Catalytic processes for the production of renewable fuels and chemicals from cellulosic biomass

George W. Huber (http://biofuels.che.wisc.edu/)
University of Wisconsin-Madison

Concerns about global warming and national security, combined with the diminishing supply and increased cost of fossil fuels are causing our society to search for new sources of transportation fuels. Lignocellulosic biomass, the non-edible portion of biomass including trees, agricultural residues and fast growing energy crops, is available as a renewable feedstock today. Currently, cellulosic biomass is significantly cheaper than petroleum (at $15 per barrel of oil energy equivalent) and abundant (estimated production of 1.3 million tons in the US). However, the chief impediment to the utilization of our biomass resources is the lack of economical conversion processes. In this presentation we will give an overview of technologies and catalysts that are currently being developed for the conversion of biomass into fuels and chemicals. We will discuss some of the advantages and disadvantages of the various conversion technologies. We will show that all the same fuels and chemicals that are made from petroleum can be made from renewable biomass resources.

The first step in any biomass conversion process is the depolymerization of the solid biomass. There are three main technologies being used to break apart the biomass: 1) gasification (forming syn-gas); 2) pyrolysis (forming a pyrolysis oil) or 3) hydrolysis (forming aqueous carbohydrates). These products then undergo a variety of catalytic reactions to make different fuels and chemicals.

Pyrolysis is the thermal decomposition of biomass into a mixture of semi-volatile molecules. These pyrolysis vapors can then be condensed into a bio-oil or pyrolysis oil that contains more than 300 compounds. This pyrolysis oil is the cheapest liquid fuel made from biomass and is on the market today. However, this oil is unstable, acidic, insoluble with petroleum based fuels, has a high oxygen content, and polymerizes with time. The resulting bio-oil can be converted into various fuels and chemicals by aqueous-phase hydrodeoxygenation. Three reaction classes occur in hydrodeoxygenation of biomass: C-C bond cleavage, C-O bond cleavage, and hydrogenation. The key C-C bond cleavage reactions include: retro-aldol condensation and decarbonylation which both occur on metal catalytic sites. Dehydration is the key C-O bond cleavage reaction and occurs on acid catalytic sites. Hydrodeoxygenation of the aqueous phase of bio-oil can produce C1-C6 alkanes, alcohols, and polyols. This research suggests that hydrodeoxygenation chemistry can be tuned to make a wide variety of products from pyrolysis derived feedstocks.

Addition of zeolite catalysts into the pyrolysis reactor can directly produce gasoline range aromatics from biomass by an approach we call catalytic fast pyrolysis (CFP). The pyrolysis vapors enter directly into the zeolite pores where they undergo a series of dehydration, decarbonylation and oligomeriation reactions. The shape, pore structure, and active sites of the zeolite catalysts are critical in obtaining high yields of the desired aromatic products. CFP has several advantages compared to other biomass conversion technologies in that a liquid fuel is being produced directly from solid biomass in a single catalytic reactor, short residence times, and inexpensive catalysts are used.

We believe that new biomass conversion technologies have a tremendous potential for the production of renewable fuels and chemicals. As will be demonstrated in this presentation chemistry, chemical catalysis and chemical engineering are critical 21st century needs to help make renewable energy a practical reality.