2.3.5 BIOCHEMICAL CONVERSION OF BIOMASS

Technology Description

Biomass resources are agricultural crops and residues, wood residues, grasses, and trees. Biomass absorbs CO_2 as it grows, offsetting the CO_2 emissions from harvesting and processing, and can be a substitute for fossil resources in the production of power, fuels, and chemicals. Biomass feedstocks currently supply about 3 quadrillion Btus (Quads) to the nation's energy supply, based primarily on the use of wood. The potential exists for increasing the total biomass contribution up to 10 Quads nationwide, which would have a positive impact on the farm economy. Cost, sustainable supply availability, biomass variability, and transportation systems are key challenges for biomass utilization. The use of biomass as an alternative to fossil resources reduces most emissions, including emissions of greenhouse gases (GHGs). Through the use of biomass materials that would otherwise go to waste, biomass systems can represent a net sink for GHG emissions because methane emissions that would result from landfilling the unused biomass would be avoided.

Sugars are important platform intermediates for producing fuels, products, and power from biomass. Technologies in manufacturing platforms – such as the sugars platform – can provide the basis for a biorefinery or be combined with those from other platforms. The sugars platform is used to break down biomass, cellulose, and hemicellulose polymers into their building blocks. The building blocks are sugars that can be converted to many products including liquid fuels (e.g., ethanol), monomeric components for the polymer market (e.g., lactic acid), and hydrogen. In addition to the sugars platform, DOE is working on the glyceride platform, which uses biomass rich in vegetable oil (oil seeds like soybean) and converts the oil into esters that can be combusted like petroleum-based diesel. Other valuable biobased products can be produced from this conversion as well.

The biorefinery is analogous to an oil refinery. Multiple feedstocks are converted to a slate of products via multiple technology routes. Fuel production provides a large-volume product to achieve economies of scale, while lower-volume biobased coproducts and power can improve the economic competitiveness of biomass as a sustainable source of energy. Integrated biorefinery systems are being evaluated for their feasibility in producing fuels and products for potentially large commercial markets. A major challenge is to develop the ability to convert the fractionated biomass components into value-added products as efficiently as the current petrochemical business.

System Concepts

- The most common sugar-platform process consists of pretreating a biomass feedstock to release sugars from the fibrous cellulose and hemicellulose fractions. These sugars can be converted biologically into products such as ethanol or lactic acid, and can also be converted catalytically into products such as sorbitol. The products are then purified and sold as liquid fuels, sold into commodity chemical markets, or further converted and sold into other markets. The residue remaining from the sugar process can be burned to produce steam and electricity or further processed into other products such as animal feed.
- The glyceride platform consists of squeezing oil from an oil seed and transesterifying the oil to produce esters and glycerol. The esters can be purified for use as a liquid fuel (biodiesel), and purified glycerol can be sold as a commodity chemical or converted to other products (e.g., 1,3 propanediol).

Representative Technologies

- Sugar platform: hydrolysis of fibrous biomass that utilizes enzymes or acid catalysts, followed by microbial or catalytic conversion of the sugars to products.
- Glyceride platform: thermochemical transesterification of triglycerides.

- Fractionating biomass materials from grain and oil seeds, agricultural and forestry residues, or dedicated biomass feedstocks (such as grasses and woody crops) into component parts allows further development of value-added products such as chemical intermediates, wood products, biodiesel fuel, and composite materials.

