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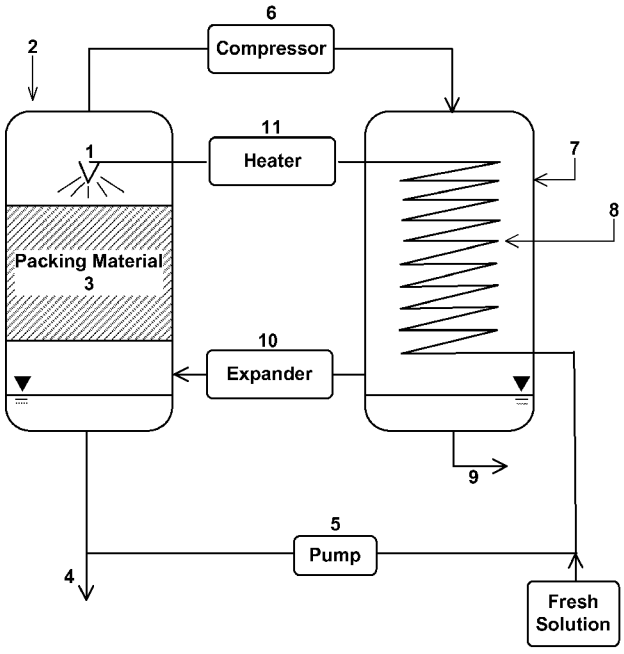
(54) Title: SUGAR SEPARATION AND PURIFICATION FROM BIOMASS

FIG. 3



(57) Abstract: Provided are methods and systems using polymeric catalysts for non-enzymatic saccharification and a humidification-dehumidification process for refining saccharide streams produced from biomass. Also provided are methods and systems for decreasing one or more undesirable products during pretreatment.

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SUGAR SEPARATION AND PURIFICATION FROM BIOMASS

CROSS-REFERENCE

[0001] This application claims the benefit of U.S. Provisional Application No. 61/827,231, filed May 24, 2013, which application is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] Biomass-derived sugars are increasingly used to replace petroleum-based products such as fuels and plastics. To compete, however, these sugars must be produced efficiently and economically. It is a difficult process to release and separate carbohydrates from lignocellulosic biomass, and the enzymes necessary to reduce the carbohydrate polymers to hexose and pentose monomers are expensive. Water recovery adds to this cost.

[0003] In addition, inhibitors such as acetic and formic acids, as well as hydroxymethylfurfural (HMF), phenolics, and furfural are formed during the process. To reduce the amounts of these inhibitors, expensive separation and clarification techniques can be required. This refinement may be only partially effective and can increases the cost of the sugars due to the high cost of evaporation later to concentrate the sugars.

[0004] There is a great need to improve the process of extracting sugars from biomass; especially the steps that can reduce the costs of the overall product without sacrificing yields.

SUMMARY

[0005] Disclosed herein are humidification:dehumidification processes for removing one or more inhibitors from a saccharide stream, the processes comprising: (a) contacting in a counter-current manner the saccharide stream with a carrier gas at a first temperature and a first pressure to produce a humidified gas, wherein at least a portion of the one or more inhibitors is transferred from the saccharide stream to the humidified gas; (b) separating the humidified gas from the saccharide stream; (c) dehumidifying the humidified gas at a second temperature and a second pressure to condense the one or more fermentation inhibitors; and (d) recovering the saccharide stream, wherein the saccharide stream comprises a lower level of the one or more inhibitors.

[0006] The one or more inhibitors can comprise acetic acid, formic acid, furfural, hydrozymethylfurfural, sulfuric acid, peroxyacetic acid, lactic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, or a combination thereof. In some embodiments, the one or more inhibitors comprise acetic acid. In some embodiments, the one or more

inhibitors comprise formic acid. In some embodiments, the one or more inhibitors comprise acetic acid and formic acid.

[0007] The carrier gas can comprise air, nitrogen, argon, carbon dioxide, or a combination thereof. In some embodiments, the carrier gas is air. In some embodiments, the carrier gas is nitrogen.

[0008] The first temperature can be at least about 4°C lower than the second temperature. In some embodiments, the first temperature is at least about 10°C lower than the second temperature.

[0009] The first temperature can be about 4°C to about 90°C lower than the second temperature. In some embodiments, the first temperature is about 10°C to about 70°C lower than the second temperature. In some embodiments, the first temperature is about 15°C to about 50°C lower than the second temperature.

[0010] The first temperature can be about 4°C to about 100°C. In some embodiments, the first temperature is about 10°C to about 70°C. In some embodiments, the first temperature is about 15°C to about 50°C.

[0011] The second pressure can be at least about 1.1 times higher than the first pressure. In some embodiments, the second pressure is at least about 1.5 times higher than the first pressure. In some embodiments, the second pressure is at least about 2.0 times higher than the first pressure.

[0012] The first pressure can be about 10 kPa to about 100 kPa. In some embodiments, the first pressure is about 20 kPa to about 60 kPa.

[0013] After recovering the saccharide stream, the process can be repeated one or more additional times with the recovered saccharide stream.

[0014] The process can further comprise dissolving a salt in the saccharide stream prior to contacting. In some embodiments, the salt comprises LiBr, NaCl, KCl, or a combination thereof. In some embodiments, the salt comprises LiBr.

[0015] The process can further comprise, after recovering the saccharide stream, separating the salt from the saccharide stream. In some embodiments, separating the salt from the saccharide stream comprises filtration.

[0016] At least about 10% of the one or more inhibitors can removed from the saccharide stream during contacting. In some embodiments, at least about 25% of the one or more inhibitors is removed from the saccharide stream. In some embodiments, at least about 50% of the one or more inhibitors is removed from the saccharide stream. In some embodiments, at least about 75% of the one or more inhibitors is removed from the saccharide stream.

[0017] Contacting the saccharide stream and the carrier gas can be performed in a humidification chamber. In some embodiments, the humidification chamber comprises packing material. In some embodiments, the packing material comprises polyvinyl chloride packing.

[0018] The saccharide stream can be introduced into a top portion of the humidifying chamber.

[0019] The first temperature can be an average temperature in the humidifying chamber.

[0020] The carrier gas can be introduced into a bottom portion of the humidification chamber.

[0021] Contacting the saccharide stream and the carrier gas can comprise spraying the saccharide stream with a spray nozzle.

[0022] Dehumidifying the humidified gas can occur in a dehumidifying chamber. In some embodiments, the second temperature is an average temperature in the dehumidifying chamber.

[0023] A compressor can be used to transfer the humidified gas from the humidifying chamber to the dehumidifying chamber.

[0024] An expander can be used to transfer the carrier gas from the dehumidifying chamber to the humidifying chamber after the one or more fermentation inhibitors are condensed out of the humidified gas.

[0025] The saccharide stream can be piped through the dehumidifying chamber to effect a heat transfer from the humidified gas to the saccharide stream.

[0026] A heater can be used to increase the temperature of the saccharide stream before contacting with the carrier gas.

[0027] The saccharide stream can comprise C5 saccharides, C6 saccharides, or a combination thereof. In some embodiments, the C5 saccharides comprise xylose, arabinose, or a combination thereof. In some embodiments, the C6 sugars comprise glucose, mannose, galactose, rhamnose, or a combination thereof. In some embodiments, the saccharide stream comprises glucose, mannose, galactose, rhamnose, xylose, arabinose, or a combination thereof.

[0028] The saccharide stream can have been produced by pretreating or hydrolyzing a biomass composition comprising cellulose, hemicellulose, or lignocellulose. In some embodiments, the biomass composition comprises alfalfa, algae, bagasse, bamboo, corn stover, corn cobs, corn kernels, corn mash, corn steep liquor, corn steep solids, distiller's grains, distiller's dried solubles, distiller's dried grains, condensed distiller's solubles, distiller's wet grains, distiller's dried grains with solubles, eucalyptus, food waste, fruit peels, garden residue, grass, grain hulls, modified crop plants, municipal waste, oat hulls, paper, paper pulp, prairie bluestem, poplar, rice hulls, seed hulls, silage, sorghum, straw, sugarcane, switchgrass, wheat, wheat straw, wheat bran, de-starched wheat bran, willows, wood, plant cells, plant tissue cultures, or a combination thereof.

[0029] Pretreating or hydrolyzing can comprise mechanical size reduction, hot water treatment, acid treatment, base treatment, steam explosion, acid-catalyzed steam explosion, ammonia fiber/freeze explosion, enzymatic hydrolysis, catalytic peptide hydrolysis, ionic liquid dissolution, or a combination thereof.

[0030] Pretreating or hydrolyzing can comprise mechanical size reduction, acid treatment, and hydrolysis with one or more enzymes or one or more polymeric catalysts.

[0031] Pretreating or hydrolyzing can comprise treating the biomass composition with hot water or dilute acid to solubilize hemicellulose, substantially separating the solubilized hemicellulose from remaining lignocellulose solids, and hydrolysis of the remaining lignocellulose solids with one or more enzymes or polymeric catalysts.

