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(71) **Demandeur/Applicant:**
SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V., NL

(72) **Inventeurs/Inventors:**
RADTKE, COREY WILLIAM, US;
HAMILTON, PHILLIP GUY, US;
KREITMAN, KEITH MICHAEL, US

(74) **Agent:** NORTON ROSE FULBRIGHT CANADA LLP/S.E.N.C.R.L., S.R.L.

(54) **Titre : PRODUITS POUR L'ALIMENTATION ANIMALE ET LEURS PROCEDES DE FABRICATION**
(54) **Title: ANIMAL FEED PRODUCTS AND METHODS OF MAKING SAME**

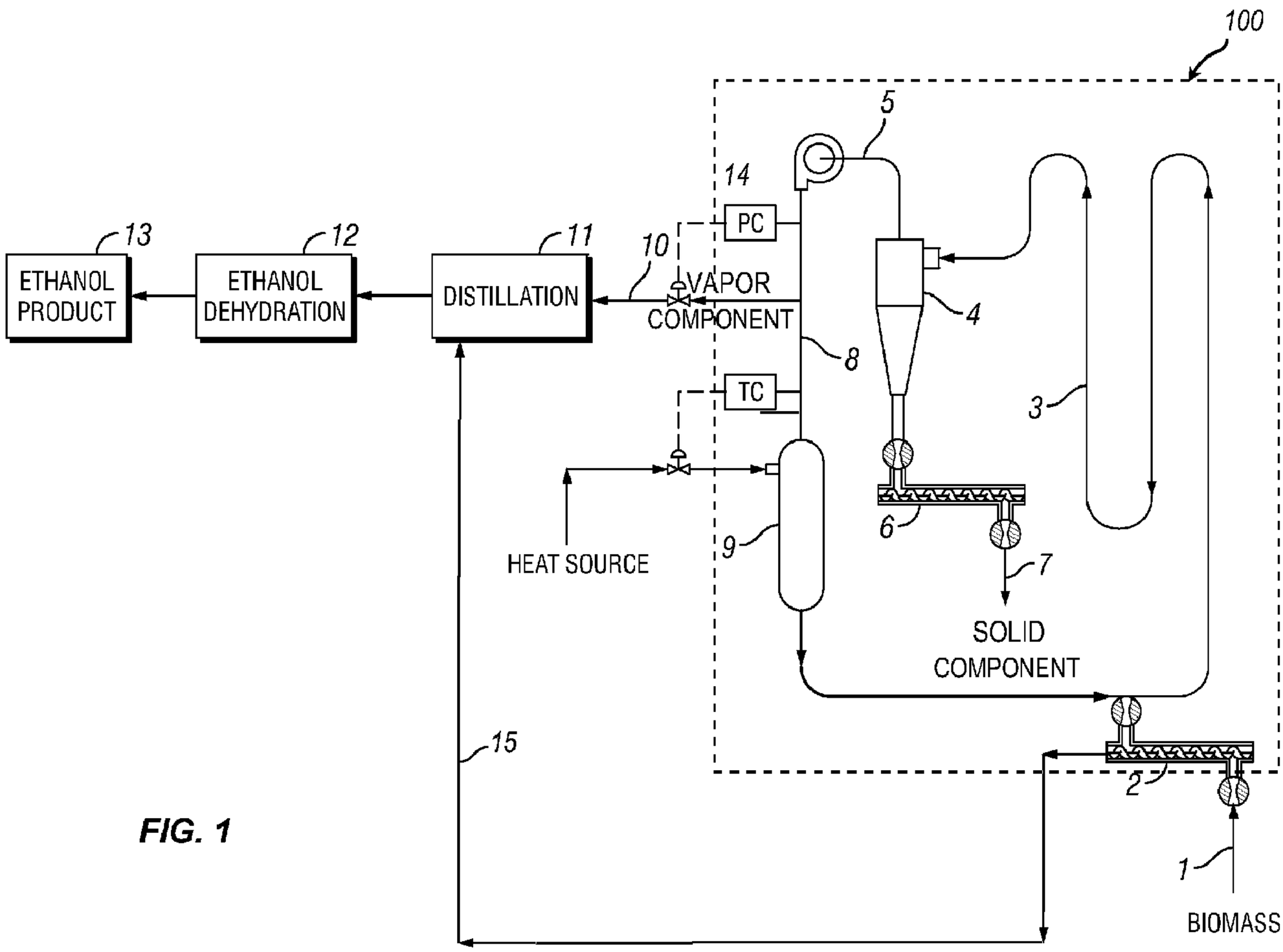

FIG. 1

(57) **Abrégé/Abstract:**
In one embodiment, the animal feed product of the present invention is devolatilized. In addition, in various embodiments, the animal feed of the present invention is already size-reduced, which allows ease of handling and transport, such as further

(21) **2 873 292**

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(57) **Abrégé(suite)/Abstract(continued):**
densification, including pelletization and/or other formatting process for rail transportation. In various embodiments, the animal feed of the present invention has a low sulfur content, high amount of ADF, and/or high amount of starch to meet desired nutritional amounts, which further can allow it to be a substantial or complete replacement of forage. In addition, in certain embodiments, grain is preferably not used in the production of the animal feed, but rather vegetative material is used instead.

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(71) Applicant *(for US only)*: **SHELL OIL COMPANY** [US/US]; One Shell Plaza, P.O. Box 2463, Houston, Texas 77252-2463 (US).

(71) Applicant *(for all designated States except US)*: **SHELL INTERNATIONALE RESEARCH MAATSCHAPPIJ B.V.** [NL/NL]; Carel van Bylandtlaan 30, NL-2596 The Hague (NL).

(72) Inventors: **RADTKE, Corey William**; 26018 Pepper Bend Lane, Katy, Texas 77494 (US). **HAMILTON, Philip Guy**; 831 Harbour Place, Sugar Land, Texas 77478 (US). **KREITMAN, Keith Michael**; 7207 Benwich Circle, Houston, Texas 77095 (US).

(74) Agent: **LUONG, Huyen**; Shell Oil Company, One Shell Plaza, P.O. Box 2463, Houston, Texas 77252-2463 (US).

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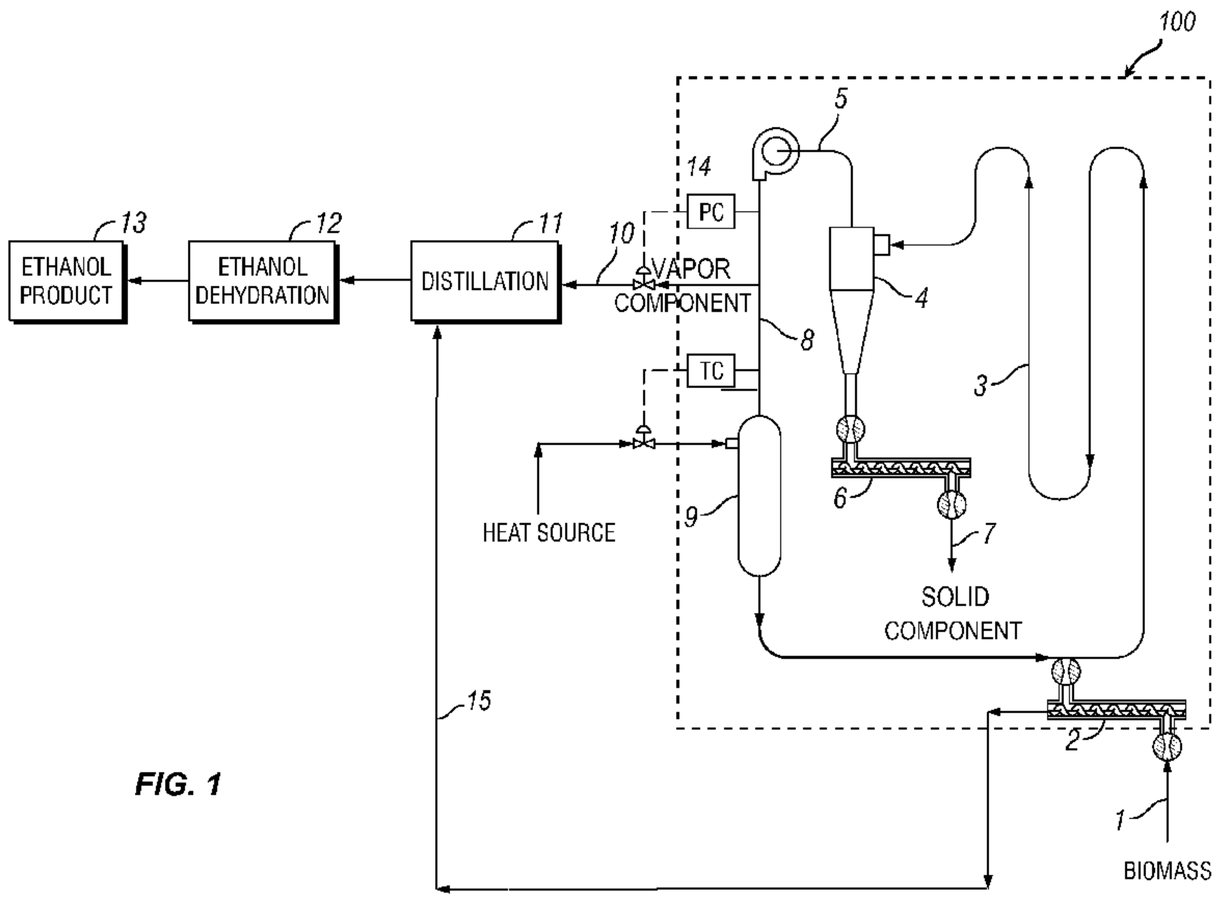

FIG. 1

(57) Abstract: In one embodiment, the animal feed product of the present invention is devolatilized. In addition, in various embodiments, the animal feed of the present invention is already size-reduced, which allows ease of handling and transport, such as further densification, including pelletization and/or other formatting process for rail transportation. In various embodiments, the animal feed of the present invention has a low sulfur content, high amount of ADF, and/or high amount of starch to meet desired nutritional amounts, which further can allow it to be a substantial or complete replacement of forage. In addition, in certain embodiments, grain is preferably not used in the production of the animal feed, but rather vegetative material is used instead.

WO 2013/173560 A1

ANIMAL FEED PRODUCTS AND METHODS OF MAKING SAME

Field of the Invention

Embodiments of this invention relate generally to livestock feed composition and methods for their preparation, particularly to feed compositions obtained from production of volatile organic compounds from biomass material.

Background

This section is intended to introduce various aspects of the art, which may be associated with exemplary embodiments of the present invention. This discussion is believed to assist in providing a framework to facilitate a better understanding of particular aspects of the present invention. Accordingly, it should be understood that this section should be read in this light, and not necessarily as admissions of any prior art.

The normal diet of the ruminant animal and other livestock is forage. Forage includes grasses, legumes and other suitable plant material. These are either fed fresh as pasture or green chop; in a dry form as hay; or in a preserved state as silage. Bales of hay are expensive. In addition, hay has increased risk of fire, rodent, dust, such as airborn dust. Fresh forage consists for instance of harvested grasses, cereals, legumes and other plant material. In most cases, it is harvested several times per year during the growing season and stored for use as animal feed during various seasons. During storage, certain active micro-organisms can metabolize the forage and produce certain volatile organic compounds, such as ethanol, and organic acids. In this way, the forage usually becomes silage (fermented forage). Such animal feed is detrimental to the environment in that the silage releases harmful volatile organic compounds into the atmosphere, particularly during feedout to animals such as when the silage is presented to the animals. Moreover, fermentation and acidification of the forage influences the desirability of the forage to the receiving animals, such as cattle, and consequent feed conversion rates. For example, high levels of butyric acid in particular are undesirable. Further, because forage is loose material, its transportation costs per unit tends to be higher than transportation costs for denser materials.

Forage is typically supplemented with a protein containing feed product such as dried distiller grain, which is obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or grain mixture by separating the resultant coarse

grain fraction of the whole stillage and drying by methods employed in the grain distilling industry. For example, in a conventional ethanol production process, a starch-containing feedstock, such as corn, is fed to a grinder to produce a milled corn. The milled corn is then sent to a mixer where water and enzymes are added to produce a liquid mash, which is then sent to a fermentation vessel. After the desired amount of fermentation has been completed, the resulting product, commonly referred to as the "beer," is sent to a distillation unit where an ethanol rich (about 95% ethanol by weight) stream is separated from the remaining fermented solids and water. The remaining fermented solids and water is generally known as the whole stillage, which is processed into wet distillers grain, which can be dried to produce an animal feed commonly known as distillers dried grain (DDG) or distillers dried grain solubles (DDGS). In a typical process, a drum dryer is used to dry the wet distillers grain. The dryer is typically operated with the hot air having an inlet temperature at about 1000° F-1200° F. The hot air remains in contact with the wet distillers grain for approximately five minutes before exiting the dryer having an exhaust temperature at about 200° F-225° F. At these conditions the protein contained in the dried solids are denatured.

