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# From Produce to Plastics

## Biomass potential grows for economical uses

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American farmers are the most productive in the world, but a great portion of the agricultural tonnage resulting from their investments and constant effort is not utilized in products that provide significant returns to farmers or to agribusinesses. Much of the non-food portion of agricultural production is left in the field as a residue (leaves, straw, stover, etc.), is sold as animal feed at very low margins, or even becomes a waste product (culls, hulls, peelings, pulp, etc.) that incurs management costs for processors. In some cases, even the food portion of the crop is available in such quantities and commands such low market prices that alternative uses are potentially appealing. These economics have always prompted a desire for alternative uses for agriculturally derived biomass. In the past several decades, research in this area has given rise to several uses, primarily for renewable energy. Unfortunately, these developments coincided with a period of low energy costs, often making it difficult to recover a profit from capital invested in converting biomass to power or fuels.

There is light at the end of the tunnel however. Recent research at Department of Energy's Pacific Northwest National Laboratory has resulted in novel processes that make it possible to derive much higher value from agricultural biomass by utilizing its carbohydrate content to produce commodity and specialty chemicals. These products typically have a higher market value than energy which, combined with increasing worldwide demand for industrial and consumer products, can justify investment in new production capacity using a renewable base. With these processes moving from the lab to

commercial application, agricultural biomass now represents a genuine market opportunity. Rather than posing a nuisance or yielding only a low-margin animal feed, by-products and wastes from agribusiness can now be considered a resource for chemical production, as well as fuels and power.

## BioPower and BioFuels - Established Uses For Biomass

Crop residues (just considering corn, soybeans, wheat and sorghum) are a 520-billion pound source of biomass. While portions of these residues need to stay in the field to maintain the soil, this material is a substantial potential resource. Unfortunately, the cost of collecting this biomass and transporting it to centralized processing facilities has always proven to be a very substantial economic barrier to alternative uses. However, in cases where localized over-availability allows affordable collection and transportation, biomass has been demonstrated as a cost-effective component of power generation. Biomass can be used directly as the primary combustion fuel or as a co-firing fuel mixed with coal to generate heat, steam, and electricity. Newer gasification technology allows clean, economical generation of power by converting biomass solids into fuel gases, then using the resulting fuel gas to generate process heat or electricity.
Gasifiers such as the Battelle-FERCO system operated in Burlington, Vermont can accommodate a variety of biomass feedstocks, but are not suitable for very wet material. Currently, the largest volume renewable fuel product is ethanol, which is primarily produced from processed cornstarch although other grains are used in some areas of the country. In 1996 21 billion pounds of corn were processed (about 6% of the US corn crop) via fermentation and novel enzymes to produce 0.9 billion gallons of ethanol (99% of US ethanol production). This ethanol is blended with gasoline to form a cleaner-burning automobile fuel. Several government and private organizations are working to develop other biofuels, including biodiesel which uses oils from crops such as rape seed or soybeans, but such fuels are very minor players in renewable fuels.