[0032] Pretreating or hydrolyzing can comprise ionic liquid dissolution with [bmim] 1-butyl-3-methylimidazolium, [emim] 1-ethyl-3-methylimidazolium, [amim] 1-allyl-3-methylimidazolium, [Ch] cholinium, [bzmim] 1-benzyl-3-methylimidazolium, [HEA] 2- hydroxyethylammonium, [bmpy] 1-butyl-3-methylpyridinium, [Me(OEt)3Et3N] triethyl-(2-(2-methoxyethoxy)ethoxy) ethylammonium, [DMEA] N,N-dimethylethanolammonium, [mmim] 1,3-dimethylimidazolium, [hmim] 1-hexyl-3-methylimidazolium, [pmim] 1-propyl-3-methylimidazolium, [abim] 1-allyl-3-butylimidazolium, [eMeOHpy] 1-ethyl-3-(hydroxymethyl)pyridine, [bHim] 1-butylimidazolium, [Cl] chloride, [CH3COO] acetate, [Et2PO4] diethylphosphate, [Me2PO4] dimethylphosphate, [MeOSO3] methylsulphate, [OTf] trifluoromethanesulphonate, [PrOO] propionate, [CF3COO] trifluoroacetate, [MeSO3] methanesulphonate, [HSO4] hydrogen sulphate, [PO(O)H2] phosphinate, [HCOO] formate, [BF4] tetrafluoroborate, [PF6] hexafluorophosphate, [Lys] lysinate, [Gly] glycinate, [Ala] alaninate, [Ser] serinate, [Thr] threoninate, [Met] methioninate, [Pro] prolinate, [Phe] phenylalaninate, [OHCH2COO] glycolate, [(CH2COO)2] succinate, [ABS] alkylbenzenesulphonate, [XS] xylenesulphonate, [MePO3] methylphosphonate, [EtPO3] ethylphosphonate, [i-PrPO3] i-propylphosphonate, [BuPO3] butylphosphonate, [NTf2] bis(trifluoromethylsulfonyl)amide, [EtOSO3] ethylsulphate , or a combination thereof.

[0033] Also provided herein are saccharide streams produced by any of the humidification:dehumidification processes disclosed herein.

[0034] Also disclosed herein are humidification:dehumidification systems for removing one or more inhibitors from a saccharide stream, the systems comprising: (a) a saccharide stream comprising one or more inhibitors; (b) a carrier gas; (c) a humidification chamber containing packing material for contacting in a counter-current manner the saccharide stream with the

carrier gas to produce a humidified gas, wherein at least a portion of the one or more inhibitors is transferred from the saccharide stream to the humidified gas; and (d) a dehumidification chamber at a second temperature and pressure for condensing the one or more fermentation inhibitors from the humidified gas.

[0035] The one or more inhibitors can comprise acetic acid, formic acid, furfural, hydrozymethylfurfural, sulfuric acid, peroxyacetic acid, lactic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, or a combination thereof. In some embodiments, the one or more inhibitors comprise acetic acid. In some embodiments, the one or more inhibitors comprise formic acid. In some embodiments, the one or more inhibitors comprise acetic acid and formic acid.

[0036] The carrier gas can comprise air, nitrogen, argon, carbon dioxide, or a combination thereof. In some embodiments, the carrier gas is air. In some embodiments, the carrier gas is nitrogen.

[0037] The first temperature can be at least about 4°C lower than the second temperature. In some embodiments, the first temperature is at least about 10°C lower than the second temperature. In some embodiments, the first temperature is about 4°C to about 90°C lower than the second temperature.

[0038] The first temperature can be about 10°C to about 70°C lower than the second temperature. In some embodiments, the first temperature is about 15°C to about 50°C lower than the second temperature.

[0039] The first temperature can be about 4°C to about 100°C. In some embodiments, the first temperature is about 10°C to about 70°C. In some embodiments, the first temperature is about 15°C to about 50°C.

[0040] The second pressure can be at least about 1.1 times higher than the first pressure. In some embodiments, the second pressure is at least about 1.5 times higher than the first pressure. In some embodiments, the second pressure is at least about 2.0 times higher than the first pressure.

[0041] The first pressure can be about 10 kPa to about 100 kPa. In some embodiments, the first pressure is about 20 kPa to about 60 kPa.

[0042] The systems can further comprise a salt dissolved in the saccharide stream prior to contacting. In some embodiments, the salt comprises LiBr, NaCl, KCl, or a combination thereof. In some embodiments, the salt comprises LiBr.

[0043] At least about 10% of the one or more inhibitors can be removed from the saccharide stream in the systems disclosed herein. In some embodiments, at least about 25% of the one or

more inhibitors is removed from the saccharide stream. In some embodiments, at least about 50% of the one or more inhibitors is removed from the saccharide stream. In some embodiments, at least about 75% of the one or more inhibitors is removed from the saccharide stream.

[0044] The packing material in the hydration chamber can comprise polyvinyl chloride packing.

[0045] The saccharide stream can be introduced into a top portion of the humidifying chamber.

[0046] The first temperature can be an average temperature in the humidifying chamber.

[0047] The carrier gas can be introduced into a bottom portion of the humidification chamber.

[0048] Contacting comprises spraying the saccharide stream with a spray nozzle.

[0049] The second temperature can be an average temperature in the dehumidifying chamber.

[0050] The system can further comprise a compressor to transfer the humidified gas from the humidifying chamber to the dehumidifying chamber.

[0051] The system can further comprise an expander to transfer the carrier gas from the dehumidifying chamber to the humidifying chamber after the one or more fermentation inhibitors are condensed out of the humidified gas.

[0052] The saccharide stream can be piped through the dehumidifying chamber to effect a heat transfer from the humidified gas to the saccharide stream.

[0053] The system can further comprise a heater to increase the temperature of the saccharide stream before contacting with the carrier gas.

[0054] The saccharide stream can comprise C5 saccharides, C6 saccharides, or a combination thereof. In some embodiments, the C5 saccharides comprise xylose, arabinose, or a combination thereof. In some embodiments, the C6 sugars comprise glucose, mannose, galactose, rhamnose, or a combination thereof. In some embodiments, the saccharide stream comprises glucose, mannose, galactose, rhamnose, xylose, arabinose, or a combination thereof.

[0055] The saccharide stream can have been produced by pretreating or hydrolyzing a biomass composition comprising cellulose, hemicellulose, or lignocellulose. In some embodiments, the biomass composition comprises alfalfa, algae, bagasse, bamboo, corn stover, corn cobs, corn kernels, corn mash, corn steep liquor, corn steep solids, distiller's grains, distiller's dried solubles, distiller's dried grains, condensed distiller's solubles, distiller's wet grains, distiller's dried grains with solubles, eucalyptus, food waste, fruit peels, garden residue, grass, grain hulls, modified crop plants, municipal waste, oat hulls, paper, paper pulp, prairie bluestem, poplar, rice hulls, seed hulls, silage, sorghum, straw, sugarcane, switchgrass, wheat, wheat straw, wheat bran, de-starched wheat bran, willows, wood, plant cells, plant tissue cultures, or a combination thereof.

[0056] Pretreating or hydrolyzing can comprise mechanical size reduction, hot water treatment, acid treatment, base treatment, steam explosion, acid-catalyzed steam explosion, ammonia fiber/freeze explosion, enzymatic hydrolysis, catalytic peptide hydrolysis, ionic liquid dissolution, or a combination thereof.

[0057] Pretreating or hydrolyzing can comprise mechanical size reduction, acid treatment, and hydrolysis with one or more enzymes or one or more polymeric catalysts.

[0058] Pretreating or hydrolyzing can comprise treating the biomass composition with hot water or dilute acid to solubilize hemicellulose, substantially separating the solubilized hemicellulose from remaining lignocellulose solids, and hydrolysis of the remaining lignocellulose solids with one or more enzymes or polymeric catalysts.

[0059] Pretreating or hydrolyzing can comprise ionic liquid dissolution with [bmim] 1-butyl-3-methylimidazolium, [emim] 1-ethyl-3-methylimidazolium, [amim] 1-allyl-3-methylimidazolium, [Ch] cholinium, [bzmim] 1-benzyl-3-methylimidazolium, [HEA] 2- hydroxyethylammonium, [bmpy] 1-butyl-3-methylpyridinium, [Me(OEt)3Et3N] triethyl-(2-(2-methoxyethoxy)ethoxy) ethylammonium, [DMEA] N,N-dimethylethanolammonium, [mmim] 1,3-dimethylimidazolium, [hmim] 1-hexyl-3-methylimidazolium, [pmim] 1-propyl-3-methylimidazolium, [abim] 1-allyl-3-butylimidazolium, [eMeOHpy] 1-ethyl-3-(hydroxymethyl)pyridine, [bHim] 1-butylimidazolium, [Cl] chloride, [CH3COO] acetate, [Et2PO4] diethylphosphate, [Me2PO4] dimethylphosphate, [MeOSO3] methylsulphate, [OTf] trifluoromethanesulphonate, [PrOO] propionate, [CF3COO] trifluoroacetate, [MeSO3] methanesulphonate, [HSO4] hydrogen sulphate, [PO(O)H2] phosphinate, [HCOO] formate, [BF4] tetrafluoroborate, [PF6] hexafluorophosphate, [Lys] lysinate, [Gly] glycinate, [Ala] alaninate, [Ser] serinate, [Thr] threoninate, [Met] methioninate, [Pro] prolinate, [Phe] phenylalaninate, [OHCH2COO] glycolate, [(CH2COO)2] succinate, [ABS] alkylbenzenesulphonate, [XS] xylenesulphonate, [MePO3] methylphosphonate, [EtPO3] ethylphosphonate, [i-PrPO3] i-propylphosphonate, [BuPO3] butylphosphonate, [NTf2] bis(trifluoromethylsulfonyl)amide, [EtOSO3] ethylsulphate , or a combination thereof.

[0060] Also disclosed are methods of producing a saccharide stream from a biomass composition comprising cellulose, hemicellulose, or lignocellulose, the methods comprising: (a) hydrating the biomass composition in an aqueous medium; (b) mechanical size reduction of the biomass composition to produce a mixture of solid particles, wherein at least 50% of the solid particles are less than 1.5 mm in a dimension; (c) heating the biomass composition; and (d) hydrolyzing the biomass composition with one or more polymeric catalysts to produce a saccharide stream.

