electron (e.g., a positron). The radiation can be applied in an amount sufficient to change the molecular structure and/or supramolecular structure of the biomass material.

In one aspect, there is provided a method of processing biomass to a product, the method comprising: irradiating with accelerated particles a combination formed by dry blending or co-comminuting the biomass with an inorganic material, wherein the inorganic material increases the effects of irradiating the biomass in the combination, thereby producing irradiated biomass; and converting the irradiated biomass in the combination to the product using an enzyme and/or a microorganism.

Other materials, such as hydrocarbon-containing materials, e.g., hydrocarbons and coal can be processed in an analogous manner. When coal is utilized, it can be in solid form, e.g, pulverized coal, or it can be in liquefied form. Coal can be liquifed by a number of techniques, such as by the Bergius process, the SRC-I and SRC-II (Solvent Refined Coal) processes and the NUS Corporation hydrogenation process. When coal is utilized, it can be lignite, flame coal, gas flame coal, fat coal, forge coal, non-baking coal, anthracite coal or mixtures of any one or more of these types of coal.

For example, protons, helium nuclei, argon ions, silicon ions, neon ions, carbon ions, phoshorus ions, oxygen ions or nitrogen ions can be utilized to modify the structure of the biomass, e.g., breakdown the molecular weight or increase the molecular weight of the biomass. In some embodiments, heavier particles can induce higher amounts of chain scission in comparison to electrons or photons. In addition, in some instances, positively charged particles can induce higher amounts of chain scission than negatively charged particles due to their acidity.

The material resulting from irradiating the combination can be used in any suitable application, such as any of those described herein, e.g., for fuel, food, or as use in composite materials. For example, some of the methods described herein further include removing the inorganic material, and then contacting the resulting material with an enzyme and/or a mircroorganism for a time and under conditions sufficient to convert the carbohydrate-containing material to a fuel, such as ethanol or butanol (e.g., n-butanol). In other embodiments, the method further includes contacting the combination with an enzyme and/or a mircroorganism for a time and under conditions sufficient to convert the carbohydrate-containing material to a fuel, such as ethanol or butanol. In some embodiments, the methods include contacting the treated biomass material (with or

without the inorganic material) with an enzyme to saccharify the material, and then inoculating the saccharified material with a microorganism to make a useful product, such as a fuel, such as ethanol, butanol or a hydrocarbon. If desired, the inorganic material can be separated and utilized again in the irradiating process.

In certain ~~aspects~~embodiments, the ~~invention~~disclosure features methods of making a carbohydrate-containing material that include combining a cellulosic and/or lignocellulosic material with an inorganic material, such as a metal or a metallic compound, a refractory material, a ceramic or mixtures of any of these, to provide a combination; and irradiating the combination. Irradiation may be, for example, with accelerated particles, such as electrons, e.g., at a speed of greater than seventy five percent of the speed of light.

In some implementations, the cellulosic or lignocellulosic materials can be selected from the group consisting of paper, paper products, wood, wood-related materials, such as sawdust and particle board, grasses, such as straw and switchgrass, rice hulls, bagasse, alfalfa, hay, cotton, jute, hemp, flax, bamboo, sisal, abaca; agricultural wastes, such as corn cobs, corn stover, bagasse and coconut hair; algae, seaweed, sewage, silage, synthetic celluloses, extruded yarn scrap textile materials, rags, and mixtures thereof.

The cellulosic and/or lignocellulosic and inorganic materials can be combined, for example, by dry blending or by co-comminuting the cellulosic and/or lignocellulosic material and inorganic materials together. Co-comminution can be performed while each material is cooled, e.g., to a temperature below 25 °C, 0 °C, the normal atmospheric sublimation temperature of dry ice, or even at or below the normal atmospheric boiling point of liquid nitrogen.

In certain embodiments, the inorganic material can be or include a metal or a metal alloy, e.g., a base metal, such as iron, nickel, lead, copper, or zinc, or a ferrous metal such as wrought iron or pig iron, or a noble metal, such as tantalum, gold, platinum, or rhodium. The metal or metal alloy can also be or include a precious metal, such as ruthenium, rhodium, palladium, osmium, iridium or platinum, or a transition metal. The metal alloy can be, e.g., steel, brass, bronze, duralumin, or hastaloy. The metal can be aluminum. In certain embodiments, the inorganic material can be or include a metallic compound, such as inorganic compound of iron or cobalt, and the inorganic compound can be in the 2+ or 3+ oxidation state.

In other embodiments, the inorganic material can be or include a refractory material, such as an acidic, neutral, or basic refractory material. The acid refractory material can be zircon, fireclay, or silica. The neutral refractory material can be alumina,

In some embodiments, the combination includes about 0.05 to about 35, about 0.1 to about 20, or about 0.5 to about 10 percent by weight inorganic material.

Some methods further include contacting the irradiated cellulosic and/or lignocellulosic material, with or without first ~~removing~~ the inorganic material, with an enzyme and/or a microorganism for a time and under conditions sufficient to convert the carbohydrate-containing material to a fuel, such as ethanol or butanol.