Technology Status/Applications

- Acid hydrolysis: This sugar-platform technology is mature, with only the recovery of acid to be proven at industrial scale. One DOE partner is working with local and state governments to plan and design a facility that would separate MSW and convert its biomass portion to fuel-grade ethanol.
- Enzymatic hydrolysis: A major barrier of this sugar-platform technology has been development of low-cost cellulase enzyme cocktails. DOE has cost-shared subcontracts with Genencor International and Novozyme Biotech to reduce the cost of enzymes to improve the economics of the process. Process options using those enzymes will lead to the first large-scale, sugar-platform biorefineries.
- R&D advances have been identified to lower the cost of sugars for products including biofuels. As production costs for biofuels are reduced commensurately, larger fuel markets will become accessible. The technical challenge is to advance biomass processing to a level of maturity comparable to that of the existing petroleum industry.
- Glyceride platform: Many small glyceride facilities exist. The technology challenge is to convert batch-type facility designs to continuous processes that are built with greater capacity. Larger, continuous facilities will produce diesel products that can better compete with crude oil-based diesel. Development of coproducts also will help.
- Biobased products will be key elements in the development of integrated processes for producing fuels, chemicals, and power from both the sugar and glyceride platforms.

Current Research, Development, and Demonstration

RD&D Goals

By 2005

- Enzyme industry partners will provide new cellulase enzymes that are 10 times more cost effective than what is commercially available today.

By 2010

- Technologies will be developed for producing ethanol from cellulosic feedstocks at $1.29/gallon or less.
- Government will work with U.S. industry to introduce up to four new biobased chemical intermediate processing systems.
- Technologies will be developed for producing a mixed sugar stream from cellulosic feedstocks at $0.07/lb.

RD&D Challenges

- Low-cost enzymatic hydrolysis process technologies need to be developed.
- Pretreatment cost, yield, and equipment reliability need to be improved.
- Process integration and optimization needs to be developed.
- Fermentation organisms need to be developed and improved.

RD&D Activities

- Evaluation of pretreatment options and advanced R&D to understand biomass feedstock mechanisms.
- Industrial partnerships for demonstrating biochemical conversion technology on corn stover.
- Joint DOE and USDA solicitations targeting key enabling technologies to meet the RD&D challenges.

Recent Progress

- Cargill-Dow, a corporate partner, has built a facility that can produce almost 300 million pounds of lactic acid annually from corn starch. The facility also converts lactic acid into PLA for the polymers markets.
- Genencor International has announced that it met the target of a 10X reduction in the cellulase portion of the production cost of ethanol from biomass. Novozyme Biotech has announced that it expects to achieve the same goal by the end of its subcontract in 2004.
- Breakthroughs in genetically engineered microorganisms capable of fermenting the broad range of sugars found in biomass. These advances have led to an R&D 100 award and a number of patents.

- A conceptual design and cost estimate of a cellulosic ethanol facility has been completed and updated by DOE and engineering and construction firms. The report outlines the process necessary to meet cost targets.

Commercialization and Deployment Activities

- Conversion of cellulosic biomass to sugars and products from those sugars is not yet commercial. The U.S. capacity to produce ethanol from corn is 3 billion gallons annually. Ethanol is used as a fuel extender and, increasingly, as an oxygenating additive for reformulated gasoline wherever MTBE is phased down.
- Starch crops play a transitional role, but large-scale displacement of petroleum will rely on cellulose.
- About 15-21 million gallons of biodiesel is produced annually in the United States.
- Biobased products can replace 1:1 their chemically derived counterpart if the cost is competitive. This approach is of interest to the existing biomass-processing community; their infrastructure is already in place.
- Oil-based products or fuels have essentially a 1:1 displacement of petroleum-based products or fuels; this is attractive in efforts to reduce dependence on imported oil.
- Biobased products can bring new properties and functions to materials and chemical intermediates. This characteristic can enable biorefinery operations and the development of small businesses. Here, the market is not fully defined, capital risk is high, and time to commercialize may be long. Investments by the Federal government can lower some of these barriers.

Market Context

- For ethanol:
  1 Quad of biomass: 1% of projected petroleum imports for 2020
  5 Quads of biomass: 6% of projected petroleum imports for 2020
- For fuels and chemicals (depending on the mix of products):
  1 Quad of biomass: 0.5-1% of projected petroleum imports for 2020
  5 Quads of biomass: 5-10% of projected petroleum imports for 2020