[0061] The one or more polymeric catalysts can be, individually, a polymer comprising acidic monomers and ionic monomers connected to form a polymeric backbone. The polymer can be cross-linked.

Each acidic monomer can comprise, individually, at least one Bronsted-Lowry acid. In some embodiments, the Bronsted-Lowry acid at each occurrence is independently selected from the group consisting of sulfonic acid, phosphonic acid, acetic acid, isophthalic acid, boronic acid, and perfluorinated acid. In some embodiments, one or more of the Bronsted-Lowry acids are directly connected to the polymeric backbone. In some embodiments, one or more of the acidic monomers further comprise a linker connecting the Bronsted-Lowry acid to the polymeric backbone. In some embodiments, the linker at each occurrence is independently selected from the group consisting of unsubstituted or substituted alkylene, unsubstituted or substituted cycloalkylene, unsubstituted or substituted alkenylene, unsubstituted or substituted arylene, unsubstituted or substituted heteroarylene, unsubstituted or substituted alkylene ether, unsubstituted or substituted alkylene ester, and unsubstituted or substituted alkylene carbamate.

[0062] Each ionic monomer can comprise, individually, at least one nitrogen containing cationic group or phosphorous-containing cationic group.

[0063] The nitrogen-containing cationic group at each occurrence can be independently selected from the group consisting of pyrrolium, imidazolium, pyrazolium, oxazolium, thiazolium, pyridinium, pyrimidinium, pyrazinium, pyradizimium, thiazinium, morpholinium, piperidinium, piperizinium, and pyrollizinium.

[0064] The phosphorous-containing cationic group at each occurrence can be independently selected from the group consisting of triphenyl phosphonium, trimethyl phosphonium, triethyl phosphonium, tripropyl phosphonium, tributyl phosphonium, trichloro phosphonium, and trifluoro phosphonium.

[0065] One or more of the ionic monomers can be directly connected to form the polymeric backbone.

[0066] One or more of the ionic monomers can each further comprise a linker connecting the nitrogen-containing cationic group or the phosphorous-containing cationic group to the polymeric backbone. In some embodiments, the linker at each occurrence is independently selected from the group consisting of unsubstituted or substituted alkylene, unsubstituted or substituted cycloalkylene, unsubstituted or substituted alkenylene, unsubstituted or substituted arylene, unsubstituted or substituted heteroarylene, unsubstituted or substituted alkylene ether, unsubstituted or substituted alkylene ester, and unsubstituted or substituted alkylene carbamate.

[0067] The polymeric backbone can be selected from the group consisting of polyethylene, polypropylene, polyvinyl alcohol, polystyrene, polyurethane, polyvinyl chloride, polyphenol-aldehyde, polytetrafluoroethylene, polybutylene terephthalate, polycaprolactam, poly(acrylonitrile butadiene styrene), polyalkyleneammonium, polyalkylenediammonium, polyalkylenepyrrolium, polyalkyleneimidazolium, polyalkylenepyrazolium, polyalkyleneoxazolium, polyalkylenethiazolium, polyalkylenepyridinium, polyalkylenepyrimidinium, polyalkylenepyrazinium, polyalkylenepyradizimium, polyalkylenethiazinium, polyalkylenemorpholinium, polyalkylenepiperidinium, polyalkylenepiperizinium, polyalkylenepyrollizinium, polyalkylenetriphenylphosphonium, polyalkylenetrimethylphosphonium, polyalkylenetriethylphosphonium, polyalkylenetripropylphosphonium, polyalkylenetributylphosphonium, polyalkylenetrichlorophosphonium, polyalkylenetrifluorophosphonium, and polyalkylenediazolium.

[0068] The polymer can further comprise hydrophobic monomers connected to form the polymeric backbone. In some embodiments, each hydrophobic monomer comprises a hydrophobic group, wherein the hydrophobic group at each occurrence is independently selected from an unsubstituted or substituted alkyl, an unsubstituted or substituted cycloalkyl, an unsubstituted or substituted aryl, or an unsubstituted or substituted heteroaryl.

[0069] The one or more polymeric catalysts can further comprise acidic-ionic monomers connected to form the polymeric backbone, wherein each acidic-ionic monomer comprises a Bronsted-Lowry acid and a cationic group.

[0070] The polymeric catalyst can have a total amount of Bronsted-Lowry acid of between 0.1 and 20 mmol per gram of polymer.

[0071] The polymeric catalyst can be coated on a solid core. In some embodiments, the solid core comprises an inert material or a magnetic material. In some embodiments, the solid core is iron. In some embodiments, the solid core is non-porous.

[0072] The one or more polymer catalysts and the biomass composition can be admixed in a ratio of about 3 : 1 to 1 : 3 polymer catalyst : biomass composition by dry weight. In some embodiments, the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 2 : 1 to 1 : 2 polymer catalyst : biomass composition by dry weight. In some embodiments, the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 1.5 : 1 to 1 : 1.5 polymer catalyst : biomass composition by dry weight. In some embodiments, the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 1:1 polymer catalyst : biomass composition by dry weight.

[0073] Hydrolyzing the biomass composition with the one or more polymeric catalysts can be performed at a temperature of about 75°C-200°C. In some embodiments, hydrolyzing is performed at a temperature of about 100°C-175°C. In some embodiments, hydrolyzing is performed at a temperature of about 120°C-150°C.

[0074] Hydrolyzing the biomass composition with the one or more polymeric catalysts can be performed at a pressure of about 100 PSIG to about 150 PSIG.

[0075] Hydrolyzing the biomass composition with the one or more polymeric catalysts can be performed for a time of about 0.5 minutes to about 24 hours. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 12 hours. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 4 hours. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 1 hour. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 30 minutes. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 5 minutes.

[0076] The methods can further comprise: (e) recovering the one or more polymer catalysts from the saccharide stream and residual biomass. In some embodiments, recovering the one or more polymeric catalysts comprises the use of a cyclone press, worm press, filter press, mechanical press, a centrifuge press, or a gravity press. In some embodiments, recovering the one or more polymeric catalysts comprises differential sedimentation, wherein the residual biomass and the polymeric catalyst sediment into one or more separate phases from the saccharide stream.

[0077] At least 50% of the mixture of solid particles in the pretreated biomass composition can be from about 0.1 mm to about 1 mm in a dimension. All of the solid particles in the pretreated biomass can be less than 7.5 mm in a dimension. In some embodiments, all of the solid particles in the pretreated biomass are less than 1 mm in a dimension. The dimension can be diameter, length, or width.

[0078] Heating the biomass composition can solubilize at least 50% of the hemicellulose in the biomass composition. In some embodiments, heating the biomass composition solubilizes at least 75% of the hemicellulose in the biomass composition. In some embodiments, heating the biomass composition solubilizes at least 95% of the hemicellulose in the biomass composition.

[0079] The hemicellulose can be solubilized as polysaccharides.

[0080] The hemicellulose can be solubilized as monosaccharides, disaccharides, or a combination thereof.

[0081] Heating the biomass composition can produce a yield of glucose that is less than about 20% of a theoretical maximum.

[0082] Hydrating the biomass composition can produce a hydrated biomass composition comprising about 1% to about 20% solids by dry biomass weight.

[0083] The aqueous medium can be at a temperature of about 30° C to about 70° C.

[0084] The aqueous medium can comprise an acid. In some embodiments, the acid is at from about 0.1% to about 5% v/w by dry biomass weight in the aqueous medium. In some embodiments, the acid comprises sulfuric acid, peroxyacetic acid, lactic acid, formic acid, acetic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, or a combination thereof.

[0085] Mechanical size reduction can comprise cutting, steam explosion, acid-catalyzed steam explosion, or a combination thereof.

[0086] Heating the biomass composition can be at a temperature of from about 100° C to about 250° C.

[0087] Heating the biomass composition can be performed at a pressure of from about 100 PSIG to about 150 PSIG.

[0088] Heating the biomass composition can be performed for about 1 minute to about 30 minutes.

[0089] Mechanical size reduction can follow hydrating the biomass composition. Heating can follow mechanical size reduction of the biomass composition.

[0090] Hydrolyzing the biomass composition with one or more polymeric catalysts can follow heating.

[0091] Hydrolyzing the biomass composition with one or more polymeric catalysts can occur during heating.

[0092] The methods can further comprise dewatering the biomass composition to from about 10% to about 40% solids by dry biomass weight prior to heating.

[0093] Heating can comprise steam injection, steam explosion, acid-catalyzed steam explosion, or a combination thereof.

[0094] The methods can be performed in a continuous mode of operation.

[0095] The methods can further comprise hydrolyzing the biomass composition with one or more enzymes. In some embodiments, the one or more enzymes comprise one or more hemicellulases, one or more cellulases, or a combination thereof.

[0096] The methods can further comprise adjusting the water content of the biomass composition to from about 5% to about 30% solids by dry biomass weight prior to hydrolyzing.

[0097] The saccharide stream can comprise C5 saccharides, C6 saccharides, or a combination thereof. In some embodiments, the saccharide stream comprises glucose, xylose, mannose, galactose, rhamnose, arabinose, or a combination thereof.

