PROCESSING BIOMASS

TECHNICAL FIELD

This invention relates to processing biomass, and products made therefrom.

BACKGROUND

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. 7,074,918, 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

Generally, this ~~invention~~disclosure relates to carbohydrate-containing materials (e.g., biomass materials or biomass-derived materials), methods of making and processing such materials (e.g., to change their structure), and products made from the 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 and/or crystallinity relative to a native material. Many of the methods provide materials that react more rapidly, e.g., with an acid, base, or an enzyme, and/or that can be more readily utilized by a variety of microorganisms to produce useful products, such as hydrogen, alcohols (e.g., ethanol or butanol), organic acids (e.g., acetic acid), hydrocarbons, co-products (e.g., proteins) or mixtures of any of these.

In one ~~aspect~~embodiment, the ~~invention~~disclosure features methods that include reducing one or more dimensions of individual pieces of biomass; treating biomass, such as size-reduced biomass, using a treatment method that changes the molecular structure of the biomass; and, optionally, subjecting the biomass to a primary process to form a product. At least one of the size-reduction and treating steps comprises treating the

biomass feedstock with a screw extrusion process. In one aspect, there is provided a method of processing biomass, the method comprising:

reducing one or more dimensions of individual pieces of biomass; and

treating the biomass using a treatment method that changes the molecular structure of the biomass wherein the treatment method comprises irradiating the biomass with electron beam radiation, wherein the irradiating with electron beam radiation is performed on the biomass during the treatment of the biomass with a screw extrusion process. The treatment method may include, or further include, for example, irradiation, sonication, pyrolysis, and oxidation. The screw extrusion process can be used, for example, to reduce the dimensions of a feedstock, pulp the feedstock, or the screw extruder can be used as a reaction vessel in which the feedstock undergoes a chemical reaction, such as along its length as the feedstock is being conveyed. The screw extrusion step can include co-extruding the biomass with a separated portion of the biomass and/or with one or more other materials, which can be organic, inorganic, or mixtures of the two. The one or more other materials can be, for example, solid or liquid, and in some instances can include a gaseous material.

The primary process may be, for example, fermentation. The primary process is preferably performed after the screw extrusion process and after any necessary detoxification step, e.g., to remove any furan compounds produced. For example, after extrusion the material can be added to a fermentation vessel that has a volume of, for example, 50,000 L, 100,000 L, 500,000 L, or more.

In some implementations, the treatment method can include irradiation and sonication, used in combination. The radiation can be ionizing radiation, for example, in the form of an electron beam or gamma rays. In some embodiments, irradiating includes applying two or more radiation sources, such as gamma rays or x-rays (e.g., bremssthrahlung radiation) and a beam of electrons, e.g., an accelerated beam of electrons in which each electron has been accelerated to 1, 2, 3, 5 or even 10 MeV. In some embodiments, at least one of the treatment methods, e.g., irradiation, is performed on the biomass feedstock while the biomass feedstock is exposed to air or air enriched with oxygen or some other oxidizing gas, such as ozone. In specific

embodiments, the electron beam radiation is applied at a total dosage of about 10 MRad and the sonication is applied at a total energy of more than 5 MJ/m^3. The radiation can have a wavelength of, for example, from about 100 nm to about 280 nm. The radiation can be applied, for example, at a total dose of between about 10 Mrad and about 150 Mrad, such as at a dose rate of about 0.5 to about 10 Mrad/day, or 1 Mrad/s to about 10 Mrad/s. Sonication can be performed at a frequency of between about 15 kHz and about 25 kHz, such as between about 18 kHz and 22 kHz.

Irradiation can precede sonication, sonication can precede irradiation, or irradiation and sonication can performed at or about the same time. In some cases, irradiation can be performed during the screw extrusion process.

The change in molecular structure of the biomass feedstock can include a change in any one or more of level of recalcitrance, an average molecular weight, average crystallinity, surface area, degree of polymerization, porosity, degree of branching, degree of grafting, domain size of the biomass and molecular make-up of the biomass. In some embodiments, the change in molecular structure of the biomass feedstock includes a decrease in either one or both of an average molecular weight and average crystallinity of the biomass or an increase in either one or both of surface area and porosity of the biomass.

In another ~~aspect~~embodiment, the ~~invention~~disclosure features methods of making products, such as combustible fuels, that include providing a material that includes a carbohydrate produced by a process that includes treating a biomass feedstock with radiation, sonication, pyrolysis, and/or oxidation; subjecting the feedstock to a screw extrusion process; and contacting the material with a microorganism having the ability to convert at least a portion, e.g., at least about 1 percent by weight, of the material to the product, such as a combustible fuel.

The microorganism can be, e.g., a bacterium or a yeast. Examples of fuels produced include one or more of hydrogen, alcohols, and hydrocarbons. For example, the alcohols can be ethanol, n-propanol, isoproanol, n-butanol, or mixtures of these. Converting can include fermenting the material to the product, such as the combustible fuel. During the screw extrusion process, the biomass can be contacted with a chemical, such as an oxidizing agent, an acid, or a base.

In some embodiments, the method does not include hydrolyzing the biomass with an acid or a base. For example, in some embodiments, at least about seventy percent by weight of the biomass is un-hydrolyzed, e.g., at least at 95 percent by weight of the biomass has not been hydrolyzed. In specific embodiments, substantially none of the biomass has been hydrolyzed.

In some embodiments, the screw extrusion process is performed on biomass in which less than about 25 percent by weight of the biomass is wetted with a liquid, such as water. Specifically, in some embodiments, substantially none of the biomass

g/cm^3. A sheared material is thus different from a material that has been cut, chopped or ground.

Changing a molecular structure of a biomass feedstock, 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 an changing an overall domain size.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this ~~invention~~disclosure belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, suitable methods and materials are described below. All publications, patent applications, patents, and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including definitions, will control. In addition, the materials, methods, and examples are illustrative only and not intended to be limiting.

Other features and advantages of the ~~invention~~disclosure will be apparent from the following detailed description, and from the claims.

DESCRIPTION OF DRAWINGS

FIG. 1 is a block diagram illustrating conversion of biomass into products and co-products.

FIG. 2 is block diagram illustrating conversion of a fiber source into a first and second fibrous material.

FIG. 3 is a cross-sectional view of a rotary knife cutter.

FIG. 4 is block diagram illustrating conversion of a fiber source into a first, second and third fibrous material.

FIG. 5 is block diagram illustrating densification of a material.

FIG. 6 is a perspective view of a pellet mill.

FIG. 7A is a densified fibrous material in pellet form.