# PROCESSING BIOMASS

## TECHNICAL FIELD

This invention relates to processing biomass and products made therefrom.

## BACKGROUND

Various carbohydrates, such as cellulosic and lignocellulosic materials, e.g., in fibrous form, are produced, processed, and used in large quantities in a number of applications. Often such materials are used once, and then discarded as waste, or are simply considered to be waste materials, e.g., sewage, bagasse, sawdust, and stover.

Various cellulosic and lignocellulosic materials, their uses, and applications have been described in U.S. Patent Nos. 7,307,108, 7,074,918, 6,448,307, 6,258,876, 6,207,729, 5,973,035 and 5,952,105; and in various patent applications, including "FIBROUS MATERIALS AND COMPOSITES," PCT/US2006/010648, filed on March 23, 2006, AND "FIBROUS MATERIALS AND COMPOSITES," U.S. Patent Application Publication No. 2007/0045456.

## SUMMARY

In one aspect of the invention, there is provided a method of making a product comprising a carboxylic acid, a salt of a carboxylic acid, or an ester of a carboxylic acid, the method comprising: treating biomass to reduce recalcitrance of the biomass; converting, utilizing an added microorganism, a portion of the treated biomass to the product, wherein the microorganism metabolizes both sugar and syngas feedstocks; and thermochemically converting a second portion of the treated biomass to a syngas feedstock, and providing a portion of the syngas feedstock to the microorganism during converting.

In another aspect, there is provided a method of making an alcohol, the method comprising: treating biomass to reduce recalcitrance of the biomass; converting, utilizing an added microorganism, a portion of the treated biomass to a product comprising a carboxylic acid, a salt of a carboxylic acid, or an ester of a carboxylic acid, wherein the microorganism metabolizes both sugar and syngas feedstocks; thermochemically converting a second portion of the treated biomass to a syngas feedstock, and providing a portion of the syngas feedstock to the microorganism during converting; and hydrogenating the product to produce an alcohol.

Generally, this disclosure~~invention~~ relates to carbon-containing materials, such as carbohydrate-containing materials (e.g., starchy materials and/or cellulosic or lignocellulosic materials), methods of making and processing such materials to change their structure and/or their recalcitrance level, and products made from the changed materials. For example, many of the methods described herein can provide cellulosic and/or lignocellulosic materials that have a lower recalcitrance level, a lower molecular weight, a different level of functionalization and/or crystallinity relative to a native material. Many of the methods provide materials that can be more readily utilized by a variety of microorganisms, such as one or more homoacetogens or heteroacetogens (with or without enzymatic hydrolysis assistance) to produce useful products, such as hydrogen, alcohols (e.g., ethanol or butanol), organic acids (e.g., acetic acid and/or lactic acid), hydrocarbons, co-products (e.g., proteins, such as single cell proteins) or mixtures of any of these.

Many of the products obtained, such as ethanol or n-butanol, can be utilized directly as a fuel or as a blend with other components, such as gasoline, for powering cars, trucks, tractors, ships or trains, e.g., as an internal combustion fuel or as a fuel cell feedstock. Other products described herein (e.g., organic acids, such as acetic acid and/or lactic acid) can be converted to other moieties (e.g., esters or anhydrides) that can be converted and utilized as a fuel. Many of the products obtained can also be utilized to power aircraft, such as planes, e.g., having jet engines, or helicopters. In addition, the products described herein can be utilized for electrical power generation, e.g., in a conventional steam generating plant or in a fuel cell plant.

Exemplary products that can be produced by employing the methods described herein include hydrocarbons, proteins, alcohols (e.g., a monohydric alcohols or a dihydric alcohols), such as ethanol, n-propanol or n-butanol, carboxylic acids, such as acetic acid or butyric acid, salts of a carboxylic acid, a mixture of carboxylic acids and salts of carboxylic acids and esters of carboxylic acids (e.g., methyl, ethyl and n-propyl esters), ketones, aldehydes, alpha, beta unsaturated acids, such as acrylic acid and olefins, such as ethylene. Specific examples include ethanol, propanol, propylene glycol, butanol, 1,4-butanediol, 1,3-propanediol, methyl or ethyl esters of any of these alcohols, methyl acrylate, methylmethacrylate, lactic acid, propionic acid, butyric acid, succinic acid, 3-hydroxypropionic acid, a salt of any of the acids and a mixture of any of the acids and respective salts.

In one embodiment~~aspect~~, the disclosure~~invention~~ features methods of making an alcohol, a carboxylic acid, a salt of a carboxylic acid, an ester of a carboxylic acid, or a mixture of any of these. The methods include treating a carbon-containing material, such a biomass material or coal, with any treatment method described herein, such as with one or more of radiation, sonication, pyrolysis, oxidation and steam explosion; and converting at least a portion of the treated carbon-containing material utilizing a microorganism to produce a product that includes one or more of an alcohol, a carboxylic acid, a salt of a carboxylic acid, a carboxylic acid ester or a mixture of any of these. The methods can further include acidifying, esterifying and/or hydrogenating the product. For example, acetogens or

homoacetogens, which are capable of utilizing a syngas from a thermochemical conversion process, can be utilized to enhance the efficiency of the conversion.

In another embodiment~~aspect~~, the disclosure~~invention~~ features methods of making one or more alcohols that include treating a carbon-containing material, such as a biomass material and/or coal, with one or more of radiation, sonication, pyrolysis, oxidation and steam explosion; converting at least a portion of the treated carbon-containing material utilizing a microorganism, such as one or more acetogens or homoacetogens which are capable of utilizing a syngas from the thermochemical conversion of coal or biomass, to a product that includes a carboxylic acid, a salt of a carboxylic acid, a carboxylic acid ester or a mixture of any of these; and hydrogenating the product to produce alcohol.

Carbon dioxide generated and/or lignin liberated in any process described herein can be captured. Any captured carbon dioxide can be sequestered, e.g., by injecting the captured carbon dioxide into a geological formation capable of maintaining the carbon dioxide, e.g., for a period of time greater than 100 years, e.g., greater than 250 years, 500 years, 1,000 years or greater than 10,000 years. For example, any carbon dioxide produced in any process described herein can be sequestered, e.g., by fixing carbon dioxide utilizing any microorganism described herein. For example, the microorganism can include algae and the carbon dioxide can be sequestered in the form of a carbohydrate and/or lipid. If desired, e.g., to produce a bio-diesel, the lipid can be converted into an ester, e.g., a methyl, ethyl or propyl ester.

Changing a molecular structure of a material, as used herein, means to change the chemical bonding arrangement or conformation of the structure. For example, the change in the molecular structure can include changing the supramolecular structure of the material, oxidation of the material, changing an average molecular weight, changing an average crystallinity, changing a surface area, changing a degree of polymerization, changing a porosity, changing a degree of branching, grafting on other materials, changing a crystalline domain size, or changing an overall domain size.