Conversion of Waste Biomass to Animal Feed, Chemicals, and Fuels

Mark Holtzapple
Department of Chemical Engineering
Texas A&M University, College Station, Texas

ABSTRACT

Waste biomass includes municipal solid waste (**MSW**), municipal sewage sludge (**SS**), industrial biosludge, manure, and agricultural residues. When treated with lime, biomass is highly digestible by a mixed culture of acid-forming microorganisms. Lime treatment doubles the ruminant digestibility of agricultural residues; thus, it may be used to upgrade their feed value. Alternatively, lime-treated biomass can be fed to an industrial-scale mixed-acid fermentor where acetic, propionic, and butyric acids are produced. To control the pH, these acids are neutralized with calcium carbonate. The resulting calcium salts may be thermally converted to ketones - such as acetone, methyl ethyl ketone, and diethyl ketone - which are useful industrial solvents. Further, these ketones may be hydrogenated to alcohols - such as propanol, butanol, and pentanol - which may be used as industrial solvents or motor fuel. Alternatively, the calcium salts may be acidified to recover the acids. In recognition of the potential environmental benefits of this technology, it was awarded the 1996 Presidential Green Chemistry Challenge Award.

INTRODUCTION

Waste biomass resources are underutilized; in fact, many have a cost associated with their disposal. At Texas A&M, a family of technologies that converts waste biomass into animal feed, industrial chemicals and fuels has been developed (Figure 1). In the first step, the waste biomass is treated with lime to render it more digestible. Lime-treated agricultural residues (e.g. straw, stover, bagasse) may be used as ruminant animal feeds. Alternatively, the lime-treated biomass can be fed to a large anaerobic fermentor in which rumen microorganisms convert the biomass into volatile fatty acid (**VFA**) salts such as calcium acetate, propionate, and butyrate. The VFA salts are concentrated and may be converted into chemicals or fuels via three routes. In one route, the VFA salts are acidified releasing the acetic, propionic, and butyric acids. In a second route, the VFA salts are thermally converted to ketones such as acetone, methyl ethyl ketone, and diethyl ketone. In the third route, the ketones may be hydrogenated to their corresponding alcohols such as propanol, butanol, and pentanol.

These technologies offer many benefits for human health and the environment. Lime-treated animal feed can displace feed grains; thereby reducing soil erosion and use of fertilizers, herbicides, and pesticides that can contaminate ground water. Chemicals (e.g. organic acids and ketones) may be economically produced from waste biomass that has a negative impact on the environment, such as MSW and SS. Typically, these wastes are landfilled or incinerated, which incurs a disposal cost, while causing land or air pollution. By producing chemicals from waste biomass, nonrenewable resources such as petroleum and natural gas, are conserved for later generations. Because 50% of U.S. petroleum consumption is now imported, displacing foreign oil could help reduce the U.S. trade deficit.

Fuels (e.g. alcohols) produced from waste biomass have the benefits cited previously, i.e. reduced environmental impact from waste disposal and reduced trade deficit. In addition, oxygenated fuels derived from biomass are clean burning and do not add net carbon dioxide to the environment; thereby reducing global warming.

TECHNOLOGY OVERVIEW

Figure 1 shows a schematic of our technologies for converting waste biomass into animal feed, chemicals and fuels. Regardless of the final product, the waste biomass first is treated with lime to render it more digestible. Table 1 shows that lime treatment essentially doubles the ruminant digestibility of agricultural residues.

Table 1. Ruminant Digestibility of Untreated and Lime-Treated[1] Agricultural Residues.

	48-h Digestion	
Agricultural Residue	Untreated	Lime Treated
Sugar-cane bagasse	30.8%	62.7%
African millet straw	45.1%	89.9%
Sorghum straw	54.1%	82.9%
Tobacco stalks	34.4%	67.9%

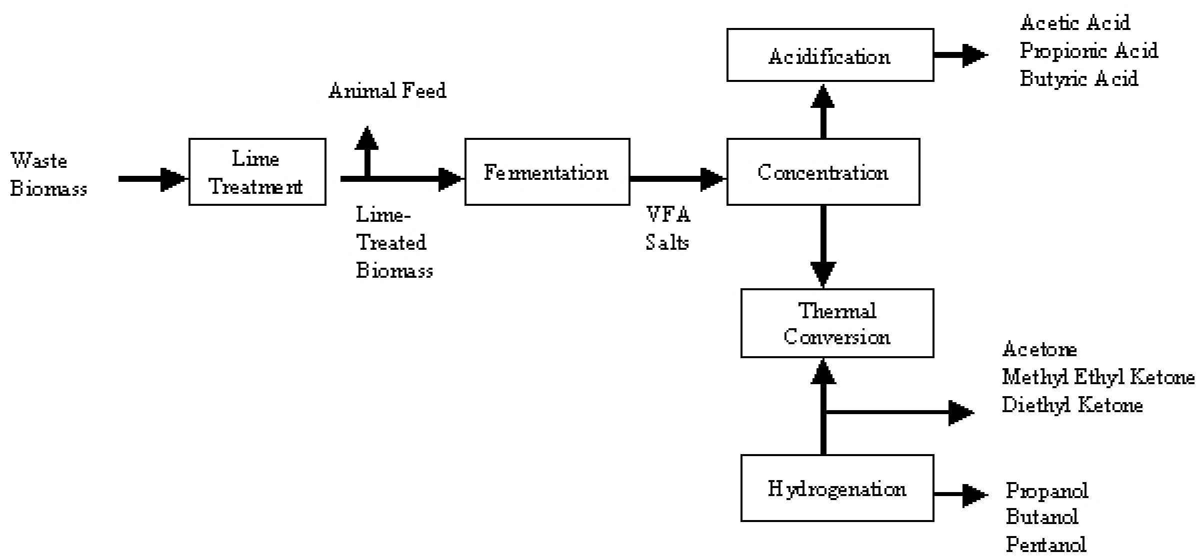
[1] Treatment: 0.1 kg $Ca(OH)_2$/kg dry biomass, 9 kg H_2O/kg dry biomass, 2 h, 100°C.