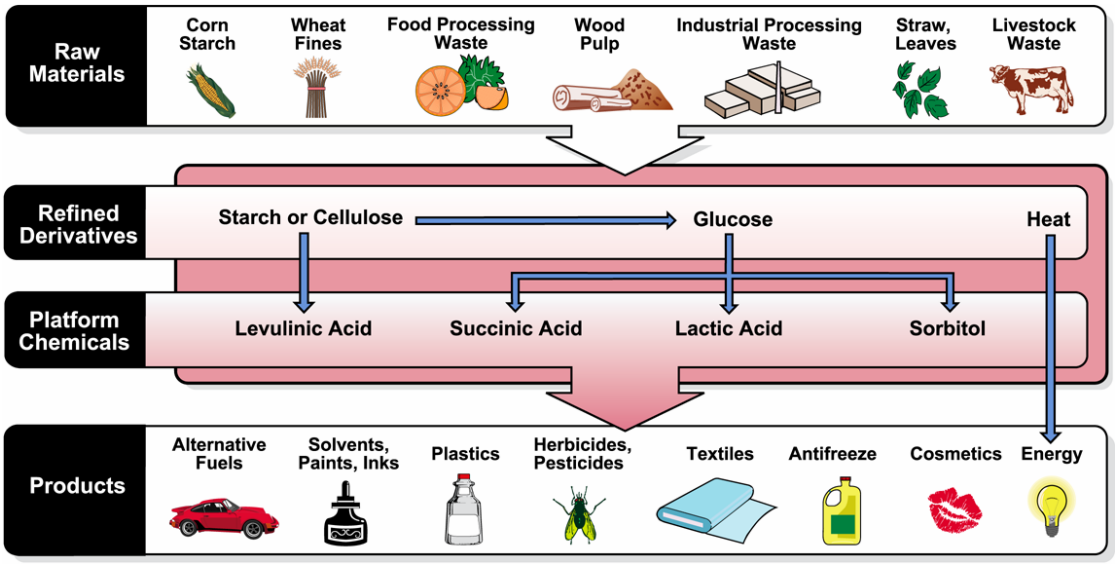
## Chemical Products From Biomass - A Promising Alternative

While biopower and biofuel production hold substantial promise, these businesses face significant financial hurdles. With natural gas costs currently quite low, combustion and gasification systems tend to be competitive only in situations where very low-value or waste biomass is readily available in large quantities and where steam and hot water can also derive value, adding to revenues from electricity. In general, these considerations have favored wood waste biomass sources, with only limited use of agricultural biomass. Ethanol on the other hand makes extensive use of agricultural products, but the primary beneficiaries have been corn processors, with only limited success using other crops. In both cases, the need for physical infrastructure to collect and transport economical quantities of biomass presents a major challenge for most agricultural biomass sources.

While power and fuel production processes are driven to very large economies of scale and require substantial collections of extremely cheap biomass, producing chemicals from biomass can be accomplished at varying scales, depending upon the end product. This makes conversion to chemicals a viable option for just about any of the lower-value

or waste products that are normally accumulated during the milling and refining processes used for agricultural products. Where sugars, starch, and other carbohydrates are available on a massive scale, as is the case with corn milling or oil seed processing, these low cost materials can be utilized to produce commodity chemicals. Where carbohydrates are accumulated in smaller quantities, as is generally true for wheat or rice milling, as well as vegetable processing, specialty chemicals suitable for regional or niche markets can be produced. In either case, technology finally allows conversion of readily available biomass to higher-value products, with commensurate economic benefit to processors and growers.

In developing processes to transform the renewable plant biomass into chemical products, the first step is to consider the biomass in terms of its chemical components. At this time most emphasis has been placed on the conversion of the carbohydrate structures, particularly use of glucose produced by depolymerizing the carbohydrate structures in the biomass. This glucose can either serve as a feedstock for biochemical conversion (i.e., fermentation) to higher value products such as alcohol or organic acids, or it can be chemically converted (using catalytic processes) to products such as levulinic acid, sorbitol, and other polyols or glycols. The biological and chemical processes can also be used jointly; fermentation provides an organic acid that can then be chemically converted to much higher value products. These processing concepts generally include recovery of the unused protein and fats for sale as higher quality (higher protein) animal feed, while maximizing the value captured from the carbohydrate portion for chemicals.




These processes are applied to wet products in essentially all cases, requiring new catalyst formulations for use in the aqueous phase. Developing, testing, and deploying these new catalysts are key capabilities of Pacific Northwest and have provided the breakthrough technologies that make cost-effective conversion of carbohydrates and fermentation products possible. Whereas petrochemical production is essentially all

organic solvent-based processing or vapor-phase processing, the oxygenates from biomass are more amenable to aqueous phase processing based on their affinity to water and low vapor pressures and high melting points. Chemical processing of carbohydrates is much less well understood and less well developed than hydrocarbon processing, but this is changing through research conducted at Pacific Northwest.