While DDG or DDGS does not release as much volatilized organic compounds into the atmosphere such as fresh forage, it is a protein supplement and cannot completely replace forage. The inclusion rate of DDG or DDGS is often restricted because of its high fat content and the use of other high-fat ingredients in the diet. Moreover, one quality concern with DDG or DDGS is the high amount of sulfur. Higher concentrations are cause for concern. Feed with high sulfur content can cause health problems in cattle consuming those feeds. As such, DDG or DDGS often needs to be mixed with forage to decrease the level of sulfur in the total feed or dry matter. Further, only small amounts of starch are present in DDGS because starch is converted to ethanol during the fermentation process. This is because the grain fermentation process employs methods to further break down starch into sugar for further fermentation, such as pre-cooking the ground corn with elevated temperatures and addition of acid followed by adding enzymes that convert starch to sugar. In addition, particular animals, such as ruminant animal like cattle, often require a minimum amount of fiber, which is typically measured by the percent of acid detergent fiber (ADF). For example, dairy cattle need a total ration ADF level about 21 percent to

maintain butterfat production while other types of cattle typically require higher ADF amounts.

Moreover, conventional ethanol production that produces DDG or DDGS uses grains such as cereals, corn, and wheat that typically compete with valuable human food resources. The impact can be further amplified by increasingly more severe climate conditions, such as droughts and floods, which reduce the amount of crop harvested every year thereby driving up prices.

Accordingly, there is a growing need for animal feeds and methods of producing such animal feeds that address these challenges.

Summary

In one embodiment, there is provided an animal feed product comprising a plant material that has been devolatilized and comprises less than about 0.4 wt % sulfur. In one embodiment, the animal feed product further comprises at least about 20 wt % acid detergent fiber (ADF). In another embodiment, the animal feed product further comprises at least about 10 wt % starch. In another embodiment, the animal feed product further comprises a particle size distribution of about 3 mm to about 80 mm. In another embodiment, the plant material consists essentially of vegetative material. In yet another embodiment, the plant material is selected from the following miscanthus, switchgrass, hemp, tropical poplar, willow, sorghum, sugarcane, sugar beet, any energy cane, and any combination thereof.

In another embodiment, there is provided a method to produce an animal feed product comprising: generating a prepared biomass material by adding at least one additive to a solid biomass comprising a sugar, wherein said at least one additive comprise a microbe, and optionally, an acid and/or an enzyme; storing the prepared biomass material for at least about 24 hours in a storage facility to allow for the production of at least one volatile organic compound from at least a portion of the sugar; capturing the at least one volatile organic compound by feeding the stored biomass material to a solventless recovery system to separate the stored biomass material into at least a gas component comprising the at least one volatile organic compound and a solid component; and removing the solid component from the solventless recovery system for use as an animal feed product.

In one embodiment, the capturing step comprises: introducing the prepared biomass material to an compartment of a solventless recovery system, wherein the prepared

biomass material contains one or more volatile organic compounds; contacting the prepared biomass material with a superheated vapor stream in the compartment to vaporize at least a portion of an initial liquid content in the prepared biomass material, said superheated vapor stream comprising at least one volatile organic compound; separating a gas component and a solid component from the prepared biomass material, said gas component comprising at least one volatile organic compound; and retaining at least a portion of the gas component for use as part of the superheated vapor stream.

In another embodiment, the method further comprises drying the solid component to further remove moisture. In another embodiment, the method further comprises densifying the solid component to increase the density of the animal feed product. In one embodiment, the densifying comprises pelletizing the solid component. In another embodiment, the method further comprises a fermentable sugar producing crop to fragments having a particle size distribution from about 3 mm to about 80 mm to use as the solid biomass.

In addition to the features described above, embodiments of the invention allow for economical production of alternative fuels, such as ethanol and other volatile organic compounds, and other related products, such as animal feed, from plants that contain fermentable sugar by addressing certain challenges, such as needs of storage and transportation plants, short harvest windows, quick degradation of sugars, and large investment in equipment. Aspects of the embodiments described herein are applicable to any biomass material, such as plants containing fermentable sugars. The features of embodiments of the present invention allow for economical use of various plants to produce alternative fuels, chemicals, and other related products, and are not limited to sorghum and other plants that suffer similar challenges. Such challenging crops are highlighted herein because other methods and systems have not been able to economically use these challenging crops to produce fuels, chemicals, and other related products. As such, the specific mention of sorghum is not intended to be limiting, but rather illustrates one particular application of embodiments of the invention.

Other features and advantages of embodiments of the present invention will become apparent from the following detailed description. It should be understood, however, that the detailed description and the specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes

and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

Brief Description of the Drawings

These drawings illustrate certain aspects of some of the embodiments of the invention, and should not be used to limit or define the invention.

FIG. 1 is a diagram of one embodiment to process biomass material according to certain aspects of the present invention.

FIG. 2 is a diagram of another embodiment to process biomass material according to certain aspects of the present invention.

Detailed Description of Preferred Embodiments

Embodiments of the present invention relate to animal feed products and methods of making same. Embodiments of the present invention provide a forage substitute that address the challenges associated with traditional feed such as forage and DDG or DDGS. In one embodiment, the animal feed product of the present invention is devolatilized, which provides for minimal release harmful volatile organic compounds into the atmosphere, particularly during feed out where the feed is spread about and left out for the animals to eat. Embodiments of the present invention may allow for substantial or complete replacement of forage, thereby reducing detrimental environmental impact of using forage silage as feed. In addition, in various embodiments, the animal feed of the present invention is already size-reduced, which places in a denser form than traditional forage, including hay, which allows ease of handling and transport, such as further densification, including pelletization and/or other formatting process for rail transportation. In comparison, traditional forage, such as hay, on the other hand, requires costly handling and transport due to its bulkiness, issues such as dust, rodent, or other risks, and required size reduction processes before it can be size reduced and formatted for cost effective transportation, such as by rail or as a denser material. DDG or DDGS, on the other hand, has too small of particle size that does not provide the desired roughage for optimal digestion by certain animals, such as ruminant animals.

In various embodiments, the animal feed of the present invention has a low sulfur content, high amount of ADF, and/or high amount of starch to meet desired nutritional amounts, which further may allow it to be a substantial or complete replacement of forage. In addition, in certain embodiments, grain is preferably not used in the production of the

animal feed, but rather predominantly vegetative material is used instead. This allows certain embodiments to preferably not compete with food sources.

As used herein, an animal feed product is a food product or a treat for animals, in particular mammals. In particular, embodiments of the present invention are suitable for livestock such as cattle, goats, sheep, swine, horses, and fowl. Furthermore, embodiments of the present invention provide an animal feed product that can be stored long-term and can be produced economically.

The term "devolatilize," or related terms such as devolatilized and devolatilization, as used herein refers to removal and capture of one or more volatile organic compounds (VOCs) from a material using a VOC recovery process. The term "vegetative" refers at least to a plant material that predominantly does not include a grain component. Reference will now be made to various embodiments, examples of which are illustrated in the accompanying drawings. However, these various exemplary embodiments are not intended to limit the disclosure.

Throughout the application, description of various embodiments may use "comprising" language, however, it will be understood by one of skill in the art, that in some specific instances, an embodiment can alternatively be described using the language "consisting essentially of" or "consisting of."

For purposes of better understanding the present teachings and in no way limiting the scope of the teachings, it will be clear to one of skill in the art that the use of the singular includes the plural unless specifically stated otherwise. Therefore, the terms "a," "an" and "at least one" are used interchangeably in this application.

In a preferred embodiment, the animal feed product has an acid detergent fiber (ADF) percent in a range from greater than about 20%, particularly from greater than about 20% to about 50%. In one embodiment, the ADF amount is in a range preferably from about 25% to about 45%, more preferably from about 30% to 35%. In one embodiment, the animal feed product has a particle size distribution of greater than about 2 mm. In another embodiment, the animal feed product has a particle size distribution from about 3 mm to about 80 mm. In a preferred embodiment, the particle size distribution is from about 3mm to about 20 mm, with examples of about 3 mm to about 13 mm being more preferred. In certain embodiments, such as those using the particular methods described further below, the particle size can be adjusted as desired, which can be done by adjusting

the chopped length of the crop. The particle size distribution of animal feed produced by certain embodiments of the invention provides the desired roughage to assist with digestion, such as that provided by traditional forage and lacking in DDG or DDGS, while cutting down on handling and transportation costs which would be associated with traditional forage.

In one embodiment, the animal feed product is devolatilized. In another embodiment, the animal feed product comprises less than about 0.40 wt % of sulfur. In a particular embodiment, the animal feed product comprises sulfur in an amount of less than about 0.35 wt %, less than about 0.30 wt %, less than about 0.25 wt %, less than about 0.20 wt %, less than about 0.15 wt%, or less than about 0.10 wt %. In a preferred embodiment, the animal feed product comprises sulfur in an amount from about 0.05 wt % to about 0.10 wt %, about 0.15 wt %, about 0.20 wt %, about 0.25 wt %, or about 0.30 wt %. In another preferred embodiment, the animal feed product comprises sulfur in an amount from about 0.10 wt % to about 0.20 wt %.

In one embodiment, the animal feed comprises starch in an amount of at least about 10 wt%. In another embodiment, the animal feed comprises starch in an amount from about greater than 10 wt% to about 50 wt%. In a preferred embodiment, the animal feed comprises starch in an amount from about greater than 10 wt % to about 35 wt%. In another preferred embodiment, the animal feed comprises starch in an amount from about 15 wt% to about 50 wt%, about 40 wt%, about 35 wt%, about 30 wt%, or about 25 wt%.

In one embodiment, the animal feed product of claim 1 comprises plant material that consists essentially of vegetative material. In addition, embodiments of animal feed products may comprise additional components beyond the meal and the liquid binding agent. Additional components include but are not limited to inert ingredients such as leavening agents, fillers, preservatives, flavorants, palatants, processing aids, etc.

In a particular preferred embodiment, the animal feed product is obtained by preparation of a biomass material and/or recovery of volatile organic compounds from the prepared biomass material containing such compounds. Exemplary descriptions of such processes can be found in U.S. Provisional Application No. 61/648109, filed on May 17, 2012, entitled A NOVEL PROCESS FOR PRODUCING ETHANOL AND OTHER VOLATILE ORGANICS and U.S. Provisional Application Nos. 61/786844 and 61/786860, both filed on March 15, 2013 and entitled PROCESS FOR PRODUCING

VOLATILE ORGANIC COMPOUNDS FROM BIOMASS MATERIAL. The disclosures of all three applications are incorporated herein by reference in their entirety.

In certain embodiments, the biomass is prepared biomass by adding at least one additive to it, wherein said at least one additive comprise a microbe, and optionally, an acid and/or an enzyme. The prepared biomass is stored the prepared biomass material for at least about 24 hours in a storage facility to allow for the production of at least one volatile organic compound. In certain embodiments, the recovery method comprises introducing a biomass material to a compartment of a solventless recovery system, wherein the biomass material contains one or more volatile organic compounds; contacting the biomass material with a superheated vapor stream in the compartment to vaporize at least a portion of an initial liquid content in the biomass material, said superheated vapor stream comprising at least one volatile organic compound; separating a vapor component and a solid component from the heated biomass material, said vapor component comprising at least one volatile organic compound; and retaining at least a portion of the gas component for use as part of the superheated vapor stream. In a preferred embodiment, the solid component serves as an animal feed product of the present invention.

As used herein, the term "solid biomass" or "biomass" refers at least to biological matter from living, or recently living organisms. Solid biomass includes plant or animal matter that can be converted into fibers or other industrial chemicals, including biofuels. Solid biomass can be derived from numerous types of plants or trees, including miscanthus, switchgrass, hemp, corn, tropical poplar, willow, sorghum, sugarcane, sugar beet, and any energy cane, and a variety of tree species, ranging from eucalyptus to oil palm (palm oil). In one embodiment, the solid biomass comprises at least one fermentable sugar-producing plant. The solid biomass can comprise two or more different plant types, including fermentable sugar-producing plant. In a preferred embodiment not intended to limit the scope of the invention, sorghum is selected, due to its high-yield on less productive lands and high sugar content.

The term "fermentable sugar" refers to oligosaccharides and monosaccharides that can be used as a carbon source (e.g., pentoses and hexoses) by a microorganism to produce an organic product such as alcohols, organic acids, esters, and aldehydes, under anaerobic and/or aerobic conditions. Such production of an organic product can be referred to generally as fermentation. The at least one fermentable sugar-producing plant contains

fermentable sugars dissolved in the water phase of the plant material at one point in time during its growth cycle. Non-limiting examples of fermentable sugar-producing plants include sorghum, sugarcane, sugar beet, and energy cane. In particular, sugarcane, energy cane, and sorghum typically contain from about 5% to about 25% soluble sugar w/w in the water phase and have moisture content between about 60% and about 80% on a wet basis when they are near or at their maximum potential fermentable sugar production (*e.g.*, maximum fermentable sugar concentration).

Unlike conventional ethanol production process that also generates DDG or DDGS, which adds enzymes under certain conditions that converts most of the starch into fermentable sugar for fermentation, a significant amount of starch in the prepared biomass is not lost generate fermentable sugar. Accordingly, most of the initial amount of starch contained in the biomass prior to fermentation remains through fermentation and/or subsequent storage period.

The term "wet basis" refers at least to the mass percentage that includes water as part of the mass. In a preferred embodiment, the sugar producing plant is sorghum. Any species or variety of the genus sorghum that provides for the microbial conversion of carbohydrates to volatile organic compounds (VOCs) can be used. For embodiments using sorghum, the plant provides certain benefits, including being water-efficient, as well as drought and heat-tolerant. These properties make the crop suitable for many locations, including various regions across the earth, such as China, Africa, Australia, and in the US, such as portions of the High Plains, the West, and across the South. Texas.