Exploitation of this *mixed culture* of rumen microorganisms transforms waste biomass into VFA's which, in turn, may be converted to useful chemicals and fuels. This approach contrasts the traditional approach whereby waste biomass is enzymatically hydrolyzed to sugars, which are subsequently fermented to products via a *pure culture* of microorganisms. The mixed culture approach has the following advantages:

- The system is adaptable to a wide variety of feedstocks because a mixed culture of microorganisms converts the biomass to VFA salts.
- Sterile process conditions are not required.
- Inexpensive tanks can be employed.
- Expensive extracellular enzymes are not required because the microbes make their own enzymes.
- The fermenting organisms do not have to be purchased because they regenerate themselves.
- Cells and enzymes can be recycled without contamination risk.
- The fermenting organisms are stable.
- The process is robust so specially skilled operators are not required.
- There are no viable contaminants to the process, so disposal of spoiled batches is not required.

In the fermentor, to prevent the pH from dropping too low, the VFA's produced by the mixed culture of microorganisms are neutralized with limestone; therefore VFA salts (e.g. calcium acetate, propionate, and butyrate) are the fermentation product. These salts are concentrated using a

Figure 1. Process schematic.



proprietary, energy-efficient, capital-efficient process.

The concentrated VFA salts may be easily converted to one of two products: VFA's or ketones. Volatile fatty acids are produced through a proprietary process in which the acidifying agent is recycled; thus, no wastes are produced. Ketones are produced by thermal conversion of the VFA salts. At 430°C, the reaction is complete in just a few minutes. The ketones may be subsequently hydrogenated to alcohols. Using 200-g/L Raney nickel catalyst, the hydrogenation is complete in 35 min. Regardless of the final product, the calcium salts are recycled back through the process so that no wastes are generated.

ECONOMICS

Some preliminary economic evaluations of the chemical and fuel technologies have been performed. The following scenarios were considered:

Scenario 1: Using very conservative assumptions, it is possible to expect incomes of about $60/dry tonne for accepting waste materials in the Northeast. Using this scenario, the selling price of the products is shown in Table 2 using a 45% return on investment (**ROI**).

Scenario 2: To use the process in more regions of the country, less ROI and less income must be received for accepting the waste. Table 2 shows the selling price assuming the biomass can be obtained for free and that a 15% ROI is acceptable.

Scenario 3: Large quantities of agricultural residues are available in the U.S. and tropical countries. Bagasse is a prime candidate because it is already collected. It is valued at about $20/tonne for its energy content. Table 2 shows the selling price assuming agricultural residues can be obtained for $20/tonne and a 15% ROI is acceptable.

In all scenarios, the selling prices are favorable compared to current chemical prices. The mixed alcohols are inexpensive enough that they can compete with the fuel oxygenates methyl tertiary butyl ether (**MTBE**) and ethanol, which are valued at about $0.80/gal and $1.10/gal, respectively.

SUMMARY

At Texas A&M, a family of technologies that converts waste biomass to animal feeds, chemicals, and fuels is being developed. By displacing grains used to feed animals, soil erosion and water contamination with fertilizers, herbicides, and pesticides can be reduced. Biomass-derived chemicals and fuels are completely renewable and reduce U.S. dependence on imported oil. Biomass-derived fuels are clean-burning, high-octane oxygenates that do not contribute net carbon dioxide to the atmosphere; thereby mitigating global warming. By using waste biomass as a feedstock in the process, rather than disposing of it by landfilling or incineration, both economic and environmental costs associated with its disposal are eliminated.

Table 2. Selling Price of Fuels and Chemicals

Product	Scenario 1	Scenario 2	Scenario 3	Current Spot Price
Mixed Alcohols	$0.59/gal	$0.72/gal	$0.88/gal	$1.70/gal isopropanol
Mixed Ketones	$0.53/gal	$0.68/gal	$0.84/gal	$2.52/gal acetone $2.96/gal methyl ethyl ketone
Mixed Acids	$0.052/lb	$0.060/lb	$0.073/lb	$0.33/lb acetic acid $0.44/lb propionic acid $0.48/lb butyric acid

Scenario 1: 45% ROI and -$60/dry tonne biomass
Scenario 2: 15% ROI and $0/dry tonne biomass
Scenario 3: 15% ROI and $20/dry tonne biomass