[0098] The biomass composition can comprise alfalfa, algae, bagasse, bamboo, corn stover, corn cobs, corn kernels, corn mash, corn steep liquor, corn steep solids, distiller's grains, distiller's dried solubles, distiller's dried grains, condensed distiller's solubles, distiller's wet grains, distiller's dried grains with solubles, eucalyptus, food waste, fruit peels, garden residue, grass, grain hulls, modified crop plants, municipal waste, oat hulls, paper, paper pulp, prairie bluestem, poplar, rice hulls, seed hulls, silage, sorghum, straw, sugarcane, switchgrass, wheat, wheat straw, wheat bran, de-starched wheat bran, willows, wood, plant cells, plant tissue cultures, tissue cultures, or a combination thereof.

[0099] In some embodiments, mechanical size reduction does not comprise milling.

[00100] The saccharide stream can comprise one or more inhibitors In some embodiments, the method further comprises removing at least a portion of the one or more inhibitors using the humidification:dehumidification process of any one of claims 1-54.

[00101] Also provided are saccharide streams produced by any of the methods disclosed herein.

INCORPORATION BY REFERENCE

[00102] All publications, patents, and patent applications mentioned in this specification are herein incorporated by reference to the same extent as if each individual publication, patent, or patent application was specifically and individually indicated to be incorporated by reference.

BRIEF DESCRIPTION OF THE DRAWINGS

[00103] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

[00104] **Figure 1** shows a processing diagram for conversion of feedstock to saccharide streams and residuals.

[00105] **Figure 2** is a block diagram depicting the overall process for producing refined saccharide streams using the methods of the present invention. The process entails a pretreatment stage entailing mechanical processing followed by a hydrolysis stage entailing

polymeric hydrolysis, and a separation and purification stage entailing water recovery and fermentation inhibitor removal.

[00106] **Figure 3** is a block diagram depicting an apparatus for conducting water recovery and fermentation inhibitor removal through a humidification-dehumidification process.

DETAILED DESCRIPTION

[00107] As used in the specification and the appended claims, the singular forms "a," "an" and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a purified monomer" includes mixtures of two or more purified monomers. The term "comprising" as used herein is synonymous with "including," "containing," or "characterized by," and is inclusive or open-ended and does not exclude additional, unrecited elements or method steps.

[00108] "About" means a referenced numeric indication plus or minus 10% of that referenced numeric indication. For example, the term about 4 would include a range of 3.6 to 4.4. All numbers expressing quantities of ingredients, reaction conditions, and so forth used in the specification are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical parameters set forth herein are approximations that can vary depending upon the desired properties sought to be obtained. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of any claims in any application claiming priority to the present application, each numerical parameter should be construed in light of the number of significant digits and ordinary rounding approaches.

[00109] Wherever the phrase "for example," "such as," "including" and the like are used herein, the phrase "and without limitation" is understood to follow unless explicitly stated otherwise. Therefore, "for example ethanol production" means "for example and without limitation ethanol production."

[00110] In this specification and in the claims that follow, reference will be made to a number of terms which shall be defined to have the following meanings. Unless characterized otherwise, technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art.

[00111] **Definitions**

[00112] "Optional" or "optionally" means that the subsequently described event or circumstance may or may not occur, and that the description includes instances where said event or circumstance occurs and instances where it does not. For example, the phrase "the medium

can optionally contain glucose" means that the medium may or may not contain glucose as an ingredient and that the description includes both media containing glucose and media not containing glucose.

[00113] "Fermentive end-product" and "fermentation end-product" are used interchangeably herein to include biofuels, chemicals, compounds suitable as liquid fuels, gaseous fuels, triacylglycerols, reagents, chemical feedstocks, chemical additives, processing aids, food additives, bioplastics and precursors to bioplastics, and other products. Examples of fermentive end-products include but are not limited to 1,4 diacids (succinic, fumaric and malic), 2,5 furan dicarboxylic acid, 3 hydroxy propionic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hydroxybutyrolactone, glycerol, sorbitol, xylitol/arabinitol, butanediol, butanol, methane, methanol, ethane, ethene, ethanol, n-propane, 1-propene, 1-propanol, propanal, acetone, propionate, n-butane, 1-butene, 1-butanol, butanal, butanoate, isobutanal, isobutanol, 2-methylbutanal, 2-methylbutanol, 3-methylbutanal, 3-methylbutanol, 2-butene, 2-butanol, 2-butanone, 2,3-butanediol, 3-hydroxy-2-butanone, 2,3-butanedione, ethylbenzene, ethenylbenzene, 2-phenylethanol, phenylacetaldehyde, 1-phenylbutane, 4-phenyl-1-butene, 4-phenyl-2-butene, 1-phenyl-2-butene, 1-phenyl-2-butanol, 4-phenyl-2-butanol, 1-phenyl-2-butanone, 4-phenyl-2-butanone, 1-phenyl-2,3-butandiol, 1-phenyl-3-hydroxy-2-butanone, 4-phenyl-3-hydroxy-2-butanone, 1-phenyl-2,3-butanedione, n-pentane, ethylphenol, ethenylphenol, 2-(4-hydroxyphenyl)ethanol, 4-hydroxyphenylacetaldehyde, 1-(4-hydroxyphenyl) butane, 4-(4-hydroxyphenyl)-1-butene, 4-(4-hydroxyphenyl)-2-butene, 1-(4-hydroxyphenyl)-1-butene, 1-(4-hydroxyphenyl)-2-butanol, 4-(4-hydroxyphenyl)-2-butanol, 1-(4-hydroxyphenyl)-2-butanone, 4-(4-hydroxyphenyl)-2-butanone, 1-(4-hydroxyphenyl)-2,3-butandiol, 1-(4-hydroxyphenyl)-3-hydroxy-2-butanone, 4-(4-hydroxyphenyl)-3-hydroxy-2-butanone, 1-(4-hydroxyphenyl)-2,3-butanonedione, indolylethane, indolylethene, 2-(indole-3-)ethanol, n-pentane, 1-pentene, 1-pentanol, pentanal, pentanoate, 2-pentene, 2-pentanol, 3-pentanol, 2-pentanone, 3-pentanone, 4-methylpentanal, 4-methylpentanol, 2,3-pentanediol, 2-hydroxy-3-pentanone, 3-hydroxy-2-pentanone, 2,3-pentanedione, 2-methylpentane, 4-methyl-1-pentene, 4-methyl-2-pentene, 4-methyl-3-pentene, 4-methyl-2-pentanol, 2-methyl-3-pentanol, 4-methyl-2-pentanone, 2-methyl-3-pentanone, 4-methyl-2,3-pentanediol, 4-methyl-2-hydroxy-3-pentanone, 4-methyl-3-hydroxy-2-pentanone, 4-methyl-2,3-pentanedione, 1-phenylpentane, 1-phenyl-1-pentene, 1-phenyl-2-pentene, 1-phenyl-3-pentene, 1-phenyl-2-pentanol, 1-phenyl-3-pentanol, 1-phenyl-2-pentanone, 1-phenyl-3-pentanone, 1-phenyl-2,3-pentanediol, 1-phenyl-2-hydroxy-3-pentanone, 1-phenyl-3-hydroxy-2-pentanone, 1-phenyl-2,3-pentanedione, 4-methyl-1-phenylpentane, 4-methyl-1-phenyl-1-pentene, 4-methyl-1-phenyl-2-pentene, 4-methyl-1-