In another ~~aspect~~embodiment, the ~~invention~~disclosure features compositions of matter that include in combination, e.g., in homogeneous combination, a particulate carbohydrate-containing material and a particulate inorganic material, such as a metal or a metallic compound, a refractory material, a ceramic or mixtures of any of these.

Generally, the inorganic material is exogenous to the carbohydrate-containing material. The composition of matter can include, for example, at least about 0.5 percent by weight inorganic material, such as at least about 1, 3, 5, 10 or 25 percent by weight inorganic material, or between about 0.5 and about 25 percent by weight inorganic material, or between about 1 and about 15 percent by weight inorganic material.

The methods for making and processing materials from biomass can include functionalizing biomass. In some instances, functionalized biomass is more soluble and is more readily utilized by microorganisms in comparison to biomass that has not been functionalized. In addition, many of the functionalized materials described herein are less prone to oxidation and can have enhanced long-term stability (e.g., oxidation in air under ambient conditions).

In some implementations, the biomass feedstock is prepared by shearing a biomass fiber source to provide a fibrous material. For example, the shearing can be performed with a rotary knife cutter. The fibers of the fibrous material can have, e.g., an average length-to-diameter ratio of greater than 5/1. The fibrous material can have, e.g., a BET surface area of greater than 0.25 m^2/g. In some cases, the biomass can have a bulk density of less than about 0.35 g/cm^3. Low bulk density materials can be deeply penetrated by charged particles. For example, for electrons at an average energy of 5 MeV and a material with a bulk density of 0.35 g/cm^3, electron penetration depths can be 5-7 inches or more.

In another ~~aspect~~embodiment, the ~~invention~~disclosure features a method of processing a hydrocarbon-containing material, the method including irradiating a combination formed by combining a hydrocarbon-containing material with an inorganic material.

In some ~~aspects~~embodiments, the hydrocarbon-containing material is selected from the group consisting of tar or oil sands, oil shale, crude oil, bitumen, coal, petroleum gases, liquefied natural and/or synthetic gas, and asphalt.

Combinations (e.g., blends) of hydrocarbon-containing materials, e.g., hydrocarbons and coal, and biomass can be processed in an analogous manner.

When a microorganism is utilized in the processes described herein, it can be a natural microorganism or an engineered microorganism. For example, the microorganism can be a bacterium, e.g., a cellulolytic bacterium, a fungus, e.g., a yeast, a plant or a protist, e.g., an algae, a protozoa or a fungus-like protist, e.g., a slime mold. When the organisms are compatible, mixtures may be utilized. Generally, various microorganisms can produce a number of useful products, such as a fuel, by operating on, e.g., fermenting the materials. For example, fermentation or other processes can be used to produce alcohols, organic acids, hydrocarbons, hydrogen, proteins, or mixtures of any of these materials.

Examples of products that may be produced include mono- and polyfunctional C1-C6 alkyl alcohols, mono- and poly-functional carboxylic acids, C1-C6 hydrocarbons, and combinations thereof. Specific examples of suitable alcohols include methanol, ethanol, propanol, isopropanol, butanol, ethylene glycol, propylene glycol, 1,4-butane diol, glycerin, and combinations thereof. Specific example of suitable carboxylic acids include formic acid, acetic acid, propionic acid, butyric acid, valeric acid, caproic acid, palmitic acid, stearic acid, oxalic acid, malonic acid, succinic acid, glutaric acid, oleic acid, linoleic acid, glycolic acid, lactic acid, γ-hydroxybutyric acid, and combinations thereof. Examples of suitable hydrocarbons include methane, ethane, propane, pentane, n-hexane, and combinations thereof. Many of these products may be used as fuels.

Changing a molecular structure of a biomass feedstock, as used herein, means to change the chemical bonding arrangement, such as the type and quantity of functional groups or conformation of the structure. For example, the change in the molecular structure can include changing the supramolecular structure of the material, oxidation of

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.

DETAILED DESCRIPTION

Systems and processes are described below that can use various biomass materials to form useful products. The biomass material is combined with one or more inorganic materials such as ceramics, metals, clays, and/or minerals and the combination is irradiated. The addition of the inorganic material modulates (increases/enhances or decreases) the effects of the radiation on the biomass in comparison to applying the same energy without the inorganic material being present. For example, the presence of the inorganic material can enhance the effect of the radiation on the biomass material by increasing the heat generated by irradiating.

For example, with the inorganic material present during irradiation, the degree of recalcitrance of the cellulosic or lignocellulosic material to structural change can be reduced to a greater extent for a given radiation dose relative to the case in which the inorganic material is not present during radiation treatment. For example, for any given dose, the average molecular weight and/or average crystallinity can be reduced by a greater degree, such as by 10, 20, 30, 40, 50, 60 or even 75 percent greater, when a combination of biomass and inorganic material is irradiated in comparison to a radiation treatment of biomass without the inorganic material being present during the irradiation. For example, for any given dose, the surface area and/or the porosity of the biomass can be increased by a greater degree, such as by 10, 20, 30, 40, 50, 60 or even 75 percent