In embodiments using sorghum, the sorghum can include any variety or combination of varieties that may be harvested with higher concentrations of fermentable sugar. Certain varieties of sorghum with preferred properties are sometimes referred to as "sweet sorghum." The sorghum can include a variety that may or may not contain enough moisture to support the juicing process in a sugar cane mill operation. In a preferred embodiment, the solid biomass includes a Sugar T sorghum variety commercially produced by Advanta and/or a male parent of Sugar T, which is also a commercially available product of Advanta. In a preferred embodiment, the crop used has from about 5 to about 25 brix, preferably from about 10 to about 20 brix, and more preferably from about 12 to about 18 brix. The term "brix" herein refers at least to the content of glucose, fructose, and sucrose in an aqueous solution where one degree brix is 1 gram of glucose,

fructose, and/or sucrose in 100 grams of solution and represents the strength of the solution as percentage by weight (% w/w). In another preferred embodiment, the moisture content of the crop used is from about 50% to 80%, preferably at least 60%.

In one embodiment, the crop is a male parent of Sugar T with a brix value of about 18 and a moisture content of about 67%. In another embodiment, the crop is Sugar T with a brix value of about 12 at a moisture content of about 73%. In these particular embodiments, the brix and moisture content values were determined by handheld refractometer.

The crop type and/or species can be selected to provide a desired starch content, such as greater than about 10 wt% to about 50 wt%, such as about 15 wt%, about 20 wt%, about 25 wt%, about 30 wt%, about 35 wt%, about 40 wt%, or about 45 wt%, since most of the initial starch content remains through fermentation and subsequent processes, such as storage and VOC recovery.

After at least one additive (a microbe, optionally, an acid and/or enzyme) is added to the solid biomass, it becomes prepared biomass material where the at least one additive facilitates the conversion of fermentable sugar into a VOC (such as ethanol). As noted above and further described below, the prepared biomass material can be stored for a certain period of time to allow more VOCs to be generated by the conversion process. At least one volatile organic compound is then recovered from the prepared biomass material. Volatile organic compounds are known to those skilled in the art. The U.S. EPA provides descriptions volatile organic compounds (VOC), one of which is any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions, except those designated by EPA as having negligible photochemical reactivity (see http://www.epa.gov/iaq/voc2.html#definition). Another description of volatile organic compounds, or VOCs, is any organic chemical compound whose composition makes it possible for them to evaporate under normal indoor atmospheric conditions of temperature and pressure. This is the general definition of VOCs that is used in the scientific literature, and is consistent with the definition used for indoor air quality. Normal indoor atmospheric conditions of temperature and pressure refer to the range of conditions usually found in buildings occupied by people, and thus can vary depending on the type of building and its geographic location. One exemplary normal indoor atmospheric condition

is provided by the International Union of Pure and Applied Chemistry (IUPAC) and the National Institute of Standards and Technology (NIST). IUPAC's standard is a temperature of 0° C (273, 15 K, 32° F) and an absolute pressure of 100 kPa (14.504 psi), and NIST's definition is a temperature of 20° C (293, 15 K, 68° F) and an absolute pressure of 101.325 kPa (14.696 psi).

Since the volatility of a compound is generally higher the lower its boiling point temperature, the volatility of organic compounds are sometimes defined and classified by their boiling points. Accordingly, a VOC can be described by its boiling point. A VOC is any organic compound having a boiling point range of about 50 degrees C to 260 degrees C measured at a standard atmospheric pressure of about 101.3 kPa. Many volatile organic compounds that can be recovered and/or further processed from VOCs recovered from embodiments of the present invention have applications in the perfume and flavoring industries. Examples of such compounds may be esters, ketones, alcohols, aldehydes, hydrocarbons and terpenes. The following Table 1 further provides non-limiting examples of volatile organic compounds that may be recovered and/or further processed from VOCs recovered from the prepared biomass material.

Table 1

Methanol	Ethyl acetate	Acetaldehyde	Diacetyl
2,3-pentanedione	Malic acid	Pyruvic acid	Succinic acid
Butyric acid	Formic acid	Acetic acid	Propionic acid
Isobutyric acid	Valeric acid	Isovaleric acid	2-methylbutyric acid
Hexanoic acid	Heptanoic acid	Octanoic acid	Nonanoic acid
Decanoic acid	Propanol	Isopropanol	Butanol
Isobutanol	Isoamyl alcohol	Hexanol	Tyrosol
Tryptoptanol	Phenethyl alcohol	2,3-butanediol	Glycerol
Fumaric acid	Ethanol	Amyl alcohol	1,2-propanol
1-propanol	2-butanol	Methyl acetate	Ethyl acetate
Propyl acetate	Ethyl lactate	Propyl lactate	Acetone
Ethyl formate	n-propyl alcohol	2-methyl-1- propanol	2-propen-1-ol
2,3-methyl-1-butanol	3-buten-2-ol		

Ethanol is a preferred volatile organic compound. As such, many examples specifically mention ethanol. This specific mention, however, is not intended to limit the invention. It should be understood that aspects of the invention also equally apply to other volatile organic compounds. Another preferred volatile organic compound is acetic acid.

Embodiments of the present invention provide for the long term storage of solid biomass material without significant degradation to the volatile organic compounds contained in the prepared biomass material, and they provide for sugar preservation to allow for continued generation of VOCs. As used in this context, "significant" refers at least to within the margin of error when measuring the amount or concentration of the volatile organic compounds in the prepared biomass material. In one embodiment, the margin of error is about 0.5%.

Accordingly, embodiments of the present invention allow for continuous production VOCs without dependence on the length of the harvest, thereby eliminating or minimizing down time of a recovery plant in traditional just-in-time harvest and recovery processes. As such, embodiments of the present invention allow for harvest of the crop at its peak without compromises typically made to lengthen the harvest season, such as harvest slightly earlier and later than peak time. That is, embodiments of the invention allow for harvest at high field yields and high sugar concentrations, such as when the selected crop has reached its peak sugar concentration or amount of fermentable sugars that can be converted into a volatile organic compound, even if this results in a shorter harvest period. In one embodiment, the solid biomass is harvested or prepared when it is at about 80%, about 85%, about 90%, about 95%, or about 100% of its maximum potential fermentable sugar concentration. As such, embodiments of the present invention, particularly the recovery phase, can be operated continuously year-round without time pressure from fear of spoilage of the solid biomass and VOCs contained therein. While embodiments of the present invention allow for harvest of the solid biomass near or at its maximum sugar production potential, the solid biomass material can be harvested at any point when it is deemed to contain a suitable amount of sugar. Further, the harvest window varies depending on the type of crop and the geographical location. For example, the harvest window for sorghum in North America can range from about 1 to 7 months. However, in Brazil and other equatorial and near equatorial areas, the harvest window may be up to twelve months.

The capability for continuous year-round operation also allows for continuous year-round generation of embodiments animal feed product, which can be transported to other locations without the geographical restrictions suffered by traditional forage due to prohibitively high handling and transportation costs beyond a certain distance.

In embodiments using plants as the solid biomass, the solid biomass can be collected or harvested from the field using any suitable means known to those skilled in the art. In one embodiment, the solid biomass comprises vegetative material, such as a stalk component and a leaf component of the plant. In another embodiment, the solid biomass further comprises a grain component. In another embodiment, the solid biomass consists essentially of vegetative material. In a preferred embodiment, the solid biomass is harvested with a forage or silage harvester (a forage or silage chopper). A silage or forage harvester refers to farm equipment used to make silage, which is grass, corn or other plant that has been chopped into small pieces, and compacted together in a storage silo, silage bunker, or in silage bags. A silage or forage harvester has a cutting mechanism, such as either a drum (cutterhead) or a flywheel with a number of knives fixed to it, which chops and transfers the chopped material into a receptacle that is either connected to the harvester or to another vehicle driving alongside. A forage harvester is preferred because it provides benefits over a sugar cane harvester or dry baled system. For example, a forage harvester provides higher density material than a sugar cane harvester, thereby allowing for more efficient transportation of the harvested material. In one embodiment, using a forage harvester results in harvested sorghum with a bulk density of about 400 kg/m^3, compared to sugarcane harvested with a sugarcane harvester with density of about 300 kg/m^3, and for sorghum harvested with a sugarcane harvester with a density of about 200 kg/m^3. In general, higher bulk density material is cheaper to transport, which tends to limit the geographical area in which cane-harvested crop can be sourced.

Thus, a forage harvester is an overall less expensive way to harvest the selected biomass, such as sorghum, than a cane harvester or dry baled system. Not to be bound by theory, it is believed the cost savings are due in part to higher material throughputs and the higher bulk density of the solid biomass harvested by a forage harvester. The solid biomass can be cut in any length. In one embodiment, the chop lengths of the harvester can be set to a range of about 3 mm to about 80 mm, preferably about 3 mm to about 20 mm, with examples of about 3 mm to about 13 mm chop lengths being most preferred. At these preferred chop lengths, there was not observable aqueous discharge in the forage harvester, so losses were minimal. When a chop length is selected, the harvester provides biomass with an average size or length distribution of about the chop length selected. In one embodiment, the average size distribution of the solid component exiting the recovery

system can be adjusted as desired, which can be done by adjusting the chop length of the harvester.

At least one additive is added to the solid biomass to facilitate and/or expedite the conversion of appropriate carbohydrates into volatile organic compounds. After selected additive(s) have been added, the solid biomass can be referred to as prepared biomass material. In one embodiment, the prepared biomass material can comprise at least one or any combination of fermentable sugar-producing plants listed above. In a preferred embodiment, the selected additive(s) can be conveniently added using the harvester during harvest.

In one embodiment, at least about 700 tons, preferably at least about 1 million tons, such as at least 1.2 million tons, or more preferably about at least 5 million tons of prepared biomass material is generated in a particular harvest window based on the growing conditions of a specific region, such as about 1 to 7 months in North America for sorghum.

The at least one additive can be added at any point during and/or after the harvest process. In a preferred embodiment using a forage harvester, additives are added to the solid biomass during the harvest process to generate a prepared biomass material. In particular, forage harvesters are designed for efficiently adding both solid and liquid additives during harvest. As mentioned above, the additives added include at least a microbe (e.g. a yeast), and optionally, an acid and/or an enzyme. In a preferred embodiment, the selected additive(s) are added as solutions. Additional details of the potential additives are further provided below.

For embodiments using a forage harvester or a similar equipment, the selected additive(s) can be added during harvest at all phases, such as before the intake feed rollers, during intake, at chopping, after chopping, through the blower, after the blower, in the accelerator, in the boom (or spout), and/or after the boom. In one embodiment where acid and enzyme are added, the acid is added near the intake feed rollers, and a microbe and the enzyme are added in the boom. In a particular embodiment, a Krone Big X forage harvester with a V12 motor with an about 30 ft wide header is used. In an embodiment using the Krone system, the acid is added as a solution through flexible tubing that discharged the solution just in front of the feed rollers. In this way, the liquid flow can be visually monitored, which showed the acid solution and solid biomass quickly mixed

inside the chopping chamber. In another embodiment, the addition of acid was also demonstrated as a viable practice using a Case New Holland FX 58 forage harvester. In certain embodiments, the forage harvester used can include an onboard rack for containing additives, at least the one(s) selected to be added during harvest. In another embodiment, the selected additive(s) to be added during harvest may be towed behind the harvester on a trailer. For example, in one embodiment, it was demonstrated that a modified utility trailer equipped with tanks containing additive solutions of yeast, enzymes and acid can be employed with minimal interfering with normal operations of the harvester, thereby substantially maintaining the expected cost and duration of the harvest process. For example, a normal harvest configuration and biomass yield employing a silage harvester travelling at about 4 miles per hour maintains a similar rate of collection of about 4 miles per hour when equipped with certain additives as described above in one embodiment.

In embodiments of the present invention, the prepared biomass material is eventually transported to a storage facility where it is stored for a period of time to allow for production of at least one volatile organic compound from at least a portion of the fermentable sugar of the solid biomass. The details of the storage phase are further provided below. In certain embodiments, selected additive(s) can also be added at the storage facility. For example, in one embodiment, the selected additive(s) can be added during unloading or after the solid biomass has been unloaded at the storage facility. In one embodiment, a conveyance system is used to assist with the adding of selected additive(s) at the storage facility. Additive(s) added at the storage facility to solid biomass can be one(s) that have not been added or additional amount of one(s) previously added. Accordingly, selected additive(s) can therefore be added at any point from the start of the harvest process to prior to storage of the prepared biomass material at the storage area or facility, such as at points where the material is transferred.

As mentioned above, additive(s) for embodiments of the present invention include at least a microbe and optionally, an acid and/or an enzyme. Selected additive(s) can be added to the solid biomass in any order. In a preferred embodiment, an acid is added to the solid biomass before adding a microbe to prime the material to provide an attractive growth environment for the microbe.

In a preferred embodiment, acid is added to reduce the pH of the solid biomass to a range that facilitates and/or expedites selected indigenous or added microbial growth,

which increases production of ethanol and/or volatile organic compounds. The acid can also stop or slow plant respiration, which consumes fermentable sugars intended for subsequent VOC production. In one embodiment, acid is added until the pH of the solid biomass is between about 2.5 and about 5.0, preferably in a range of about 3.7 to about 4.3, and more preferably about 4.2. The acid used can include known acids, such as sulfuric acid, formic acid, or phosphoric acid. The following Table 2 provides non-limiting examples of an acid that can be used individually or in combination.