phenyl-3-pentene, 4-methyl-1-phenyl-3-pentanol, 4-methyl-1-phenyl-2-pentanol, 4-methyl-1-phenyl-3-pentanone, 4-methyl-1-phenyl-2-pentanone, 4-methyl-1-phenyl-2,3-pentanediol, 4-methyl-1-phenyl-2,3-pentanedione, 4-methyl-1-phenyl-3-hydroxy-2-pentanone, 4-methyl-1-phenyl-2-hydroxy-3-pentanone, 1-(4-hydroxyphenyl) pentane, 1-(4-hydroxyphenyl)-1-pentene, 1-(4-hydroxyphenyl)-2-pentene, 1-(4-hydroxyphenyl)-3-pentene, 1-(4-hydroxyphenyl)-2-pentanol, 1-(4-hydroxyphenyl)-3-pentanol, 1-(4-hydroxyphenyl)-2-pentanone, 1-(4-hydroxyphenyl)-3-pentanone, 1-(4-hydroxyphenyl)-2,3-pentanediol, 1-(4-hydroxyphenyl)-2-hydroxy-3-pentanone, 1-(4-hydroxyphenyl)-3-hydroxy-2-pentanone, 1-(4-hydroxyphenyl)-2,3-pentanedione, 4-methyl-1-(4-hydroxyphenyl) pentane, 4-methyl-1-(4-hydroxyphenyl)-2-pentene, 4-methyl-1-(4-hydroxyphenyl)-3-pentene, 4-methyl-1-(4-hydroxyphenyl)-1-pentene, 4-methyl-1-(4-hydroxyphenyl)-3-pentanol, 4-methyl-1-(4-hydroxyphenyl)-2-pentanol, 4-methyl-1-(4-hydroxyphenyl)-3-pentanone, 4-methyl-1-(4-hydroxyphenyl)-2-pentanone, 4-methyl-1-(4-hydroxyphenyl)-2,3-pentanediol, 4-methyl-1-(4-hydroxyphenyl)-2,3-pentanedione, 4-methyl-1-(4-hydroxyphenyl)-3-hydroxy-2-pentanone, 4-methyl-1-(4-hydroxyphenyl)-2-hydroxy-3-pentanone, 1-indole-3-pentane, 1-(indole-3)-1-pentene, 1-(indole-3)-2-pentene, 1-(indole-3)-3-pentene, 1-(indole-3)-2-pentanol, 1-(indole-3)-3-pentanol, 1-(indole-3)-2-pentanone, 1-(indole-3)-3-pentanone, 1-(indole-3)-2,3-pentanediol, 1-(indole-3)-2-hydroxy-3-pentanone, 1-(indole-3)-3-hydroxy-2-pentanone, 1-(indole-3)-2,3-pentanedione, 4-methyl-1-(indole-3-)pentane, 4-methyl-1-(indole-3)-2-pentene, 4-methyl-1-(indole-3)-3-pentene, 4-methyl-1-(indole-3)-1-pentene, 4-methyl-2-(indole-3)-3-pentanol, 4-methyl-1-(indole-3)-2-pentanol, 4-methyl-1-(indole-3)-3-pentanone, 4-methyl-1-(indole-3)-2-pentanone, 4-methyl-1-(indole-3)-2,3-pentanediol, 4-methyl-1-(indole-3)-2,3-pentanedione, 4-methyl-1-(indole-3)-3-hydroxy-2-pentanone, 4-methyl-1-(indole-3)-2-hydroxy-3-pentanone, n-hexane, 1-hexene, 1-hexanol, hexanal, hexanoate, 2-hexene, 3-hexene, 2-hexanol, 3-hexanol, 2-hexanone, 3-hexanone, 2,3-hexanediol, 2,3-hexanedione, 3,4-hexanediol, 3,4-hexanedione, 2-hydroxy-3-hexanone, 3-hydroxy-2-hexanone, 3-hydroxy-4-hexanone, 4-hydroxy-3-hexanone, 2-methylhexane, 3-methylhexane, 2-methyl-2-hexene, 2-methyl-3-hexene, 5-methyl-1-hexene, 5-methyl-2-hexene, 4-methyl-1-hexene, 4-methyl-2-hexene, 3-methyl-3-hexene, 3-methyl-2-hexene, 3-methyl-1-hexene, 2-methyl-3-hexanol, 5-methyl-2-hexanol, 5-methyl-3-hexanol, 2-methyl-3-hexanone, 5-methyl-2-hexanone, 5-methyl-3-hexanone, 2-methyl-3,4-hexanediol, 2-methyl-3,4-hexanedione, 5-methyl-2,3-hexanediol, 5-methyl-2,3-hexanedione, 4-methyl-2,3-hexanediol, 4-methyl-2,3-hexanedione, 2-methyl-3-hydroxy-4-hexanone, 2-methyl-4-hydroxy-3-hexanone, 5-methyl-2-hydroxy-3-hexanone, 5-methyl-3-hydroxy-2-hexanone, 4-methyl-2-hydroxy-3-hexanone, 4-methyl-3-hydroxy-2-hexanone, 2,5-dimethylhexane, 2,5-dimethyl-2-hexene, 2,5-dimethyl-3-

hexene, 2,5-dimethyl-3-hexanol, 2,5-dimethyl-3-hexanone, 2,5-dimethyl-3,4-hexanediol, 2,5-dimethyl-3,4-hexanedione, 2,5-dimethyl-3-hydroxy-4-hexanone, 5-methyl-1-phenylhexane, 4-methyl-1-phenylhexane, 5-methyl-1-phenyl-1-hexene, 5-methyl-1-phenyl-2-hexene, 5-methyl-1-phenyl-3-hexene, 4-methyl-1-phenyl-1-hexene, 4-methyl-1-phenyl-2-hexene, 4-methyl-1-phenyl-3-hexene, 5-methyl-1-phenyl-2-hexanol, 5-methyl-1-phenyl-3-hexanol, 4-methyl-1-phenyl-2-hexanol, 4-methyl-1-phenyl-3-hexanol, 5-methyl-1-phenyl-2-hexanone, 5-methyl-1-phenyl-3-hexanone, 4-methyl-1-phenyl-2-hexanone, 4-methyl-1-phenyl-3-hexanone, 5-methyl-1-phenyl-2,3-hexanediol, 4-methyl-1-phenyl-2,3-hexanediol, 5-methyl-1-phenyl-3-hydroxy-2-hexanone, 5-methyl-1-phenyl-2-hydroxy-3-hexanone, 4-methyl-1-phenyl-3-hydroxy-2-hexanone, 4-methyl-1-phenyl-2-hydroxy-3-hexanone, 5-methyl-1-phenyl-2,3-hexanedione, 4-methyl-1-phenyl-2,3-hexanedione, 4-methyl-1-(4-hydroxyphenyl)hexane, 5-methyl-1-(4-hydroxyphenyl)-1-hexene, 5-methyl-1-(4-hydroxyphenyl)-2-hexene, 5-methyl-1-(4-hydroxyphenyl)-3-hexene, 4-methyl-1-(4-hydroxyphenyl)-1-hexene, 4-methyl-1-(4-hydroxyphenyl)-2-hexene, 4-methyl-1-(4-hydroxyphenyl)-3-hexene, 5-methyl-1-(4-hydroxyphenyl)-2-hexanol, 5-methyl-1-(4-hydroxyphenyl)-3-hexanol, 4-methyl-1-(4-hydroxyphenyl)-2-hexanol, 4-methyl-1-(4-hydroxyphenyl)-3-hexanol, 5-methyl-1-(4-hydroxyphenyl)-2-hexanone, 5-methyl-1-(4-hydroxyphenyl)-3-hexanone, 4-methyl-1-(4-hydroxyphenyl)-2-hexanone, 4-methyl-1-(4-hydroxyphenyl)-3-hexanone, 5-methyl-1-(4-hydroxyphenyl)-2,3-hexanediol, 4-methyl-1-(4-hydroxyphenyl)-2,3-hexanediol, 5-methyl-1-(4-hydroxyphenyl)-3-hydroxy-2-hexanone, 5-methyl-1-(4-hydroxyphenyl)-2-hydroxy-3-hexanone, 4-methyl-1-(4-hydroxyphenyl)-3-hydroxy-2-hexanone, 4-methyl-1-(4-hydroxyphenyl)-2-hydroxy-3-hexanone, 5-methyl-1-(4-hydroxyphenyl)-2,3-hexanedione, 4-methyl-1-(4-hydroxyphenyl)-2,3-hexanedione, 4-methyl-1-(indole-3-)hexane, 5-methyl-1-(indole-3)-1-hexene, 5-methyl-1-(indole-3)-2-hexene, 5-methyl-1-(indole-3)-3-hexene, 4-methyl-1-(indole-3)-1-hexene, 4-methyl-1-(indole-3)-2-hexene, 4-methyl-1-(indole-3)-3-hexene, 5-methyl-1-(indole-3)-2-hexanol, 5-methyl-1-(indole-3)-3-hexanol, 4-methyl-1-(indole-3)-2-hexanol, 4-methyl-1-(indole-3)-3-hexanol, 5-methyl-1-(indole-3)-2-hexanone, 5-methyl-1-(indole-3)-3-hexanone, 4-methyl-1-(indole-3)-2-hexanone, 4-methyl-1-(indole-3)-3-hexanone, 5-methyl-1-(indole-3)-2,3-hexanediol, 4-methyl-1-(indole-3)-2,3-hexanediol, 5-methyl-1-(indole-3)-3-hydroxy-2-hexanone, 5-methyl-1-(indole-3)-2-hydroxy-3-hexanone, 4-methyl-1-(indole-3)-3-hydroxy-2-hexanone, 4-methyl-1-(indole-3)-2-hydroxy-3-hexanone, 5-methyl-1-(indole-3)-2,3-hexanedione, 4-methyl-1-(indole-3)-2,3-hexanedione, n-heptane, 1-heptene, 1-heptanol, heptanal, heptanoate, 2-heptene, 3-heptene, 2-heptanol, 3-heptanol, 4-heptanol, 2-heptanone, 3-heptanone, 4-heptanone, 2,3-heptanediol, 2,3-heptanedione, 3,4-heptanediol, 3,4-heptanedione,