The processes developed at Pacific Northwest have significant potential. Researchers already have developed improved catalysts that enable cost-effective conversion of sugars that are not recovered during food processing into important chemicals called polyols. About four million tons of polyols are sold each year in the U.S., ultimately used in products like antifreeze, polyester fibers, cosmetics and plastics. Polyols can be produced from plant-based sugars much more energy-efficiently and cost effectively than from petroleum, which is how they are produced currently. Production of polyols is currently being demonstrated using recovered molasses generated as a by-product of sugar cane refining and will soon be demonstrated using glucose extracted from corn.

Researchers from Pacific Northwest and other DOE laboratories in Tennessee, Illinois and Colorado have also developed and demonstrated a process that converts corn into a cost-effective source of chemicals that can be used to make industrial and consumer products. This process uses a novel microorganism to ferment corn glucose into succinic acid, which is then catalytically converted into a chemical that is used by manufacturers to make polymers, clothing fibers, solvents, paints, inks, food additives, automobile parts and an assortment of other products. Currently, more than 90% of the basic feedstocks used to make these products originate from crude oil and natural gas.

## Benefits of Renewable Chemicals

Renewable biomass sources will certainly supplement chemical production from fossil resources and there are several clear advantages to displacing use of petroleum. First, biomass resources are domestic, reducing dependence on foreign oil and reducing concerns over the stability of that supply. The conversion processes used with biomass sources also have a major advantage over petroleum refining processes, releasing far fewer pollutants to the atmosphere and generating no toxic wastes during production.

Perhaps most importantly to many in the US, producing chemicals from renewable biomass resources means new markets for agriculture. Opening new uses for agricultural crops and processed derivatives can reduce the effect of food commodity market limits on agricultural product prices, delivering higher returns to producers.

## Renewable Chemicals Attracting Attention

In the recent past, the use of biomass for chemicals production has seen less development compared to fuels production, yet the economic advantages of higher-value chemical products are attracting attention, as underscored by recent developments in the chemical industry. Dow has gone into partnership with Cargill to produce and market polylactic acid plastics derived from corn. Shell, one of the major petroleum and petrochemical

marketers in the world, has reorganized to add a unit emphasizing biomass-derived fuels and chemicals as one of its five core business organizations. Concerns about supply and price stability for petroleum, pollution prevention, and greenhouse gas generation are turning industry to renewable biomass resources.

The benefits of producing chemicals from biomass are beginning to be recognized as valuable on a national level. By Presidential directive, the EPA set up the Green Chemistry Challenge award to recognize organizations that successfully develop and implement outstanding technologies that incorporate green chemistry principles (i.e., technologies for a sustainable environment). Included in this concept is the use of renewable feedstocks and non-hazardous chemical processes, such as aqueous phase processing, for manufacturing chemical products. Recognized with one of the five Green Chemistry Challenge awards in 1999 was a process development group led by Biofine, Inc. and including Pacific Northwest National Laboratory, which demonstrated new processing technologies for production of chemical products from cellulosic wastes. This process demonstrated a cost-effective process for converting materials such as waste sludge from paper mills or agricultural biomass such as straw to products that include a valuable fuel additive and a pesticide formulation.

Biomass conversion is receiving positive budgetary attention on Capitol Hill as well. President Clinton is asking Congress for a total $439 million in the 2001 budget to fund research that will lead to production of energy and other products such plastics and chemicals from agricultural biomass. The President suggests that new uses for biomass would generate billions of dollars of new income for farmers and produce thousands of additional high paying jobs in rural areas.

## Summary

The production of new chemical products from agricultural byproducts and wastes is a growing field for industrial development. The processes being developed by Pacific Northwest and other government laboratories hold the promise of producing power, fuels, and chemicals from renewable biomass resources, particularly agricultural resources. Several research programs are focused upon ambitious goals, including producing at least 10% of basic chemicals from biomass by the year 2020 and tripling the amount of agricultural biomass utilized in commercially viable enterprises by 2010. Accomplishing these objectives clearly benefits agricultural producers, as well as commodity processors, by opening new markets and creating new industries in America's agricultural heartland. Achieving these goals will require a combined effort of producers, processors, chemical manufacturers and distributors, in association with developers of new technology.