Table 2

Sulfuric Acid	Formic Acid	Propionic Acid	Malic Acid
Phosphoric Acid	Maleic Acid	Folic Acid	Citric Acid

In a preferred embodiment, after the solid biomass has reached the desired pH with the addition of acid, a microbe is added. A microbe in the additive context refers at least to a living organism added to the solid biomass that is capable of impacting or affecting the prepared biomass material. One exemplary impact or effect from added microbe(s) includes providing fermentation or other metabolism to convert fermentable sugars from various sources, including cellulosic material, into ethanol or other volatile organic compounds. Another exemplary impact or effect may be production of certain enzyme(s) that help to deconstruct cellulose in the prepared biomass material into fermentable sugars which can be metabolized to ethanol or other VOC. Yet another exemplary impact or effect provided by a microbe includes production of compounds such as vitamins, co-factors, and proteins that can improve the quality, and thus value, of certain embodiments of the feed product described herein. Further, microbial activity provides heat for the pile. Parts of the microbial cell walls or other catabolite or anabolite may also offer value-added chemicals that may be recovered by a recovery unit. These impacts and effects may also be provided by microbes indigenous to the solid biomass.

Any microbe that is capable of impacting or affecting the prepared biomass material can be added. In a preferred embodiment, the microbe(s) can include microbes used in the silage, animal feed, wine, and industrial ethanol fermentation applications. In one embodiment, the microbe selected includes yeast, fungi, and bacteria according to application and the desired profile of the organic molecule to be made. In a preferred embodiment, yeast is the selected microbe. In another embodiment, bacteria can be added

to make lactic acid or acetic acid. Certain fungi can also be added to make these acids. For example, Acetobacterium acetii can be added to generate acetic acid; Lactobacillus, Streptococcus thermophilus can be added to generate lactic acid; Actinobacillus succinogenes, Mannheimia succiniciproducens, and/or Anaerobiospirillum succiniciproducens can be added to generate succinic acid; Clostridium acetobutylicum can be added to generate acetone and butanol; and/or Aerobacter aerogenes can be added to generate butanediol.

The following Table 3 provides non-limiting examples of preferred microbes, which can be used individually or in combination.

Table 3

Saccharomyces cerevisiae	Saccharomyces japonicas	Saccharomyces bayanus	Saccharomyces fermentatti
Saccharomyces exiguous	Saccharomyces chevalieri	Clostridium acetobutylicum	Clostridium amylosaccharobutyl propylicum
Clostridium propyl-butylicum	Clostridium viscifaciens	Clostridium propionicum	Aerobacter species
Aerobacter aerogenes	Zymomonas mobilis	Zymomonas species	Clostridium species
Saccharomyces species	Bacillus species	Clostridium thermocellum	Lactobacillus buchneri
Lactobacillus plantarum	Enterococcus faecium	Pediococcus species	Propionibacteria
Acetobacterium acetii	Streptococcus thermophilus	Lactobacillus paracasei	Lactobacillus species
Actinobacillus succinogenes	Mannheimia succiniciproducens	Anaerobiospirillum succiniciproducens	

Preferred microbes also include Saccharomyces cerevisiae strains that can tolerate high ethanol concentrations and are strong competitors in its respective microbial community. The microbes may be mesophiles or thermophiles. Thermophiles are organisms that grow best at temperatures above about 45°C, and are found in all three domains of life: Bacteria, Archaea and Eukarya. Mesophiles generally are active between about 20 degrees C and 45 degrees C. In an embodiment using a strain of Saccharomyces cerevisiae, the strain can come from a commercially available source such as Biosaf from Lesaffre, Ethanol Red from Phibro, and Lallamand activated liquid yeast. If the microbe is obtained from a commercial source, the microbe can be added according to the recommended rate of the provider, which is typically based on the expected sugar content per wet ton, where

water is included in the mass calculation. The term "wet ton" refers at least to the mass unit including water. The recommended amount can be adjusted according to reaction conditions. The microbe added can comprise one strain or multiple strains of a particular microbe. In one embodiment, the microbes are added at a rate of up to 500 mL per wet ton of solid biomass. In a particular embodiment using commercially available yeast, about 300 mL of Lallamand yeast preparation is added per wet ton of solid biomass. In another embodiment, an additional yeast strain can be added. For example, Ethanol Red can be added at a rate between about 0.001 kg/wet ton to about 0.5 kg/wet ton, particularly about 0.1 kg/wet ton. In yet another embodiment, another yeast strain can be added, e.g., Biosaf, at a rate between about 0.001 kg/wet tone to about 0.5 kg/wet ton, particularly about 0.1 kg/wet ton. It is understood that other amounts of any yeast strain can be added. For example, about 10%, about 20%, about 30%, about 40%, about 50%, about 60%, about 70%, about 80%, about 90%, about 1.5 times, about 2 times, about 2.5 times, or about 3 times of the provided amounts of microbes can be added.

In certain embodiments, an enzyme is further added. The enzyme can be one that assists in the generation of fermentable sugars from plant materials that are more difficult for the microbe to metabolize, such as different cellulosic materials, and/or to improve the value of embodiments of the animal feed product described herein, such as by making the feed more digestable. The enzyme can also be an antibiotic, such as a lysozyme as discussed further below. The enzyme added can include one type of enzyme or many types of enzymes. The enzyme can come from commercially available enzyme preparations. Non-limiting examples of enzymes that assist in converting certain difficult to metabolize plant materials into fermentable sugars include cellulases, hemicellulases, ferulic acid esterases, and/or proteases. Additional examples also include other enzymes that either provide or assist the provision for the production of fermentable sugars from the feedstock, or increase the value of embodiments of the feed product described herein.

In certain embodiments, the enzymes that assist in converting certain difficult to metabolize plant materials into fermentable sugars can be produced by the plant itself, *e.g. in-plantae*. Examples of plants that can produce cellulases, hemicellulases, and other plant-polymer degrading enzymes may be produced within the growing plants are described in the patent publications and patent WO2011057159, WO2007100897, WO9811235, and US6818803, which show that enzymes for depolymerizing plant cell

walls may be produced in plants. In another embodiment, ensilagement can be used to activate such plant produced enzymes as well as temper the biomass for further processing. One example is described in patent publication WO201096510. If used, such transgenic plants can be included in the harvest in any amount. For example, certain embodiments may employ *in-plantae* enzymes produced in plants by using particular transgenic plants exclusively as a feedstock, or incorporating the transgenic plants in an interspersed manner within like or different crops.

In certain embodiments that include such plant-polymer degrading enzymes, ethanol can be produced from cellulosic fractions of the plant. In a particular embodiment, when Novazymes CTEC2 enzyme was added to a sorghum storage system in excess of the recommended amount, about 100 times more than the recommended amount, about 152% of the theoretical ethanol conversion efficiency based on the initial free sugar content was achieved. While such an amount of enzymes can be added using commercially available formulations, doing so can be costly. On the other hand, such an amount of enzymes can be obtained in a more cost effective manner by growing transgenic plants that produce these enzymes at least interspersingly among the biomass crop.

The ethanol production from cellulose occurred during the storage phase, *e.g.*, in silage and was stable for about 102 days of storage, after which the experiment was terminated. This demonstrates that, under the conditions of that particular experiment, an excess of such enzyme activity results in at least about 52% production of ethanol using fermentable sugars from cellulose. Not intended to be bound by theory, for certain embodiments, the immediate addition of acid during harvest in the experiment may have lowered the pH, thereby potentially inducing the enzyme activity, which otherwise could damage the plants if produced while the plants were still growing.

In a preferred embodiment, if an enzyme is added, the enzyme can be any family of cellulase preparations. In one embodiment, the cellulose preparation used is Novozymes Cellic CTec 2 or CTec 3. In another embodiment, a fibrolytic enzyme preparation is used, particularly, Liquicell 2500. If used, the amount of enzyme added to degrade plant polymer can be any amount that achieves the desired conversion of plant material to fermentable sugar, such as the recommended amount. In a particular embodiment, about 80,000 FPU to about 90,000,000 FPU, preferably about 400,000 FPU to about 45,000,000 FPU, more preferably about 800,000 FPU to about 10,000,000 FPU of

enzyme is added per wet ton of biomass. The term "FPU" refers to Filter Paper Unit, which refers at least to the amount of enzyme required to liberate 2 mg of reducing sugar (e.g., glucose) from a 50 mg piece of Whatman No. 1 filter paper in 1 hour at 50° C at approximately pH 4.8.

In certain other embodiments, selected additive(s) added can include other substances capable of slowing or controlling bacterial growth. Non-limiting examples of these other substances include antibiotics (including antibiotic enzymes), such as Lysovin (lysozyme) and Lactrol® (Virginiamycin, a bacterial inhibitor). Control of bacterial growth can allow the appropriate microbe to expedite and/or provide the production of volatile organic compounds. Antibiotic is a general term for something which suppresses or kills life. An example of an antibiotic is a bacterial inhibitor. In one embodiment, a selective antibiotic that is intended to impact bacteria and not other microbes is used. One example of a selective antibiotic is Lactrol, which affects bacteria but does not affect yeasts.

In a particular embodiment, if used, Lactrol can be added at rates of about 1 to 20 part-per-million (ppm) w/v (weight Lactrol per volume liquid) as dissolved in the water phase of the prepared biomass material, for example at about at about 5 ppm w/v. In an embodiment using an enzyme to control bacterial growth, lysozyme is preferably used. The lysozyme can come from a commercial source. An exemplary commercially available lysozyme preparation is Lysovin, which is a preparation of the enzyme lysozyme that has been declared permissible for use in food, such as wine.

The enzyme and/or other antibiotic material, if used, can be added independently or in conjunction with one another and/or with the microbe. In certain embodiments, other compounds serving as nutrients to the microbes facilitating and/or providing the volatile organic compound production can also be added as an additive. The following Table 4 provides non-limiting examples of other substances, including antibiotics, which can be added to the solid biomass.

Table 4

Potassium Metabisulfite	Potassium Bicarbonate	FermaSure® (from Dupont™) – oxychlorine products including chlorite	Lysovin
Thiamin	Magnesium Sulfate	Calcium Pantothenate	Diammonium Phosphate
Ammonia	Antibiotics	Lactrol	Biotin

Yeasts and other microbes that are attached to solids individually, as small aggregates, or biofilms have been shown to have increased tolerance to inhibitory compounds. Not intended to be bound by theory, part of the long-term fermentation may be possible or enhanced by such microbial-to-solids binding. As such, the prepared biomass material that includes the microbe optimized for microbial binding as well as additives that may bind microorganisms can experience a greater extent of fermentation and or efficiency of fermentation. Substances providing and/or facilitating long term fermentation is different from substances that increase the rate of fermentation. In certain embodiments, an increase in the rate of fermentation is not as an important factor as the long-term fermentation, particularly over a period of many weeks or months.

The following provides particular amounts of additives applied to one specific embodiment. If used, the rate and amount of adding an acid varies with the buffering capacity of the particular solid biomass to which the particular acid is added. In a particular embodiment using sulfuric acid, 9.3% w/w sulfuric acid is added at rates of up to about 10 liter/ton wet biomass, for example at about 3.8 liter/ton wet biomass to achieve a pH of about 4.2. In other embodiments, the rate will vary depending on the concentration and type of acid, liquid and other content and buffering capacity of the particular solid biomass, and/or desired pH. In this particular embodiment, Lactrol is added at a rate of about 3.2 g/wet ton of solid biomass. Yeasts or other microbes are added according to the recommended rate from the provider, such as according to the expected sugar content per wet ton. In one particular embodiment, Lallemand stabilized liquid yeast is added at about 18 fl oz per wet ton, and Novozymes Cellic CTec2 is added at about 20 fl oz per wet ton.

In a preferred embodiment, selected additive(s) are added to the solid biomass stream during harvest according to aspects of the invention described above to generate the prepared biomass material. Preferably, the prepared biomass material is transported to a storage facility to allow for conversion of carbohydrates of the prepared biomass material into volatile organic compounds of the desired amount and/or await recovery of the volatile organic compounds. Any suitable transportation method and/or device can be used, such as vehicles, trains, etc, and any suitable method to place the prepared biomass material onto the transportation means. Non-limiting examples of vehicles that can be used to transport the biomass material include end-unloading dump trucks, side-unloading dump

trucks, and self-unloading silage trucks. In a preferred embodiment, a silage truck is used. In embodiments using a forage harvester to collect the biomass, transportation of such solid biomass is more efficient than transportation of materials collected by conventional means, such as sugar cane billets, because the bulk density is higher in the solid biomass cut with a forage harvester. That is, materials chopped into smaller pieces pack more densely than materials in billets. In one embodiment, the range of bulk densities in a silage truck varies between about 150 kg/m^3 and about 350 kg/m^3, for example about 256 kg/m^3. Because in certain embodiments, all selected additives are added during harvest, preferably on the harvester, the microbe may begin to interact with the biomass during transportation, and in this way transportation is not detrimental to the overall process.

The biomass, whether prepared or not, is delivered to at least one storage area or facility. The storage facility can be located any distance from the harvest site. Selected additive(s) can be added if they have not been added already or if additional amounts or types need to be further added to generate the prepared biomass material. In a preferred embodiment, the prepared biomass is stored in at least one pile on a prepared surface for a period of time. The facility can incorporate man-made or natural topography. Man-made structures can include existing structures at the site not initially designated for silage, such as canals and water treatment ponds. Non-limiting examples of a prepared surface includes a concrete, asphalt, fly ash, or soil surface. The at least one pile can have any dimension or shape, which can depend on operating conditions, such as space available, amount of biomass, desired storage duration, etc.

