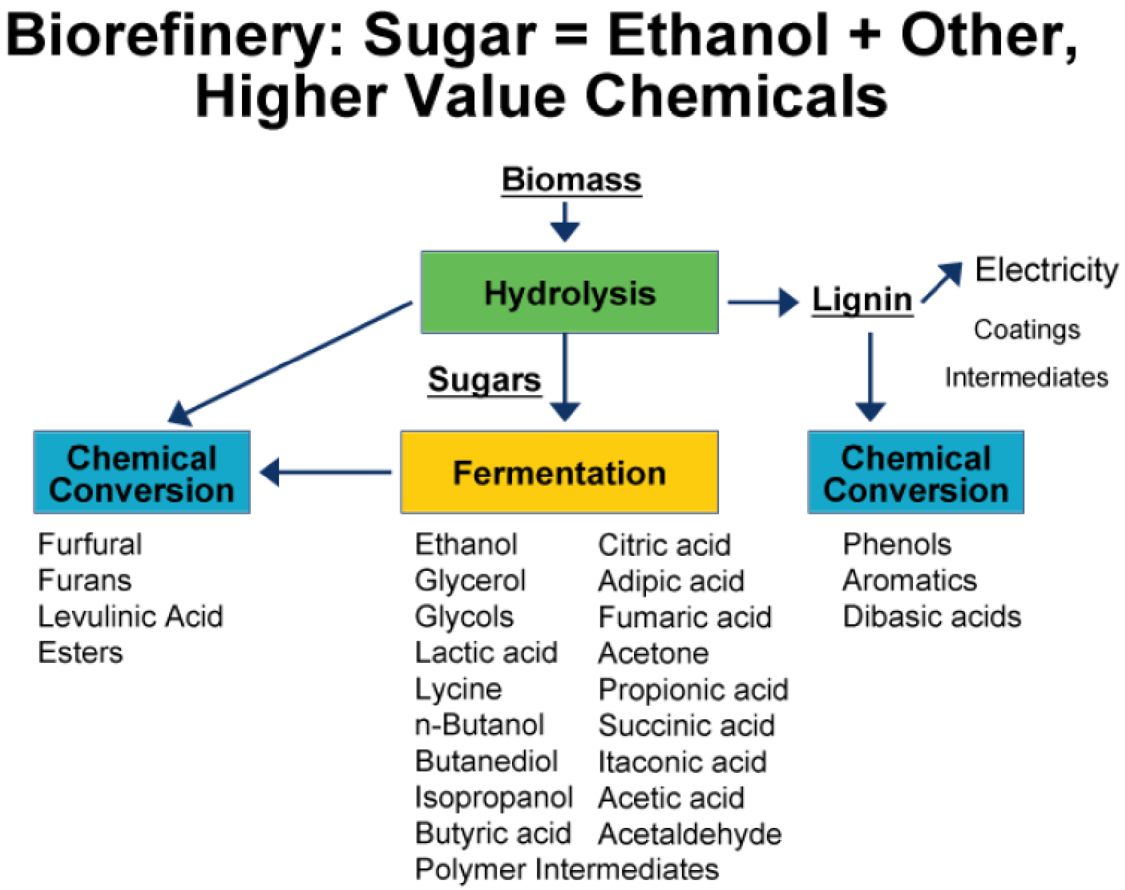
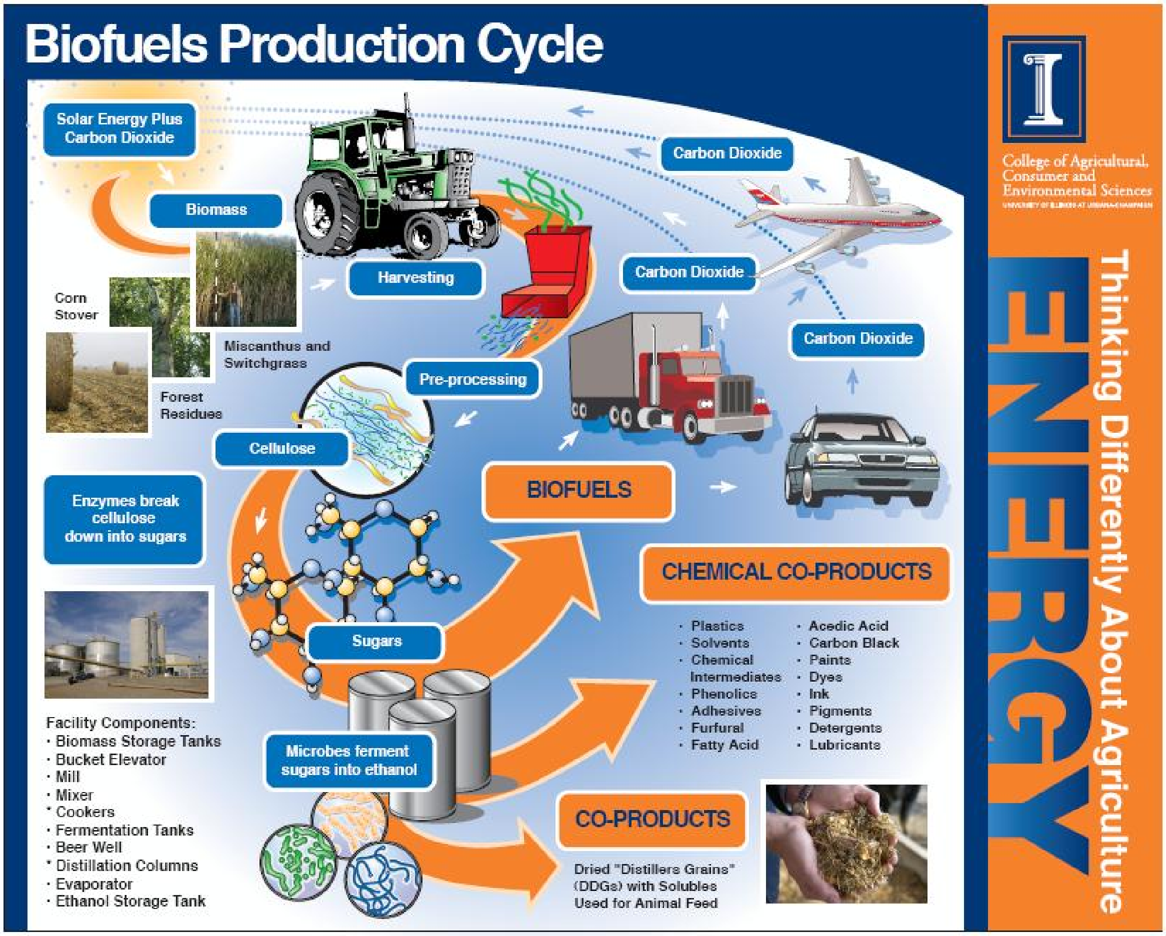


Figure 6. The biorefinery of the future.

The future is bright for the bio-production of fuels and chemicals. An overview of the biofuels production cycle can be seen in Figure 7.



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