2-hydroxy-3-heptanone, 3-hydroxy-2-heptanone, 3-hydroxy-4-heptanone, 4-hydroxy-3-heptanone, 2-methylheptane, 3-methylheptane, 6-methyl-2-heptene, 6-methyl-3-heptene, 2-methyl-3-heptene, 2-methyl-2-heptene, 5-methyl-2-heptene, 5-methyl-3-heptene, 3-methyl-3-heptene, 2-methyl-3-heptanol, 2-methyl-4-heptanol, 6-methyl-3-heptanol, 5-methyl-3-heptanol, 3-methyl-4-heptanol, 2-methyl-3-heptanone, 2-methyl-4-heptanone, 6-methyl-3-heptanone, 5-methyl-3-heptanone, 3-methyl-4-heptanone, 2-methyl-3,4-heptanediol, 2-methyl-3,4-heptanedione, 6-methyl-3,4-heptanediol, 6-methyl-3,4-heptanedione, 5-methyl-3,4-heptanediol, 5-methyl-3,4-heptanedione, 2-methyl-3-hydroxy-4-heptanone, 2-methyl-4-hydroxy-3-heptanone, 6-methyl-3-hydroxy-4-heptanone, 6-methyl-4-hydroxy-3-heptanone, 5-methyl-3-hydroxy-4-heptanone, 5-methyl-4-hydroxy-3-heptanone, 2,6-dimethylheptane, 2,5-dimethylheptane, 2,6-dimethyl-2-heptene, 2,6-dimethyl-3-heptene, 2,5-dimethyl-2-heptene, 2,5-dimethyl-3-heptene, 3,6-dimethyl-3-heptene, 2,6-dimethyl-3-heptanol, 2,6-dimethyl-4-heptanol, 2,5-dimethyl-3-heptanol, 2,5-dimethyl-4-heptanol, 2,6-dimethyl-3,4-heptanediol, 2,6-dimethyl-3,4-heptanedione, 2,5-dimethyl-3,4-heptanediol, 2,5-dimethyl-3,4-heptanedione, 2,6-dimethyl-3-hydroxy-4-heptanone, 2,6-dimethyl-4-hydroxy-3-heptanone, 2,5-dimethyl-3-hydroxy-4-heptanone, 2,5-dimethyl-4-hydroxy-3-heptanone, n-octane, 1-octene, 2-octene, 1-octanol, octanal, octanoate, 3-octene, 4-octene, 4-octanol, 4-octanone, 4,5-octanediol, 4,5-octanedione, 4-hydroxy-5-octanone, 2-methyloctane, 2-methyl-3-octene, 2-methyl-4-octene, 7-methyl-3-octene, 3-methyl-3-octene, 3-methyl-4-octene, 6-methyl-3-octene, 2-methyl-4-octanol, 7-methyl-4-octanol, 3-methyl-4-octanol, 6-methyl-4-octanol, 2-methyl-4-octanone, 7-methyl-4-octanone, 3-methyl-4-octanone, 6-methyl-4-octanone, 2-methyl-4,5-octanediol, 2-methyl-4,5-octanedione, 3-methyl-4,5-octanediol, 3-methyl-4,5-octanedione, 2-methyl-4-hydroxy-5-octanone, 2-methyl-5-hydroxy-4-octanone, 3-methyl-4-hydroxy-5-octanone, 3-methyl-5-hydroxy-4-octanone, 2,7-dimethyloctane, 2,7-dimethyl-3-octene, 2,7-dimethyl-4-octene, 2,7-dimethyl-4-octanol, 2,7-dimethyl-4-octanone, 2,7-dimethyl-4,5-octanediol, 2,7-dimethyl-4,5-octanedione, 2,7-dimethyl-4-hydroxy-5-octanone, 2,6-dimethyloctane, 2,6-dimethyl-3-octene, 2,6-dimethyl-4-octene, 3,7-dimethyl-3-octene, 2,6-dimethyl-4-octanol, 3,7-dimethyl-4-octanol, 2,6-dimethyl-4-octanone, 3,7-dimethyl-4-octanone, 2,6-dimethyl-4,5-octanediol, 2,6-dimethyl-4,5-octanedione, 2,6-dimethyl-4-hydroxy-5-octanone, 2,6-dimethyl-5-hydroxy-4-octanone, 3,6-dimethyloctane, 3,6-dimethyl-3-octene, 3,6-dimethyl-4-octene, 3,6-dimethyl-4-octanol, 3,6-dimethyl-4-octanone, 3,6-dimethyl-4,5-octanediol, 3,6-dimethyl-4,5-octanedione, 3,6-dimethyl-4-hydroxy-5-octanone, n-nonane, 1-nonene, 1-nonanol, nonanal, nonanoate, 2-methylnonane, 2-methyl-4-nonene, 2-methyl-5-nonene, 8-methyl-4-nonene, 2-methyl-5-nonanol, 8-methyl-4-nonanol, 2-methyl-5-nonanone, 8-methyl-4-nonanone, 8-methyl-4,5-nonanediol, 8-methyl-4,5-nonanedione, 8-

methyl-4-hydroxy-5-nonanone, 8-methyl-5-hydroxy-4-nonanone, 2,8-dimethylnonane, 2,8-dimethyl-3-nonene, 2,8-dimethyl-4-nonene, 2,8-dimethyl-5-nonene, 2,8-dimethyl-4-nonanol, 2,8-dimethyl-5-nonanol, 2,8-dimethyl-4-nonanone, 2,8-dimethyl-5-nonanone, 2,8-dimethyl-4,5-nonanediol, 2,8-dimethyl-4,5-nonanedione, 2,8-dimethyl-4-hydroxy-5-nonanone, 2,8-dimethyl-5-hydroxy-4-nonanone, 2,7-dimethylnonane, 3,8-dimethyl-3-nonene, 3,8-dimethyl-4-nonene, 3,8-dimethyl-5-nonene, 3,8-dimethyl-4-nonanol, 3,8-dimethyl-5-nonanol, 3,8-dimethyl-4-nonanone, 3,8-dimethyl-5-nonanone, 3,8-dimethyl-4,5-nonanediol, 3,8-dimethyl-4,5-nonanedione, 3,8-dimethyl-4-hydroxy-5-nonanone, 3,8-dimethyl-5-hydroxy-4-nonanone, n-decane, 1-decene, 1-decanol, decanoate, 2,9-dimethyldecane, 2,9-dimethyl-3-decene, 2,9-dimethyl-4-decene, 2,9-dimethyl-5-decanol, 2,9-dimethyl-5-decanone, 2,9-dimethyl-5,6-decanediol, 2,9-dimethyl-6-hydroxy-5-decanone, 2,9-dimethyl-5,6-decanedionen-undecane, 1-undecene, 1-undecanol, undecanal, undecanoate, n-dodecane, 1-dodecene, 1-dodecanol, dodecanal, dodecanoate, n-dodecane, 1-decadecene, n-tridecane, 1-tridecene, 1-tridecanol, tridecanal, tridecanoate, n-tetradecane, 1-tetradecene, 1-tetradecanol, tetradecanal, tetradecanoate, n-pentadecane, 1-pentadecene, 1-pentadecanol, pentadecanal, pentadecanoate, n-hexadecane, 1-hexadecene, 1-hexadecanol, hexadecanal, hexadecanoate, n-heptadecane, 1-heptadecene, 1-heptadecanol, heptadecanal, heptadecanoate, n-octadecane, 1-octadecene, 1-octadecanol, octadecanal, octadecanoate, n-nonadecane, 1-nonadecene, 1-nonadecanol, nonadecanal, nonadecanoate, eicosane, 1-eicosene, 1-eicosanol, eicosanal, eicosanoate, 3-hydroxy propanal, 1,3-propanediol, 4-hydroxybutanal, 1,4-butanediol, 3-hydroxy-2-butanone, 2,3-butandiol, 1,5-pentane diol, homocitrate, homoisocitorate, b-hydroxy adipate, glutarate, glutarsemialdehyde, glutaraldehyde, 2-hydroxy-1-cyclopentanone, 1,2-cyclopentanediol, cyclopentanone, cyclopentanol, (S)-2-acetolactate, (R)-2,3-Dihydroxy-isovalerate, 2-oxoisovalerate, isobutyryl-CoA, isobutyrate, isobutyraldehyde, 5-amino pentaldehyde, 1,10-diaminodecane, 1,10-diamino-5-decene, 1,10-diamino-5-hydroxydecane, 1,10-diamino-5-decanone, 1,10-diamino-5,6-decanediol, 1,10-diamino-6-hydroxy-5-decanone, phenylacetoaldehyde, 1,4-diphenylbutane, 1,4-diphenyl-1-butene, 1,4-diphenyl-2-butene, 1,4-diphenyl-2-butanol, 1,4-diphenyl-2-butanone, 1,4-diphenyl-2,3-butanediol, 1,4-diphenyl-3-hydroxy-2-butanone, 1-(4-hydeoxyphenyl)-4-phenylbutane, 1-(4-hydeoxyphenyl)-4-phenyl-1-butene, 1-(4-hydeoxyphenyl)-4-phenyl-2-butene, 1-(4-hydeoxyphenyl)-4-phenyl-2-butanol, 1-(4-hydeoxyphenyl)-4-phenyl-2-butanone, 1-(4-hydeoxyphenyl)-4-phenyl-2,3-butanediol, 1-(4-hydeoxyphenyl)-4-phenyl-3-hydroxy-2-butanone, 1-(indole-3)-4-phenylbutane, 1-(indole-3)-4-phenyl-1-butene, 1-(indole-3)-4-phenyl-2-butene, 1-(indole-3)-4-phenyl-2-butanol, 1-(indole-3)-4-phenyl-2-butanone, 1-(indole-3)-4-phenyl-2,3-butanediol, 1-(indole-3)-4-phenyl-3-hydroxy-2-

butanone, 4-hydroxyphenylacetoaldehyde, 1,4-di(4-hydroxyphenyl)butane, 1,4-di(4-hydroxyphenyl)-1-butene, 1,4-di(4-hydroxyphenyl)-2-butene, 1,4-di(4-hydroxyphenyl)-2-butanol, 1,4-di(4-hydroxyphenyl)-2-butanone, 1,4-di(4-hydroxyphenyl)-2,3-butanediol, 1,4-di(4-hydroxyphenyl)-3-hydroxy-2-butanone, 1-(4-hydroxyphenyl)-4-(indole-3-)butane, 1-(4-hydroxyphenyl)-4-(indole-3)-1-butene, 1-di(4-hydroxyphenyl)-4-(indole-3)-2-butene, 1-(4-hydroxyphenyl)-4-(indole-3)-2-butanol, 1-(4-hydroxyphenyl)-4-(indole-3)-2-butanone, 1-(4-hydroxyphenyl)-4-(indole-3)-2,3-butanediol, 1-(4-hydroxyphenyl-4-(indole-3)-3-hydroxy-2-butanone, indole-3-acetoaldehyde, 1,4-di(indole-3-)butane, 1,4-di(indole-3)-1-butene, 1,4-di(indole-3)-2-butene, 1,4-di(indole-3)-2-butanol, 1,4-di(indole-3)-2-butanone, 1,4-di(indole-3)-2,3-butanediol, 1,4-di(indole-3)-3-hydroxy-2-butanone, succinate semialdehyde, hexane-1,8-dicarboxylic acid, 3-hexene-1,8-dicarboxylic acid, 3-hydroxy-hexane-1,8-dicarboxylic acid, 3-hexanone-1,8-dicarboxylic acid, 3,4-hexanediol-1,8-dicarboxylic acid, 4-hydroxy-3-hexanone-1,8-dicarboxylic acid, glycerol, fucoidan, iodine, chlorophyll, carotenoid, calcium, magnesium, iron, sodium, potassium, phosphate, lactic acid, acetic acid, formic acid, isoprenoids, and polyisoprenes, including rubber. Further, such products can include succinic acid, pyruvic acid, enzymes such as cellulases, polysaccharases, lipases, proteases, ligninases, and hemicellulases and may be present as a pure compound, a mixture, or an impure or diluted form.