The conversion process of fermentable sugars is an exothermic reaction. Too much heat, however, can be detrimental to the conversion process if the temperature is in the lethal range for the microbes in the prepared biomass material. However, in an embodiment using about 700 wet tons of biomass and piling up to about 12 feet, ethanol production and stability were satisfactory. Therefore larger piles will likely not suffer from overheating. In one embodiment, an inner portion of the pile maintains a temperature in a range of about 20 degrees C to about 60 degrees C for microbes of all types, including thermophiles. In an embodiment not employing thermophiles, an inner portion of the pile maintains a temperature in a range of about 35 degrees C to about 45 degrees C.

The prepared biomass material that is stored as at least one pile at the storage facility can also be referred to as a wet stored biomass aggregate. After addition of the

selected additive(s), at least a portion of the solid biomass is converted to volatile organic compounds, such as fermentation of sugars into ethanol. In one embodiment, the prepared biomass material is stored for a period of time sufficient to achieve an anaerobiasis environment. In a preferred embodiment, the anaerobiasis environment is achieved in about 24 hours. In another embodiment, the anaerobiasis environment is achieved in more than about 4 hours. In yet another embodiment, the anaerobiasis environment is achieved in up to about 72 hours.

The pile can be free standing or formed in another structure, such as a silage bunker, designed to accept silage, including provisions to collect aqueous runoff and leachate, placement of a tarp over the biomass, and to facilitate both efficient initial silage truck unloading into the bunker as well as removal of the biomass year around. The individual bunkers may be sized at about the size to support annual feedstock requirements of about 700 wet tons to 10,000,000 wet tons or more. For example, the storage facility may have 50 bunkers, where each individual bunker can accept 100,000 wet tons of prepared biomass material for a total of a maximum of about 5 million wet tons of stored material at any one time. In a preferred embodiment where ethanol is the volatile organic compound of choice, about 14 gallons to about 16 gallons of ethanol is recovered per one wet ton of prepared biomass material. The provided numbers are exemplary and not intended to limit the amount of prepared biomass material a storage facility can accommodate.

In a particular embodiment, the storage pile further includes a leachate collection system. In one embodiment, the collection system is used to remove leachate collected from the storage pile. For example, the leachate collection system can be adapted to remove liquid from the pile at certain points during the storage period. In another embodiment, the leachate collection system is adapted to circulate the liquid in the storage pile. For example, circulation can involve taking at least a portion of the recovered liquid and routing it back to the pile, preferably at or near the top portion. Such recirculation allows for longer retention time of certain portions of the liquids in the pile, even as the recovery phase of the prepared biomass material begins and portions of the non-liquid component of the prepared biomass material are sent to the recovery unit. The longer retention time results in longer microbial reaction time, and hence, higher concentrations of organic volatile compounds, such as ethanol.

Any suitable leachate collection system known to those skilled in the art can be employed as described. In a particular embodiment, the leachate collection system comprises at least one trough along the bottom of the pile, preferably positioned near the middle, of the storage pile or bunker if one is used, where the storage pile is prepared at a grade designed to direct liquid from the prepared biomass material to the trough and out to a desired collection receptacle or routed to other applications.

In another embodiment, the leachate collection system comprises one or more perforated conduits, preferably pipes made of polyvinyl chloride (PVC), that run along the bottom of the pile to allow the liquid collected in the conduits to be directed away from the pile.

In one embodiment, as the prepared biomass material is added to the bunker or laid on top of the prepared surface, a tractor or other heavy implement is driven over the pile repeatedly to facilitate packing. In one embodiment, the packing ranges from about 7 lbs/ft^3 to about 50 lbs/ft^3 per cubic foot for the prepared biomass material. In a preferred embodiment, the packing is from about 30 lbs/ft^3 to about 50 lbs/ft^3, particularly about 44 lbs/ft^3. In one embodiment, the compacting of the prepared biomass material in a pile facilitates and/or allows an anaerobiasis environment to be achieved in the preferred time periods described above. In another embodiment, after the packing is performed or during the time the packing is being performed, an air impermeable membrane is placed on the pile, typically a fit for purpose plastic tarp. In a particular embodiment, the tarp is placed on the pile as soon as is practical. For instance, the tar is placed on the pile within a 24-hour period.

In one embodiment, the prepared biomass material is stored for at least about 24 hours and preferably at least about 72 hours (or 3 days) to allow for production of volatile organic compounds, such as ethanol. In one embodiment, the prepared biomass material is stored for about three days, preferably ten days, more preferably greater than ten days. In one embodiment, the time period for storage of the prepared biomass is about 1 day to about 700 days, preferably about 10 to 700 days. In another embodiment, the biomass material is stored for up to about three years. In one embodiment, the prepared biomass material is stored for a time period sufficient to allow a conversion efficiency of sugar to at least one volatile organic compound of at least about 95% of the theoretical production efficiency as calculated through a stoichiometric assessment of the relevant biochemical

pathway. In another embodiment, the prepared biomass material is stored for a time period sufficient to allow a calculated conversion efficiency of sugar to at least one volatile organic compound of at least about 100%. In yet another embodiment, the prepared biomass material is prepared with certain additives, such as enzymes, that allow a calculated conversion efficiency of sugar to at least one volatile organic compound of up to about 150% of the theoretical value based on the initial amount of available fermentable sugars. Not intended to be bound by theory, it is believed that, at or above 100% efficiency, the volatile organic compound(s) are produced from both the initially available fermentable sugars and fermentable sugars from cellulosic or other polymeric material in the prepared biomass material, which can be achieved by enzymatic hydrolysis or acid hydrolysis facilitated by certain additive(s) applied to the biomass.

The produced volatile organic products, such as ethanol, remain stable in the stored prepared biomass material for the duration of the storage period. In particular, the prepared biomass material can be stored up to 700 days without significant degradation to the volatile organic compounds. "Significant" in this context refers at least to within the margin of error when measuring the amount or concentration of the volatile organic compounds in the prepared biomass material. In one embodiment, the margin of error is 0.5%. It has been demonstrated that ethanol remains stable in the pile after at least about 330 days with no significant ethanol losses observed. This aspect of embodiments of the present invention is important because it provides for at least eight months of stable storage, which enables year-round VOCs production and recovery with a harvest window of only about four months. Embodiments of the invention provide significant advantages over the conventional just-in-time processing that would only be able to operate during the four months harvest window per year. That is, embodiments of the invention allow a plant to operate year-round using only a four-month harvest window, thereby reducing capitals cost for a plant of the same size as one used for just-in-time processing.

Also, in an embodiment employing a tarp, it is envisioned that placing soil or other medium around and on the tarp edges to 1) provide weight for holding the tarp down; and also 2) to act as a biofilter of the off-gas from the pile. In such an embodiment, biofilters are efficient for organics and carbon monoxide detoxification/degradation. The prepared biomass material can also be stored as compressed modules, drive over piles, bunkers, silos, bags, tubes, or wrapped bales or other anaerobic storage system.

In one embodiment, the off-gas stream from a pile of prepared biomass material was monitored, and it was found that only small levels of organics, and also very low levels of nitrogen oxides, were present. For example, Tables 5.1, 5.2, and 5.3 below show the analysis of various off-gas samples collected during the storage phase of one implementation of certain embodiments of the invention. The designation "BDL" refers to an amount below detectable limit. Summa and Tedlar refer to gas sampling containers commercially available. As shown below, embodiments of the present invention may be less detrimental to the environment as compared to conventional feed products and/or their manufacturing method.

Table 5.1

Container type	Container ID	% H_2	% O_2	% N_2	% CH_4	% CO_2	% H_2O	Normalized CO2
Tedlar bag	A	BDL	1.72	7.84	BDL	95.90	5.23	85.21
Tedlar bag	B	BDL	2.30	9.12	BDL	89.97	5.97	82.62
Tedlar bag	C	BDL	0.71	3.57	BDL	97.45	5.54	90.18
Tedlar bag	D	BDL	0.72	3.18	BDL	97.50	5.97	90.14
Tedlar bag	E	BDL	1.86	7.24	BDL	91.75	7.64	83.26
Summa Container	EQ #8	0.01	5.74	22.14	0.07	73.74	5.28	66.84
Summa Container	EQ #13	0.09	3.28	12.89	0.33	84.48	5.66	78.18
Summa Container	EQ #16	0.12	3.30	13.01	0.12	84.65	4.99	78.70

Table 5.2

Container type	Container ID	% O_2	ppm v CO	% CO_2	ppm v HC	ppm v NO	ppmv NO_2	ppmv NO_X	ppmv SO_2
Tedlar bag	A	1.6	13	72.7	104	3.8	1.90	5.70	BDL
Tedlar bag	B	4.4	19	66.2	739	2.5	122.90	125.40	6

Tedlar bag	C	0.6	29	75.3	158	8.9	27.20	36.10	4
Tedlar bag	D	0.6	35	75.7	222	7.9	56.50	64.40	5
Tedlar bag	E	4.1	35	66.8	423	3.0	20.30	23.90	4

Table 5.3

Container type	Container ID	ppmv CH2O	ppmv C2H4O	ppmv methanol	ppmv 2-propanol	ppmv ethanol	ppmv propanol
Tedlar bag	A	386	870	63.4	0.593	78.5	BDL
Tedlar bag	B	BDL	1299	678	0.186	1065	15.2
Tedlar bag	C	18.2	590	89.2	2.784	171	6.098
Tedlar bag	D	BDL	941	170	3.031	264	7.648
Tedlar bag	E	BDL	819	389	2.512	634	11.3

Embodiments of the present invention, although relatively uncontained in the bunker, should be environmentally benign. Even so, certain aspects of the present invention fit well with using soil or other media as a biofilter placed around and on the bunkers because the escape of gas from under the tarp is radial in nature. As such, the vapors have a higher amount of surface area in contact with the edges of the pile. In embodiments using a biofilter, vapor phase releases pass through the biofilter (such as soil or compost) placed near the edge mass before entering into the atmosphere. The biofilter retains many potential environmental pollutants and odors released by the storage pile, and it eliminates or greatly reduces the potentially harmful off-gases released from the storage pile.

In one embodiment, the prepared biomass material is stored until it contains no more than about 80 wt% liquid. The prepared biomass material is stored until it contains at least about 4 to about 5% higher than initial content. At this stage, the wet stored biomass aggregate is not considered “beer” yet since it still contains over about 20% solids. In one embodiment, the prepared biomass material is stored until it contains between about 2 wt% and about 50 wt% ethanol, and preferably between about 4 wt% and about 10 wt% ethanol.

The balance of the liquid is primarily water but can contain many other organic compounds, such as acetic acid, lactic acid, etc.

Embodiments of the present invention allow the solid biomass to be harvested in a much shorter harvest window than typical sugar cane juicing operations, which allows for

1) a much larger geographic area where the facilities could be placed,
2) harvest of the crop when the crop has its highest yield potential,
3) harvest of the crop at its highest sugar concentration potential,
4) shorter harvest window still economical, and
5) decoupling the need for taking the juice from the biomass for fermentation.

Certain embodiments may further allow for selection of a crop that is optimal to generate an animal feed that has greater benefits, such as higher starch content, higher ADF content, and better particle size distribution and others as described herein, which may serve as a substantial or complete replacement to forage without the detrimental environmental effects of releasing VOCs into the atmosphere. The additive(s) selected and its/their amount(s), as well as storage conditions, including location and duration, can be adjusted to achieve optimal properties for the feed product without consideration to the amount ethanol generated and/or recovered. That is, in certain embodiments, the focus of the methods and systems described herein may be to generate a feed product of certain properties and not generation and recovery of VOCs.

Once the prepared biomass material has been stored for the desired amount of time and/or contains a desired concentration of volatile organic compounds, such as ethanol, it can be routed to the recovery system for recovery of particular volatile organic compounds. The recovery system and storage facility can be located any distance from one another. Embodiments of systems and methods described herein allow flexibility in the geographical location of both and their locations relative to each other. In a particular embodiment, the recovery system is located about 0.5 to about 2 miles from the storage facility. Any suitable method and/or equipment can be used to transfer the prepared biomass material from the storage facility to the recovery system. In one embodiment, a feed hopper is used. In one embodiment, a silage facer, a front end loader or payloader, a sweep auger or other auger system can be used to place the prepared biomass material into the feed hopper. The material can be placed directly into the feed hopper or it can be

transferred to by conveyer system, such as belt system. The feed hopper containing the prepared biomass material can then be driven to the recovery system.

The recovery system is solventless and uses a superheated vapor stream to vaporize the liquid in the prepared biomass material into a gas component, which can then be collected. A super-heated vapor is a vapor that is heated above its saturation temperature at the pressure of operation. In a preferred embodiment, after the recovery system reaches steady state, the superheated vapor stream comprises only vapor previously evaporated from the prepared biomass material, so that no other gas is introduced, thereby reducing the risk of combustion of the volatile organic compounds and/or dilution of the recovered product stream of volatile organic compounds. The remaining solid component is discharged from the system and can have various subsequent uses. A portion of the vapor is removed as product and the remainder is recycled back for use in transferring heat to fresh incoming prepared biomass material. The super-heated vapor directly contacts the biomass transferring energy and vaporizing the liquid present there. The heat or thermal energy source does not directly contact the prepared biomass material. Thus, the VOC recovery system can also be described as providing "indirect" heat contact.

