The biomass may not in itself be converted to the product (such as an alcohol), or may be partially or fully converted to the product along with the low molecular weight sugar.

In instances where the biomass is partially converted, the surface area and porosity of the biomass is increased relative to the surface area and porosity of the starting biomass, which can advantageously increase the conversion rate of the low molecular weight sugar to the product.

In some cases, the biomass may be the remnants of a cellulosic or lignocellulosic material that has been saccharified, e.g., lignin and/or other materials that are left over after cellulose has been converted to sugar.

~~In one aspect, t~~The present disclosure~~invention~~ features a method that includes utilizing a microorganism and/or enzyme that is immobilized on a biomass material, e.g., functionalized biomass fibers, to convert a carbohydrate, e.g., a low molecular weight sugar, to a product. By "immobilized," it is meant that the microorganism and/or enzyme is bonded, directly or indirectly (e.g., through a chemical linker), to the fibers by covalent, hydrogen, ionic, or equivalent bonding, and/or by mechanical interaction, e.g., between the microorganism and pores of the biomass material, e.g., fibers. Bonding may be created, e.g., by electrically polarizing the biomass material. The interaction can be permanent, semi-permanent, or fleeting. Mechanical interaction may include the microorganism or enzyme nesting in or clinging to pores or other sites of the biomass material.

Some implementations include one or more of the following features.

Converting can include allowing the microorganism to convert at least a portion of the low molecular weight sugar to an alcohol, e.g., ethanol or butanol, or to a hydrocarbon or hydrogen. Converting may include fermentation. The microorganism may comprise a yeast, e.g., S. cerevisiae and/or P. stipitis, or a bacterium, e.g., Zymomonas mobilis. The method may further include irradiating the biomass fibers, e.g., with ionizing radiation, for example using a particle beam. The biomass fibers may have a BET surface area of greater than 0.25 m^2/g, and/or a porosity of at least 70%. The biomass fibers may be derived from a biomass material that has internal fibers, and that has been sheared to an extent that its internal fibers are substantially exposed.

In another embodimentaspect, the disclosureinvention features a mixture that includes a biomass material having polar functional groups, a microorganism having complementary attractive functional groups, and a liquid medium.

In a further embodimentaspect, the disclosureinvention features a composition comprising biomass fibers having functional groups, and a microorganism having complementary attractive functional groups, the microorganism being immobilized on the biomass fibers.

The disclosureinvention also features a method that includes converting a low molecular weight sugar, or a material that includes a low molecular weight sugar, in a mixture with a biomass, a microorganism, and a solvent or a solvent system, e.g., water or a mixture of water and an organic solvent, to a product. Examples of solvents or solvent systems include water, hexane, hexadecane, glycerol, chloroform, toluene, ethyl acetate, petroleum ether, liquefied petroleum gas (LPG), ionic liquids and mixtures thereof. The solvent or solvent system can be in the form of a single phase or two or more phases. The biomass can be, e.g., in fibrous form.

In some instances, having a biomass material (e.g., treated by any method described herein or untreated) present during production of a product, can enhance the production rate of the product. Without wishing to be bound by any particular theory, it is believed that having a solid present, such as a high surface area and/or high porosity solid, can increase reaction rates by increasing the effective concentration of solutes and providing a substrate on which reactions can occur.

In some embodiments, a biomass material that has been irradiated, oxidized, chemically treated, mechanically treated, sonicated, steam exploded and/or pyrolyzed, can be added to a low molecular weight sugar fermentation process, e.g., to enhance fermentation rate and output.

For example, an irradiated or an un-irradiated biomass material, e.g., a paper fiber, can be added to a fermentation process, such as during a corn-ethanol fermentation or a sugarcane extract fermentation, to increase the rate of production by at least 10, 15, 20, 30, 40, 50, 75, 100 percent or more, e.g., at least 150 percent, or even up to 1000 percent. Conversion, e.g., fermentation, can exhibit a percent performance, as defined in the Examples herein, of at least 140%, in some cases at least 170%.

mechanically treated biomass can have a bulk density of less than about 0.5 g/cm^3, e.g., less than 0.35 g/cm^3.

In any of the methods disclosed herein, radiation may be applied from a device that is in a vault.

In one aspect, there is provided a method for fermenting a low molecular weight sugar to a product comprising: contacting a low molecular weight sugar, in a medium, with a sheet comprising oxidized biomass fibers and a fermenting microorganism immobilized on the fibers; and fermenting the low molecular weight sugar under conditions suitable for converting said sugar to a product by the fermenting microorganism; wherein the biomass fibers have been oxidized in an oxidizing medium by a method selected from the group consisting of about 5 to 60 Mrad radiation, chemical oxidation, sonication and pyrolysis.

In another aspect, there is provided a method for fermenting a low molecular weight sugar to a product comprising: contacting a low molecular weight sugar, in a medium, with a sheet consisting essentially of oxidized biomass fibers and a fermenting microorganism immobilized on the fibers; and fermenting the low molecular weight sugar under conditions suitable for converting said sugar to a product by the fermenting microorganism; wherein the biomass fibers have been oxidized in an oxidizing environment by a method selected from the group consisting of about 5 to 60 Mrad radiation chemical, oxidation, sonication and pyrolysis.

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 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 will be apparent from the following detailed description, and from the claims.

DESCRIPTION OF DRAWINGS

FIG. 1 is a block diagram illustrating treatment of biomass and the use of the treated biomass in a fermentation process.

FIG. 2 is a schematic representation of functionalized biomass interacting with a microorganism.

FIG. 3 is an infrared spectrum of Kraft board paper sheared on a rotary knife cutter.

FIG. 4 is an infrared spectrum of the Kraft paper of FIG. 3 after irradiation with 100 Mrad of gamma radiation.

FIGS. 5A-5I are ^{1}H-NMR spectra of samples P132, P132-10, P132-100, P-1e, P-5e, P-10e, P-30e, P-70e, and P-100e in Example 13. FIG. 5J is a comparison of the exchangeable proton at ~16ppm from FIGS. 5A-5I. FIG. 5K is a ^{13}C-NMR of sample P-100e. FIGS. 5L-5M are ^{13}C-NMR of sample P-100e with a delay time of 10 seconds. FIG. 5N is a ^{1}H-NMR at a concentration of 10% wt./wt. of sample P-100e.