[00114] Fermentation end-products can include polyols or sugar alcohols; for example, methanol, glycol, glycerol, erythritol, threitol, arabitol, xylitol, ribitol, mannitol, sorbitol, dulcitol, fucitol, iditol, inositol, volemitol, isomalt, maltitol, lactitol, and/or polyglycitol.

[00115] The term "fatty acid comprising material" as used herein has its ordinary meaning as known to those skilled in the art and can comprise one or more chemical compounds that include one or more fatty acid moieties as well as derivatives of these compounds and materials that comprise one or more of these compounds. Common examples of compounds that include one or more fatty acid moieties include triacylglycerides, diacylglycerides, monoacylglycerides, phospholipids, lysophospholipids, free fatty acids, fatty acid salts, soaps, fatty acid comprising amides, esters of fatty acids and monohydric alcohols, esters of fatty acids and polyhydric alcohols including glycols (*e.g.* ethylene glycol, propylene glycol, etc.), esters of fatty acids and polyethylene glycol, esters of fatty acids and polyethers, esters of fatty acids and polyglycol, esters of fatty acids and saccharides, esters of fatty acids with other hydroxyl-containing compounds, etc.

[00116] A fatty acid comprising material can be one or more of these compounds in an isolated or purified form. It can be a material that includes one or more of these compounds that is combined or blended with other similar or different materials. It can be a material where the

fatty acid comprising material occurs with or is provided with other similar or different materials, such as vegetable and animal oils; mixtures of vegetable and animal oils; vegetable and animal oil byproducts; mixtures of vegetable and animal oil byproducts; vegetable and animal wax esters; mixtures, derivatives and byproducts of vegetable and animal wax esters; seeds; processed seeds; seed byproducts; nuts; processed nuts; nut byproducts; animal matter; processed animal matter; byproducts of animal matter; corn; processed corn; corn byproducts; distiller's grains; beans; processed beans; bean byproducts; soy products; lipid containing plant, fish or animal matter; processed lipid containing plant or animal matter; byproducts of lipid containing plant, fish or animal matter; lipid containing microbial material; processed lipid containing microbial material; and byproducts of lipid containing microbial matter. Such materials can be utilized in liquid or solid forms. Solid forms include whole forms, such as cells, beans, and seeds; ground, chopped, slurried, extracted, flaked, milled, *etc.* The fatty acid portion of the fatty acid comprising compound can be a simple fatty acid, such as one that includes a carboxyl group attached to a substituted or un-substituted alkyl group. The substituted or unsubstituted alkyl group can be straight or branched, saturated or unsaturated. Substitutions on the alkyl group can include hydroxyls, phosphates, halogens, alkoxy, or aryl groups. The substituted or unsubstituted alkyl group can have 7 to 29 carbons and preferably 11 to 23 carbons (*e.g.*, 8 to 30 carbons and preferably 12 to 24 carbons counting the carboxyl group) arranged in a linear chain with or without side chains and/or substitutions. Addition of the fatty acid comprising compound can be by way of adding a material comprising the fatty acid comprising compound.

[00117] The term "pH modifier" as used herein has its ordinary meaning as known to those skilled in the art and can include any material that will tend to increase, decrease or hold steady the pH of the broth or medium. A pH modifier can be an acid, a base, a buffer, or a material that reacts with other materials present to serve to raise, lower, or hold steady the pH. In one embodiment, more than one pH modifier can be used, such as more than one acid, more than one base, one or more acid with one or more bases, one or more acids with one or more buffers, one or more bases with one or more buffers, or one or more acids with one or more bases with one or more buffers. In one embodiment, a buffer can be produced in the broth or medium or separately and used as an ingredient by at least partially reacting in acid or base with a base or an acid, respectively. When more than one pH modifiers are utilized, they can be added at the same time or at different times. In one embodiment, one or more acids and one or more bases are combined, resulting in a buffer. In one embodiment, media components, such as a carbon source or a nitrogen source serve as a pH modifier; suitable media components include those with high

or low pH or those with buffering capacity. Exemplary media components include acid- or base-hydrolyzed plant polysaccharides having residual acid or base, ammonia fiber explosion (AFEX) treated plant material with residual ammonia, lactic acid, corn steep solids or liquor.

[00118] The term "fermentation" as used herein has its ordinary meaning as known to those skilled in the art and can include culturing of a microorganism or group of microorganisms in or on a suitable medium for the microorganisms. The microorganisms can be aerobes, anaerobes, facultative anaerobes, heterotrophs, autotrophs, photoautotrophs, photoheterotrophs, chemoautotrophs, and/or chemoheterotrophs. The microorganisms can be growing aerobically or anaerobically. They can be in any phase of growth, including lag (or conduction), exponential, transition, stationary, death, dormant, vegetative, sporulating, *etc.*

[00119] "Growth phase" is used herein to describe the type of cellular growth that occurs after the "Initiation phase" and before the "Stationary phase" and the "Death phase." The growth phase is sometimes referred to as the exponential phase or log phase or logarithmic phase.

[00120] The term "plant polysaccharide" as used herein has its ordinary meaning as known to those skilled in the art and can comprise one or more polymers of sugars and sugar derivatives as well as derivatives of sugar polymers and/or other polymeric materials that occur in plant matter. Exemplary plant polysaccharides include lignin, cellulose, starch, pectin, and hemicellulose. Others are chitin, sulfonated polysaccharides such as alginic acid, agarose, carrageenan, porphyran, furcelleran and funoran. Generally, the polysaccharide can have two or more sugar units or derivatives of sugar units. The sugar units and/or derivatives of sugar units can repeat in a regular pattern, or otherwise. The sugar units can be hexose units or pentose units, or combinations of these. The derivatives of sugar units can be sugar alcohols, sugar acids, amino sugars, etc. The polysaccharides can be linear, branched, cross-linked, or a mixture thereof. One type or class of polysaccharide can be cross-linked to another type or class of polysaccharide.

[00121] The term "fermentable saccharides" as used herein has its ordinary meaning as known to those skilled in the art and can include one or more saccharides and/or saccharide derivatives that can be utilized as a carbon source by the microorganism, including monomers, dimers, and polymers of these compounds including two or more of these compounds. In some cases, the organism can break down these polymers, such as by hydrolysis, prior to incorporating the broken down material. Exemplary fermentable saccharides include, but are not limited to glucose, dextrose, xylose, arabinose, galactose, mannose, rhamnose, cellobiose, lactose, sucrose, maltose, and fructose.

[00122] The term "saccharification" as used herein has its ordinary meaning as known to those skilled in the art and can include conversion of plant polysaccharides to lower molecular weight species that can be utilized by the organism at hand. For some organisms, this would include conversion to monosaccharides, disaccharides, trisaccharides, and oligosaccharides of up to about seven monomer units, as well as similar sized chains of sugar or saccharide derivatives and combinations of sugars or saccharides and sugar or saccharide derivatives. The terms "SSF" and "SHF" are known to those skilled in the art; SSF meaning simultaneous saccharification and fermentation, or the conversion from polysaccharides or oligosaccharides into monosaccharides at the same time and in the same fermentation vessel wherein monosaccharides are converted to another chemical product such as ethanol. "SHF" indicates a physical separation of the polymer hydrolysis or saccharification and fermentation processes.

[00123] The term "biomass" as used herein has its ordinary meaning as known to those skilled in the art and can include one or more biological materials that can be converted into a biofuel, chemical or other product. Biomass as used herein is synonymous with the term "feedstock" and includes corn syrup, molasses, silage, agricultural residues (corn stalks, grass, straw, grain hulls, bagasse, etc.), animal waste (manure from cattle, poultry, and hogs), Distillers Dried Solubles (DDS), Distillers Dried Grains (DDG), Condensed Distillers Solubles (CDS), Distillers Wet Grains (DWG), Distillers Dried Grains with Solubles (DDGS), woody materials (wood or bark, sawdust, timber slash, and mill scrap), municipal waste (waste paper, recycled toilet papers, yard clippings, etc.), and energy crops (poplars, willows, Eucalyptus, switchgrass, alfalfa, prairie bluestem, algae, including macroalgae, etc.). One exemplary source of biomass is plant matter. Plant matter can be, for example, woody plant matter, non-woody plant matter, cellulosic material, lignocellulosic material, hemicellulosic material, carbohydrates, pectin, starch, inulin, fructans, glucans, corn, sugar cane, grasses, switchgrass, sorghum, high biomass sorghum, bamboo, algae and material derived from these. Plants can be in their natural state or genetically modified, *e.g.*, to increase the cellulosic or hemicellulosic portion of the cell wall, or to produce additional exogenous or endogenous enzymes to increase the separation of cell wall components. Plant matter can be further described by reference to the chemical species present, such as proteins, polysaccharides and oils. Polysaccharides include polymers of various monosaccharides and derivatives of monosaccharides including glucose, fructose, lactose, galacturonic acid, rhamnose, etc. Plant matter also includes agricultural waste byproducts or side streams such as pomace, corn steep liquor, corn steep solids, distillers grains, peels, pits, fermentation waste, straw, lumber, sewage, garbage and food leftovers. Peels can be citrus which include, but are not limited to, tangerine peel, grapefruit peel, orange peel, tangerine peel,

lime peel and lemon peel. These materials can come from farms, forestry, industrial sources, households, etc. Another non-limiting example of biomass is animal matter, including, for example milk, meat, fat, animal processing waste, and animal waste. "Feedstock" is frequently used to refer to biomass being used for a process, such as those described herein.