To provide solventless recovery of volatile organic compounds, the recovery system comprises a compartment that allows superheated vapor to flow in a continuous manner, *i.e.*, as a stream. In one embodiment, the compartment has a loop shape. In another embodiment, the compartment comprises a rotating drum. The compartment has an inlet through which the prepared biomass material can enter. In one embodiment, the inlet comprises a pressure tight rotary valve, plug screw, or other similar device, which can assist in separating the prepared biomass material to increase the surface area exposed to the superheated vapor stream.

In yet another embodiment, the system comprises a dewatering mechanism to remove at least a portion of the liquid in the prepared biomass material before the liquid is vaporized. The liquid removal can occur before and/or while the prepared biomass material enters the compartment. The liquid from the prepared biomass material contains at least one volatile organic compound, which can be recovered by further processing the liquid, such as feeding the liquid to a distillation column. The liquid can be routed directly to further processing unit, such as a distillation column. Alternatively or in addition to, the

system further includes a collection unit to collect the liquid removed from the prepared biomass material. Any portion of the collected liquid can then be further processed.

In one embodiment, the dewatering mechanism comprises a component adapted to squeeze the liquid from the prepared biomass material. In such an embodiment, the squeezing can be performed while the prepared biomass material is being fed into the compartment. For instance, the inlet can comprise a squeezing mechanism to squeeze liquid from the prepared biomass material as it is introduced into the compartment. Alternatively or in addition to, the squeezing can be performed separately before the prepared biomass material enters the compartment. A non-limiting example of such a squeezing mechanism is a screw plug feeder.

In one embodiment, the liquid removal mechanism comprises a mechanical press. Non-limiting examples of types of mechanical presses include belt filter presses, V-type presses, ring presses, screw presses and drum presses. In a particular embodiment of a belt filter press, the prepared biomass material is sandwiched between two porous belts, which are passed over and under rollers to squeeze moisture out. In another particular embodiment, a drum press comprises a perforated drum with a revolving press roll inside it that presses material against the perforated drum. In yet another embodiment, in a bowl centrifuge, the material enters a conical, spinning bowl in which solids accumulate on the perimeter.

The compartment provides a space where the superheated vapor stream can contact the prepared biomass material to vaporize the liquid from the prepared biomass material. The vaporization of at least a portion of the liquid provides a gas component and a solid component of the prepared biomass material. The system further comprises a separating unit where the solid component of the prepared biomass material can be separated from the gas component, so each component can be removed as desired for further processing. In one embodiment, the separating unit comprises a centrifugal collector. An example of such centrifugal collector is high efficiency cyclone equipment. In a preferred embodiment, the separating unit also serves as an outlet for the solid component. For example, the separating unit can discharge the solid component from the solventless recovery system. There is a separate outlet for the gas component where it can exit the system for further processing, such as distillation. In one embodiment, the separating unit is further coupled to a second pressure tight rotary valve or the like to extrude or discharge the solid component. In one embodiment, the superheated vapor is maintained at a target or desired temperature above its saturation temperature by a heat exchange component coupled to a

heat source where the superheated vapor does not contact the heat source. The heat transfer between the heat source and the system occurs via convection to the superheated vapor. In one embodiment, the heat source can include electrical elements or hot vapors through an appropriate heat exchanger. In one embodiment, the operating pressure is in a range from about 1 psig to about 120 psig. In a preferred embodiment, the operating pressure is in a range from about 3 psig to about 40 psig. In a particularly preferred embodiment, the system is pressurized at an operating pressure of about 60 psig to force the vapor component from the system.

In one embodiment, at start up of the recovery system, the prepared biomass material is introduced into the compartment via the inlet. Steam is initially used as the superheated vapor to initially vaporize the liquid in the prepared biomass material. The superheated vapor continuously moves through the compartment. When the prepared biomass material enters the superheated vapor stream, it becomes fluidized where it flows through the compartment like a fluid. As the prepared biomass material is introduced, it comes into contact with the superheated vapor stream. Heat from the superheated vapor is transferred to the prepared biomass material and vaporizes at least a portion of the liquid in the prepared biomass material and is separated from the solid component, which may still contain moisture. The gas component contains volatile organic compound(s) produced in the prepared biomass material. In a preferred embodiment, as liquid from the prepared biomass material begins to vaporize, at least a portion of the vaporized liquid can be recycled in the system as superheated fluid. That is, during any one cycle, at least a portion of the vaporized liquid remains in the compartment to serve as superheated vapor instead of being collected for further processing, until the next cycle where more prepared biomass material is fed into the system.

In a preferred embodiment, during the initial start up procedure, the superheated fluid can be purged as needed, preferably continuously (intermittently or constantly), until steady state is achieved where the superheated vapor comprises only vaporized liquid of the prepared biomass material. The gas component and solid component can be collected via the respective outlet. Heat can be added continuously (intermittently or constantly) to the system via the heat exchanger coupled to the heat source to maintain the temperature of the superheated vapor, to maintain a desired operating pressure in the system, or to maintain a target vaporization rate. Various conditions of the system, such as flow rate of

the superheated vapor stream, pressure, and temperature, can be adjusted to achieve the desired liquid and/or volatile organic compounds removal rate.

In one embodiment, the collected gas component is condensed for further processing, such as being transferred to a purification process to obtain a higher concentration of the volatile organic compound(s) of choice. In a preferred embodiment, the collected gas component is fed directly into a distillation column, which provides savings of energy not used to condense the gas component. In another embodiment, the gas component is condensed and fed to the next purification step as liquid.

In one embodiment, before entering the recovery phase, the prepared biomass material has an initial liquid content of about at least 10 wt% and up to about 80 wt% based on the biomass material. In a particular embodiment, the initial liquid content is at least about 50 wt % based on the biomass material. In one embodiment, the initial liquid content comprises from about 2 to 50 wt%, and preferably from about 4 to 10 wt% ethanol based on the initial liquid content.

In one embodiment, the solid component collected contains from about 5 wt% to about 70 wt%, and preferably from about 30 wt% to about 50 wt%, liquid depending on the ethanol removal target. In another component, the collected gas component contains between about 1 wt% and about 50 wt% ethanol, preferably between about 4 wt% and about 15 wt% ethanol. In one embodiment, the recovery system recovers from about 50% to about 100% of the volatile organic compounds contained in the prepared biomass material. The residence time of the prepared biomass varies based on a number of factors, including the volatile organic compound removal target. In one embodiment, the residence time of the prepared biomass material in the compartment is in a range of about 1 to about 10 seconds. In one embodiment, the recovery system can be operated between about 0.06 barg and about 16 barg. The term "barg" refers to bar gauge as understood by one of ordinary skill in the art, and 1 bar equals to 0.1 MegaPascal. In one embodiment, the gas in the recovery system has a temperature in a range of about 100 °C to about 375 °C, particularly from about 104 °C to about 372 °C, and the solid component exiting the system has a temperature of less than about 50 °C. In a preferred embodiment, the collected solid component can serve as an embodiment of the animal feed described herein. The solid component can also be used in other applications. Non-limiting examples include feed for a biomass burner to supply process energy or generate electricity.

The operating conditions of the solventless recovery system include at least temperature, pressure, flow velocity, and residence time. Any one or combination of these conditions can be controlled to achieve a target or desired removal target, such as the amount of the initial liquid content removed or the amount of the liquid remaining in the separated liquid component exiting the recovery system. In one embodiment, at least one operating condition is controlled to achieve removal of about 10-90 wt%, preferably about 45-65 wt%, and more preferably about 50 wt%, of the initial liquid content.

In a preferred embodiment, increasing the temperature of the system at constant pressure will cause the liquid in the biomass to be vaporized more quickly and thus for a given residence time will cause a higher percentage of the liquid in the biomass to be evaporated. The vapor flow rate exiting the system has to be controlled to match the rate of vaporization of liquid from the biomass in order to achieve steady state and can also be used as a mechanism to control the system pressure. Increasing the system pressure will cause more energy to be stored in the vapor phase in the system which can then be used to aid in further processing or to help move the vapor to the next downstream processing unit. Increasing the biomass residence time in the system causes more heat to be transferred from the vapor phase to the biomass resulting in more liquid being vaporized.

In a specific exemplary embodiment, the recovery system comprises a closed loop pneumatic superheated steam dryer, which can be obtained from commercially available sources. In one embodiment, the closed loop pneumatic superheated steam dryer is an SSD™ model of GEA Barr-Rosin Inc. Other suitable commercially available equipment include the Superheated Steam Processor, SSP™ from GEA Barr-Rosin Inc, the Ring Dryer from several companies including GEA Barr-Rosin Inc. and Dupps; the Airless Dryer from Dupps; the QuadPass™ Rotary Drum Dryer from DuppsEvactherm™, Vacuum Superheated Steam Drying from Eirich; the rotary drum dryer using superheated vapor from Swiss Combi Ecodry; and the airless dryer from Ceramic Drying Systems Ltd.

Still other types of indirect dryers that could serve as the volatile organics recovery unit for this process are batch tray dryers, indirect-contact rotary dryers, rotating batch vacuum dryers, and agitated dryers. The basic principle for these dryers is that they will be enclosed and attached to a vacuum system to remove vapors from the solids as they are generated (also by lowering the pressure with the vacuum the volatiles are removed more easily). The wet solids contact a hot surface such as trays or paddles, the heat is transferred

to the wet solids causing the liquids to evaporate so they can be collected in the vacuum system and condensed.

FIG. 1 illustrates an exemplary VOC recovery system and process employing a superheated steam dryer, referenced as system 100. In a particular embodiment, the superheated steam dry can be obtained from GEA Barr-Rosin Inc. In FIG. 1, prepared biomass material 1 containing ethanol and/or other VOCs following solid state fermentation in the silage piles is fed into compartment 3 through input 2. In the particular embodiment shown, input 2 comprises a screw extruder. As shown in FIG. 1, at least a portion of the liquid of the prepared biomass material 1 is removed prior to entering compartment 3. The dewatering mechanism can be a screw plug feeder through which the prepared biomass material 1 passes. At least a portion of the liquid removed from biomass material 1 can be routed directly to distillation step 11 via stream 15 without going through recovery system 100. Optionally, a delumper can be coupled to the output of the dewatering mechanism can be used to facilitate introduction of the dewatered biomass material into compartment 3.

Referring to FIG. 1, recovery system 100 comprises compartment 3, which can be pressurized, shown as a conduit that has an appropriate diameter, length and shape, adapted to provide the desired operating conditions, such as residence time of prepared biomass material 1, heat transfer to the superheated vapor, and operating pressure and temperature. After entering compartment 3, during steady state operation, prepared biomass material 1 contacts superheated vapor flowing through system 100 at a desired or target temperature and becomes fluidized. As described above, in a preferred embodiment, the superheated vapor, or at least a portion thereof, is vapor component obtained from prepared biomass materials previously fed into system 100 for VOC recovery. The fluidized biomass flows through compartment 3 at a target flow rate and remains in contact with the superheated vapor for a target residence time sufficient to evaporate the desired amount of liquid from prepared biomass material 1. In the embodiment shown, the flow of the superheated vapor and prepared biomass material 1 through system 100 is facilitated by system fan 14. System 100 can have one or more fans. The flow rate or velocity of the superheated vapor and biomass material 1 can be controlled by system fan 14. Biomass material 1 flows through compartment 3 and reaches separating unit 4, which is preferably a cyclone separator, where a vapor component and a solid component of biomass material 1 are

separated from each other. As shown, the vapor component is routed away from the solid component via overhead stream 5 and the remaining portion of biomass material 1 is considered a solid component, which is discharged from separating unit 4 as solid component 7, preferably by screw extruder 6. At least a portion of the discharged solid component 7 can be used as animal feed as described according to aspects of the invention.

Referring to FIG. 1, a portion of the vapor component, referenced as stream 8, is retained and recycled as a portion of the superheated vapor used to vaporize newly introduced prepared biomass material. In the embodiment shown, the retained vapor component in stream 8 is routed through heat exchanger 9 to heat it to the target operating temperature. The heat source can include steam, electricity, hot flue gases or any other applicable heating source known to those skilled in the art.

In a preferred embodiment, the temperature is controlled such that the pressure in the system is maintained at the target and there is adequate energy present to evaporate the desired amount of liquid. The pressure can also be controlled by the flow rate of the superheated vapor stream and the heat input to heat exchanger 9. Preferably, recovery system 100 operates continuously where prepared biomass material 1 is continuously fed at a desired rate, and vapor component 10 and solid component 6 are continuously removed at a continuous rate. In a preferred embodiment, "fresh" vapor component 8 from one run is retained continuously at a target rate to be used as the superheated vapor stream for the next run. Any of these rates are adjustable to achieve the desired operating conditions. As mentioned, system fan 14 circulates the superheated vapor stream through system 100 and can be adjusted to obtain the target flow rate or velocity.

Referring to FIG. 1, the remaining portion of vapor component stream 5, represented as numeral 10 is routed to a distillation step 11. Depending on the distillation configuration, vapor component portion 10 may be condensed before further purification or preferably fed directly into the distillation column as a vapor. In a preferred embodiment, the distillation product from distillation step 11 has an ethanol content of about 95.6 wt% ethanol (the ethanol/water azeotrope), which can further be purified to above about 99 wt% using common ethanol dehydration technology, which is shown as step 12. The final ethanol product 13 will then typically be used as a biofuel for blending with gasoline.

FIG. 2 illustrates another exemplary recovery system and process employing a superheated steam dryer, referenced as system 200 that is representative of the Ring Dryer provided by various manufacturers. Prepared biomass material 201 is fed into system 200 through input 202, which preferably comprises a screw extruder. In one embodiment, least a portion of the liquid of the prepared biomass material 201 is removed prior to entering system 200. The dewatering mechanism can be a screw plug feeder through which the prepared biomass material 201 passes. At least a portion of the liquid removed from biomass material 201 can be routed directly to distillation step 211 via stream 215 without going through recovery system 200. Optionally, a delumper can be coupled to the output of the dewatering mechanism can be used to facilitate introduction of the dewatered biomass material into compartment 203.

Referring to FIG. 2, recovery system 200 comprises compartment 203, which preferably comprises a rotating drum that provides the target operating conditions for VOC recovery, including residence time of prepared biomass material 201, heat transfer to the superheated vapor, and operating pressure and temperature. After entering compartment 203, during steady state operation, prepared biomass material 201 contacts superheated vapor flowing through system 200 at the operating temperature and flow rate and becomes fluidized. As described above, in a preferred embodiment, the superheated vapor, or at least a portion thereof, is the vapor component obtained from prepared biomass material previously fed into system 200 for VOC recovery. The fluidized biomass flows through compartment 203 at a target flow rate and remains in contact with the superheated vapor for the target residence time to achieve the target vaporization of liquid from the biomass. The fluidized biomass then reaches separating unit 204, which is preferably a cyclone separator, where the vapor component and solid component are separated from each other. As shown, the vapor component is routed away from the solid component through overhead stream 205, and solid component 207 is discharged from separating unit 204 and can be used as an animal feed product according to aspects of the invention. As shown, solid component 207 exits system 100 via extruder 206. A portion of the vapor component, referenced as stream 208, is retained and recycled as a portion of the superheated vapor used to vaporize newly introduced prepared biomass material. As shown, retained vapor component 208 is routed through heat exchanger 209 to heat it to the desired or target temperature. The heat source or thermal energy source can include

steam, electricity, hot flue gases or any other desired heating source. As shown, hot flue gas is used. The temperature is controlled such that the pressure in the system is maintained at the target and there is adequate energy present to evaporate the desired amount of liquid. The pressure can also be controlled by the flow rate of the superheated vapor stream and the heat input to heat exchanger 209.

Referring to FIG. 2, the remaining portion of vapor component stream 205, represented as numeral 210 is routed to a distillation step. Depending on the distillation configuration, vapor component portion 210 may be condensed before further purification or preferably fed directly into the distillation column as a vapor. The product from the distillation step can further be concentrated using known processes.

Preferably, recovery system 200 operates continuously where prepared biomass material 201 is continuously fed at a desired rate, and vapor component 210 and solid component 206 are continuously removed at a continuous rate. In a preferred embodiment, "fresh" vapor component 208 from one run is retained continuously at a target rate to be used as the superheated vapor stream for the next run. All these rates are adjustable to achieve the desired operating conditions. System fan 214 creates a circulating loop of superheated vapor stream and can be adjusted to obtain the target flow rate.

In certain embodiments, the solventless recovery system as described herein may further include a dryer to remove additional moisture from the solid component to achieve a certain moisture level as animal feed. In addition to or alternatively, the dryer can be at another location other than where the solventless recovery unit is located. Any suitable dryer known to those skilled in the art can be used. In various embodiments, further processing of the solid component such as addition of one or more feed additives, pelletization, etc. may subsequently occur near the storage facility and/or or the solid component can be transported to another location for processing to become the final animal feed product. In certain embodiments, further processing of the solid component may not be necessary, and the solid component can serve as the final animal feed product.

By using a solventless recovery system according to aspects of the present invention, the points of heat transfer in the system, *i.e.*, addition of heat to the system and heat transfer to the prepared biomass material, take place in the vapor phase in a preferred embodiment, which provides an advantage cause vapor phase heat transfer (convection) is more efficient than solid phase heat transfer (conduction) in the prepared biomass material,

which is a bad conductor because it has insulating properties. As mentioned above, in certain embodiments, once steady state is reached no vapor other than that vaporized from the liquid of the prepared biomass material contacts the solid component and gas component of the prepared biomass material in the system, which prevents or reduces dilution that would come from the addition of process steam or other vapor to replenish the superheated vapor stream. The collected gas component can be fed directly to a distillation column for separation of the desired volatile organic compound(s), which can provide significant energy savings. The advantage of this system is that the vapors that contact the wet solids are only those vapors that have been previously removed from the solids so that there is no dilution or explosion risk, etc.

The following examples are presented to further illustrate the invention, but they are not to be construed as limiting the scope of the invention.

ILLUSTRATIVE EMBODIMENTS

Example A

In this example, various samples of fresh chopped sorghum are mixed with a variety of added components as listed in Table A.1. The addition rates of the additives are shown in Table A.2. Table A.3 shows the initial amount of ADF, starch, and sulfur (S), and the amounts about 11 days after storage for these samples in wt%. These values are on a 100% dry matter basis. The sampling period is after the majority of conversion of fermentable sugar (*e.g.*, fermentation) has completed.

Table A.1

2010 Experiments	WITHOUT ACID	WITHOUT ACID	WITHOUT ACID	WITHOUT ACID	WITHOUT ACID	WITH ACID	WITH ACID	WITH ACID	WITH ACID
Experiment #	1	2	3	4	5	6	7	8	9
Estimated Mass	20 tonnes	20 tonnes	20 tonnes	20 tonnes	20 tonnes	20 tonnes	20 tonnes	20 tonnes	20 tonnes
Moisture Content	68%	68%	68%	68%	68%	68%	68%	68%	68%
Storage Method	Silage Tube	Silage Tube	Silage Tube	Silage Tube	Silage Tube	Silage Tube	Silage Tube	Silage Tube	Silage Tube
Primary Yeast	Ethanol Red	Ethanol Red	Ethanol Red	Ethanol Red	Ethanol Red	Ethanol Red	Ethanol Red	Ethanol Red	Ethanol Red
Helper Yeast			BioSaf	BioSaf	BioSaf			BioSaf	BioSaf
Bacterial Inhibitor	Lactrol	Lactrol	Lactrol	Lactrol	Lactrol	Lactrol	Lactrol	Lactrol	Lactrol
Cellulose to Glucose		Cellulase CE-2		Cellulase CE-2	Cellulase CE-2		Cellulase CE-2	Cellulase CE-2	Cellulase CE-2
Starch to Glucose		Amylase		Amylase	Amylase		Amylase	Amylase	Amylase
Other enzyme activities: accessory enzymes					Liquicell 2500				Liquicell 2500

WO 2013/173560 PCT/US2013/041306
CA 02873292 2014-11-10

Table A.2

ADDITIVE Rates		
LACTROL	1.6	g/wet tonne
Ethanol Red	0.11	kg/wet tonne
BioSaf	0.11	kg/wet tonne
Cellulase CE-2	0.22	kg/wet tonne
Amylase	0.11	kg/wet tonne
Liquicell	0.11	kg/wet tonne
93% Concentrated Sulfuric Acid	0.42	L/wet tonne

Table A.3

Experiment #	**% ADF**	**% STARCH**	**% S**
T = 0	21.95	20.88	0.04
T = 0	23.3	18.28	0.04
1	35.28	12.02	0.06
2	33.39	13.26	0.06
3	30.58	12.97	0.07
4	26.54	17.55	0.06
5	25.04	15.6	0.05
6	31.95	13.45	0.14
7	30.65	14.4	0.15
8	31.1	14.41	0.15
9	29.96	16.04	0.13

As can be seen, the amount of ADF in the prepared biomass of Experiments 1 – 9 is greater than 20 wt%, ranging from about 25 wt % to about 35 wt%, which is an increase from the initial amount of from about 22 wt% to about 23 wt%. The amount of starch in the prepared biomass of Experiments 1 – 9 is greater than 10 wt%, ranging from about 12 wt% to about 18

wt%. While there are various decreases in the amount of starch from the initial amount at T = 0 from about 18 wt% to 21 wt%, the starch values of Experiments 1 – 9 show that the conditions of embodiments of the invention can be adjusted to optimize preservation of starch through the conversion process. The amount of sulfur in the prepared biomass of Experiments 1 – 9 is less than about 0.40 wt%, ranging from about 0.05 wt% to about 0.15 wt%.

Example B

In Example B, additional experiments were conducted using various types of sorghum under conditions shown in Table B.1 and addition rates of the additives shown in Table B.2. Table B.3 shows the amount of ADF, starch, and sulfur after more than at least one month in storage. These experiments were conducted in a bunker demonstrating that certain embodiments of the invention can be efficient at commercial scale. Two samples of some experiments of stored prepared biomass were collected, from the top and from the bottom of the bunker, which are indicated as such in Table B.3 where available.

Table B.1

2011 Experiments	WITH ACID
Estimated Mass	450 tonnes
Moisture Content	76%
Storage Method	Bunker
Yeast	Lallemand Liquid Yeast
Bacterial Inhibitor	Lactrol
Cellulose to Glucose	Novozymes Cellic CTec2
Chop Size	3 mm

Table B.2

ADDITIVE	Rates
LACTROL	3.2 g/wet ton
Lallemand Stabilized Liquid Yeast	18 fl oz/wet ton
Novozymes Cellic CTec2	20 fl oz/wet ton
9.3% Concentrated Sulfuric Acid	3.8 L/wet ton

Table B.3

Experiment #	% ADF	% STARCH	% S
10 Top	32.26	21.45	0.06
10 Bottom	34.42	21.45	0.06
11 Top	29.74	20.5	0.05
11 Bottom	32.01	20.13	0.06
12 Top	31.8	16.48	0.06
13 Top	32.07	16.84	0.06
13 Bottom	30.81	16.87	0.06
14 Top	30.54	17.73	0.11
14 Bottom	29.92	15.66	0.14
15 Top	31.62	16.81	0.15
15 Bottom	31.81	16.5	0.14
16 Top	31.82	20.36	0.13
16 Bottom	30.76	20.85	0.13

The experiments of Example B the effects of scale, as well as the fact that certain type of plant can be selected to provide higher amounts of starch, which remains in the biomass even after most conversion activity has been completed. The experiments also demonstrate that the ADF and sulfur amounts remain above 20 wt% and below 0.40 wt%, respectively.

Example C

In these experiments, other types of sorghum which are different from the sorghum variety of Examples A and B were used. This particular type of sorghum was subject to conditions shown in Table B.1 and addition rates of the additives shown in Table B.2 above. Further, some of the experiments were devolatilized using the GEA SSD™ as the solventless recovery unit. Table C.1 below shows the amount of ADF, starch, and sulfur for both

experiments that have not been subject the VOC recovery process (no indication) and devolatilized experiments (indicated as “Devolatilized”).

Table C.1

Experiment #	% ADF	% STARCH	% S
17 (Devolatilized)	42.48	1.86	0.2
18 (Devolatilized)	42.92	3.01	0.16
19 (Devolatilized)	41.85	2.93	0.16
20 (Devolatilized)	43.59	3.01	0.19
21	39.81	3.45	0.16
22	37.8	3.41	0.18

These experiments demonstrate that the effect of devolatilization according to aspects of this invention does not significantly affect the ADF, starch, and sulfur value. For example, the amount of ADF does not significantly increase between Experiments 21 – 22 and devolatilized Experiments 17 – 20. While the starch values are low in these experiments, this is not due to the fermentation or devolitalization process. Instead, this is because the selected crop has a low initial amount of starch. These experiments demonstrate that the devolatilization process does not significantly reduce the starch amount. Likewise, the amount of sulfur is not signifantly increased by devolitalization.

Further modifications and alternative embodiments of various aspects of the invention will be apparent to those skilled in the art in view of this description. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the general manner of carrying out the invention. It is to be understood that the forms of the invention shown and described herein are to be taken as the presently preferred embodiments. Elements and materials may be substituted for those illustrated and described herein, parts and processes may be reversed, and certain features of the invention may be utilized independently, all as would be apparent to one skilled in the art after having the benefit of this description of the invention. Changes may be made in the elements described herein without departing from the spirit and scope of the invention as described in the following claims.

CLAIMS

1. An animal feed product comprising:

a plant material that has been devolatilized and comprises less than about 0.4 wt % sulfur.

2. The animal feed product of claim 1 further comprising at least about 20 wt % acid detergent fiber (ADF).

3. The animal feed product of claim 1 further comprising at least about 10 wt % starch.

4. The animal feed product of claim 1 further comprising a particle size distribution of about 3 mm to about 80 mm.

5. The animal feed product of claim 1 wherein the plant material consists essentially of vegetative material.

6. The animal feed product of claim 1 wherein the plant material is selected from the following miscanthus, switchgrass, hemp, tropical poplar, willow, sorghum, sugarcane, sugar beet, any energy cane, and any combination thereof.

7. A method to produce an animal feed product comprising:

generating a prepared biomass material by adding at least one additive to a solid biomass comprising a sugar, wherein said at least one additive comprise a microbe, and optionally, an acid and/or an enzyme;

storing the prepared biomass material for at least about 24 hours in a storage facility to allow for the production of at least one volatile organic compound from at least a portion of the sugar;

capturing the at least one volatile organic compound by feeding the stored biomass material to a solventless recovery system to separate the stored biomass material into at least a gas component comprising the at least one volatile organic compound and a solid component; and

removing the solid component from the solventless recovery system for use as an animal feed product.

8. The method of claim 7 wherein the animal feed product comprises less than about 0.4 wt % sulfur.

9. The method of claim 7 wherein the animal feed product comprises at least about 20 wt % acid detergent fiber (ADF).

10. The method of claim 7 wherein the animal feed product comprises at least about 10 wt % starch.

11. The method of claim 7 wherein the animal feed product comprises a particle size distribution of about 3 mm to about 80 mm.

12. The method of claim 7 wherein the solid biomass consists essentially of vegetative material.

13. The method of claim 7 further comprising drying the solid component to further remove moisture.

14. The method of claim 7 further comprising densifying the solid component to increase the density of the animal feed product.

15. The method of claim 14 wherein the densifying comprises pelletizing the solid component.

16. The method of claim 7 further comprising cutting a fermentable sugar producing crop to fragments having a particle size distribution from about 3 mm to about 80 mm to use as the solid biomass.

17. The method of claim 7 wherein the capturing step comprises:

introducing the prepared biomass material to a compartment of a solventless recovery system, wherein the prepared biomass material contains one or more volatile organic compounds;

contacting the prepared biomass material with a superheated vapor stream in the compartment to vaporize at least a portion of an initial liquid content in the prepared biomass material, said superheated vapor stream comprising at least one volatile organic compound;

separating a gas component and a solid component from the prepared biomass material, said gas component comprising at least one volatile organic compound; and

retaining at least a portion of the gas component for use as part of the superheated vapor stream.

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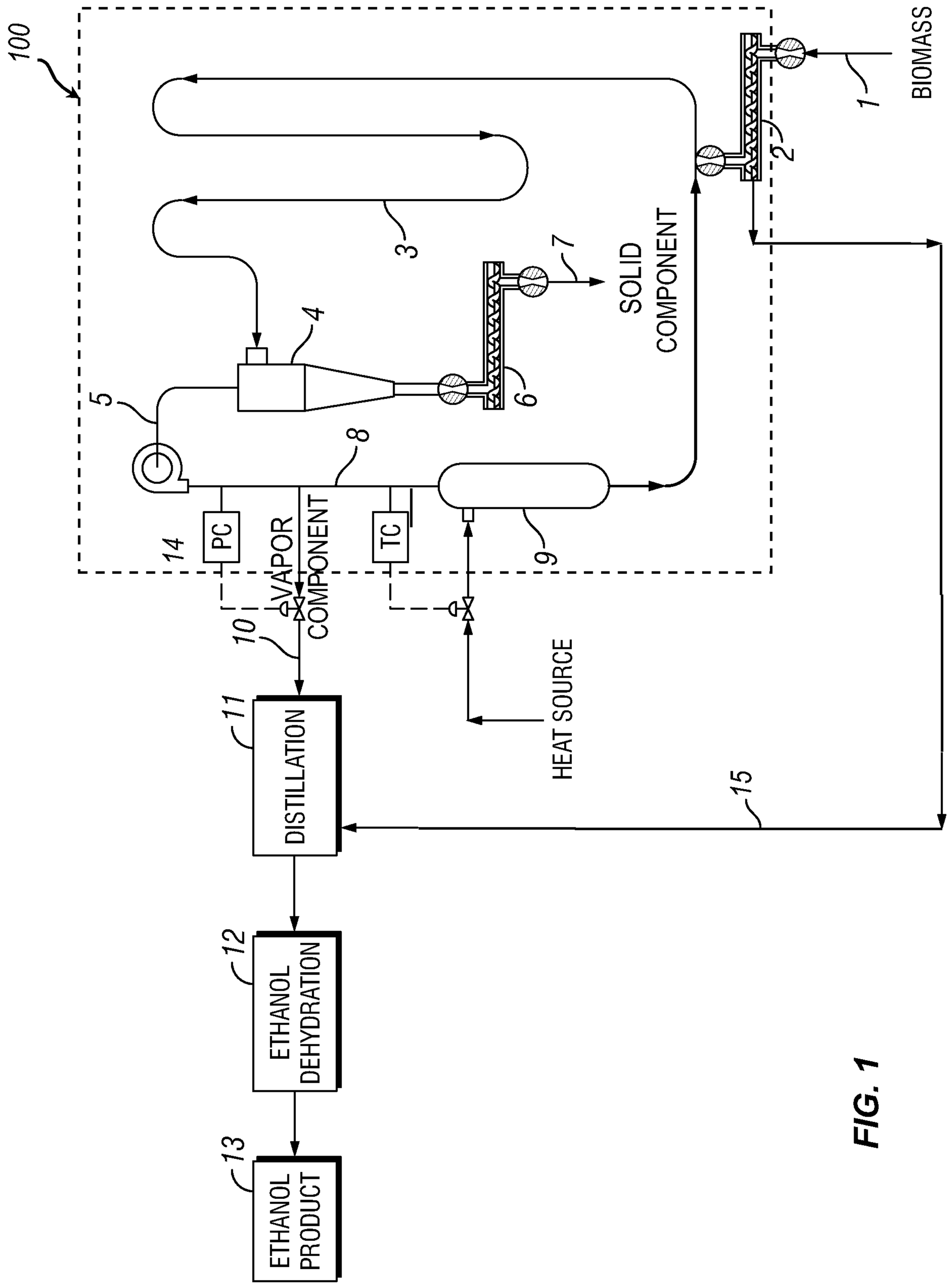
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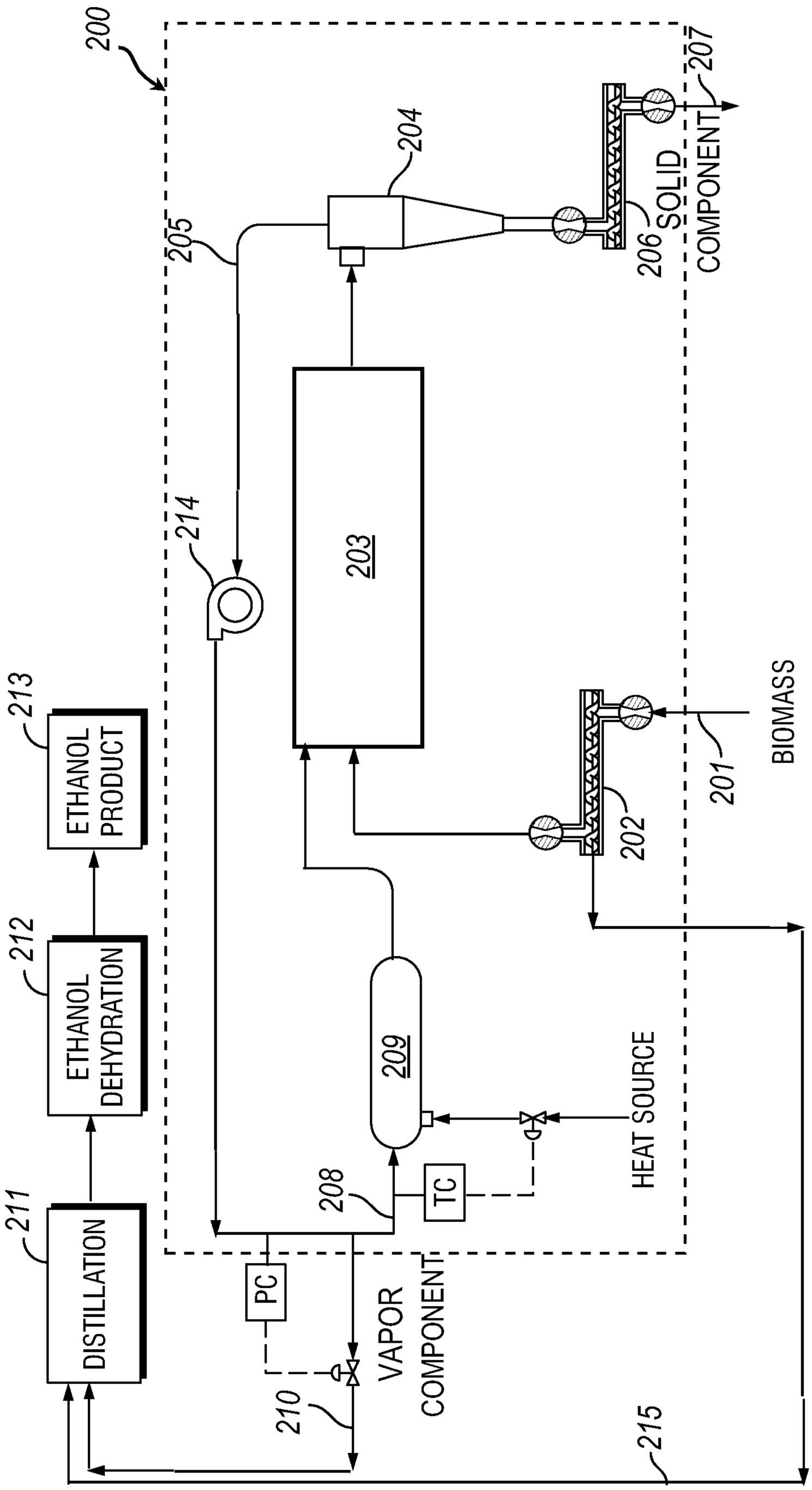
3
4
5
6
7
SOLID COMPONENT
8
9
PC
14
VAPOR COMPONENT
TC
10
HEAT SOURCE
11
DISTILLATION
15
12
ETHANOL DEHYDRATION
13
ETHANOL PRODUCT

FIG. 1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204
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ETHANOL PRODUCT
212
ETHANOL DEHYDRATION
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DISTILLATION
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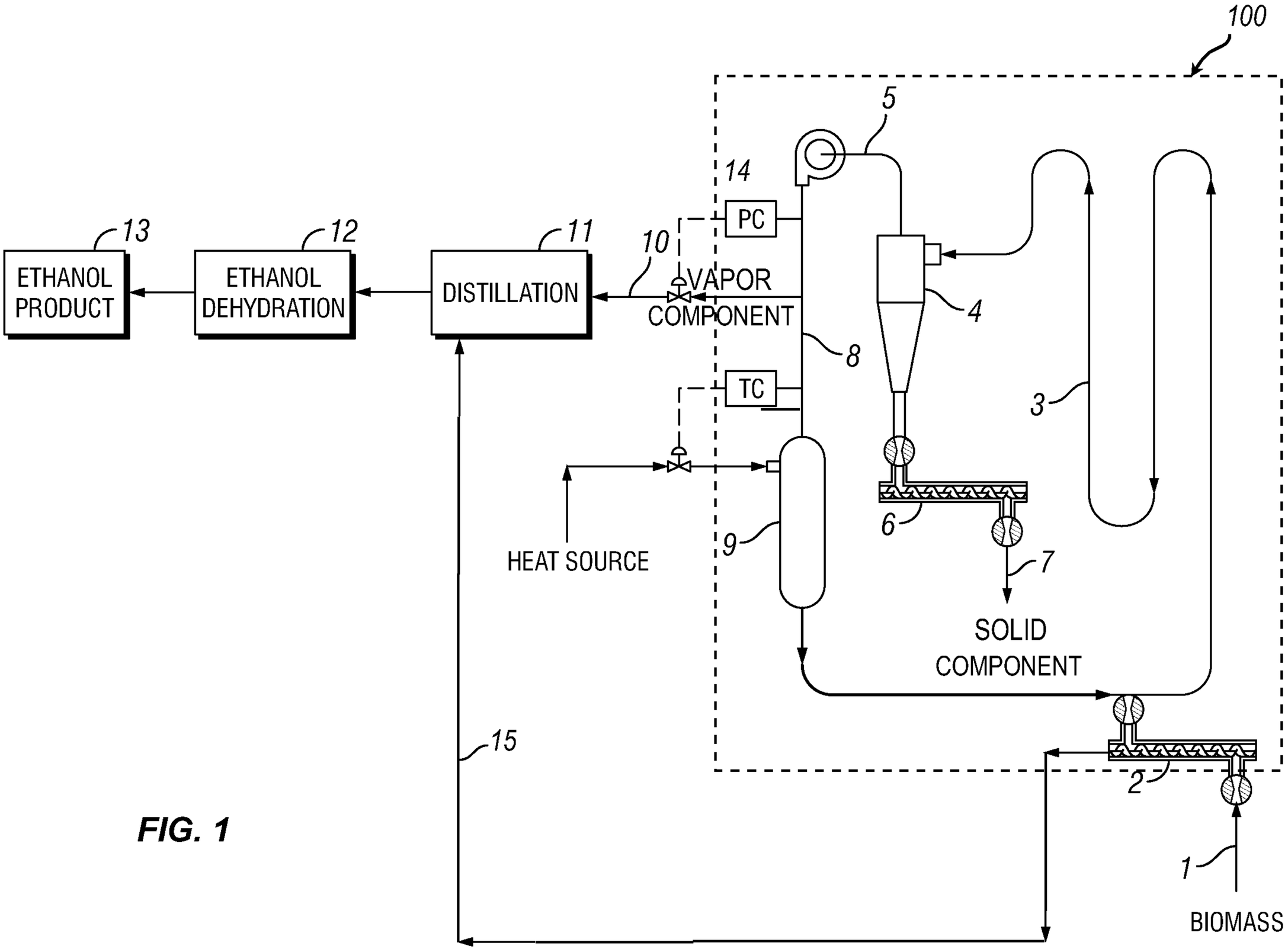
208
TC
PC
210
VAPOR COMPONENT
HEAT SOURCE
202
201
BIOMASS
215

FIG. 2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PC
13
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11
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ETHANOL DEHYDRATION
DISTILLATION
VAPOR COMPONENT
4
8
TC
3
6
9
7
HEAT SOURCE
SOLID COMPONENT
15
2
1
BIOMASS

FIG. 1