[00124] "Broth" is used herein to refer to inoculated medium at any stage of growth, including the point immediately after inoculation and the period after any or all cellular activity has ceased and can include the material after post-fermentation processing. It includes the entire contents of the combination of soluble and insoluble matter, suspended matter, cells and medium, as appropriate.

[00125] The term "productivity" as used herein has its ordinary meaning as known to those skilled in the art and can include the mass of a material of interest produced in a given time in a given volume. Units can be, for example, grams per liter-hour, or some other combination of mass, volume, and time. In fermentation, productivity is frequently used to characterize how fast a product can be made within a given fermentation volume. The volume can be referenced to the total volume of the fermentation vessel, the working volume of the fermentation vessel, or the actual volume of broth being fermented. The context of the phrase will indicate the meaning intended to one of skill in the art. Productivity is different from "titer" in that productivity includes a time term, and titer is analogous to concentration. Titer and Productivity can generally be measured at any time during the fermentation, such as at the beginning, the end, or at some intermediate time, with titer relating the amount of a particular material present or produced at the point in time of interest and the productivity relating the amount of a particular material produced per liter in a given amount of time. The amount of time used in the productivity determination can be from the beginning of the fermentation or from some other time, and go to the end of the fermentation, such as when no additional material is produced or when harvest occurs, or some other time as indicated by the context of the use of the term. "Overall productivity" refers to the productivity determined by utilizing the final titer and the overall fermentation time.

[00126] "Titer" refers to the amount of a particular material present in a fermentation broth. It is similar to concentration and can refer to the amount of material made by the organism in the broth from all fermentation cycles, or the amount of material made in the current fermentation cycle or over a given period of time, or the amount of material present from whatever source, such as produced by the organism or added to the broth. Frequently, the titer of soluble species will be referenced to the liquid portion of the broth, with insolubles removed, and the titer of insoluble species will be referenced to the total amount of broth with insoluble

species being present, however, the titer of soluble species can be referenced to the total broth volume and the titer of insoluble species can be referenced to the liquid portion, with the context indicating the which system is used with both reference systems intended in some cases. Frequently, the value determined referenced to one system will be the same or a sufficient approximation of the value referenced to the other.

[00127] "Concentration" when referring to material in the broth or in solution generally refers to the amount of a material present from all sources, whether made by the organism or added to the broth or solution. Concentration can refer to soluble species or insoluble species, and is referenced to either the liquid portion of the broth or the total volume of the broth, as for "titer." When referring to a solution, such as "concentration of the sugar in solution", the term indicates increasing one or more components of the solution through evaporation, filtering, extraction, etc., by removal or reduction of a liquid portion.

[00128] The term "biocatalyst" as used herein has its ordinary meaning as known to those skilled in the art and can include one or more enzymes, and/or microorganisms, including solutions, suspensions, and mixtures of enzymes and microorganisms. In some contexts this word will refer to the possible use of either enzymes or microorganisms to serve a particular function, in other contexts the word will refer to the combined use of the two, and in other contexts the word will refer to only one of the two. The context of the phrase will indicate the meaning intended to one of skill in the art. For example, a biocatalyst can be a fermenting microorganism.

[00129] The terms "conversion efficiency" or "yield" as used herein have their ordinary meaning as known to those skilled in the art and can include the mass of product made from a mass of substrate. The term can be expressed as a percentage yield of the product from a starting mass of substrate. For the production of C5 and C6 saccharides (*e.g.*, monosaccharides, *e.g.*, glucose, xylose, arabinose, *etc.*) or soluble saccharide polymers (*e.g.*, polymers comprising two or more saccharide units or residues), the yield is based upon the actual weight of the saccharides released compared to the weight of the oligosaccharides or-polysaccharides (*e.g.*, cellulose, hemicellulose) in the input biomass. For the production of ethanol from glucose, the net reaction is generally accepted as:

$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$$

and the theoretical maximum conversion efficiency, or yield, is 51% (wt.). Frequently, the conversion efficiency will be referenced to the theoretical maximum, for example, "80% of the theoretical maximum." In the case of conversion of glucose to ethanol, this statement would

indicate a conversion efficiency of 41% (wt.). The context of the phrase will indicate the substrate and product intended to one of skill in the art.

[00130] For substrates (*e.g.*, a biomass composition) comprising a mixture of different carbon sources (*e.g.*, xylan, xylose, glucose, cellobiose, arabinose, cellulose, hemicellulose, *etc.*), the theoretical maximum conversion efficiency of the biomass to saccharides or ethanol can be calculated as an average of the maximum yields or conversion efficiencies of the individual carbon source constituents weighted by the relative concentration of each carbon source. In some cases, the theoretical maximum conversion efficiency can be calculated based on an assumed saccharification efficiency. By way of example only, given a carbon source comprising 10 g of cellulose, the theoretical maximum conversion efficiency can be calculated by assuming saccharification of the cellulose to the assimilable carbon source (glucose) of about 75% by weight. In this example, 10 g of cellulose can provide 7.5 g of glucose which can provide a maximum theoretical conversion efficiency of about 7.5 g*51% or 3.8 g of ethanol. In another aspect, the assimilable carbon source can be a sugar or saccharide polymer or oligomer containing multiple saccharide residues or units. In this aspect, assuming a maximum theoretical conversion efficiency of about 75% by weight, a carbon source comprising 10 g of a polysaccharide can provide 7.5 g of sugar polymers which can be further hydrolyzed and/or fermented using a biocatalyst and/or exogenous enzymes. In other cases, the efficiency of the saccharification step can be calculated or determined based upon a measurement of the sugars content of an input biomass, *e.g.*, following hydrolysis with 72% sulfuric acid. *See* A Sluiter, *et al.*, Determination of Structural Carbohydrates and Lignin in Biomass (NREL, revised June 2010), which is hereby incorporated by reference in its entirety. Saccharification efficiencies anticipated by the present invention include about 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, 99% or about 100% for any carbohydrate carbon sources larger than a single monosaccharide subunit.

[00131] "Pretreatment" or "pretreated" is used herein to refer to any mechanical, chemical, thermal, biochemical process or combination of these processes whether in a combined step or performed sequentially, that achieves disruption or expansion of the biomass so as to render the biomass more susceptible to attack by enzymes and/or microbes, and can include the enzymatic hydrolysis of released carbohydrate polymers or oligomers to monomers. In one embodiment, pretreatment includes removal or disruption of lignin so as to make the cellulose and hemicellulose polymers in the plant biomass more available to cellulolytic and/or hemicellulolytic enzymes and/or microbes, for example, by treatment with acid or base. In one embodiment, pretreatment includes disruption or expansion of cellulosic and/or hemicellulosic

material. In another embodiment, it can refer to starch release and/or enzymatic hydrolysis to glucose. Steam explosion, and ammonia fiber expansion (or explosion) (AFEX) are well known thermal/chemical techniques. Hydrolysis, including methods that utilize acids, bases, and/or enzymes can be used. Other thermal, chemical, biochemical, enzymatic techniques can also be used.

[00132] "Fed-batch" or "fed-batch fermentation" is used herein to include methods of culturing microorganisms where nutrients, other medium components, or biocatalysts (including, for example, enzymes, fresh organisms, extracellular broth, genetically modified plants and/or organisms, etc.) are supplied to the fermentor during cultivation, but culture broth is not harvested from the fermentor until the end of the fermentation, although it can also include "self seeding" or "partial harvest" techniques where a portion of the fermentor volume is harvested and then fresh medium is added to the remaining broth in the fermentor, with at least a portion of the inoculum being the broth that was left in the fermentor. During a fed-batch fermentation, the broth volume can increase, at least for a period, by adding medium or nutrients to the broth while fermentation organisms are present. Suitable nutrients which can be utilized include those that are soluble, insoluble, and partially soluble, including gasses, liquids and solids. In one embodiment, a fed-batch process is referred to with a phrase such as, "fed-batch with cell augmentation." This phrase can include an operation where nutrients and cells are added or one where cells with no substantial amount of nutrients are added. The more general phrase "fed-batch" encompasses these operations as well. The context where any of these phrases is used will indicate to one of skill in the art the techniques being considered.

[00133] "Sugar compounds" or "sugar streams" or "saccharide compounds" or "saccharide streams" is used herein to indicate mostly monosaccharide sugars, dissolved, crystallized, evaporated, or partially dissolved, including but not limited to hexoses and pentoses; sugar alcohols; sugar acids; sugar amines; compounds containing two or more of these linked together directly or indirectly through covalent or ionic bonds; and mixtures thereof. Included within this description are disaccharides; trisaccharides; oligosaccharides; polysaccharides; and sugar chains, branched and/or linear, of any length. A saccharide stream can consist of primarily or substantially C6 sugars, C5 sugars, or mixtures of both C6 and C5 sugars in varying ratios of said sugars. C6 sugars have a six-carbon molecular backbone and C5 sugars have a five-carbon molecular backbone.

[00134] "C5-rich" composition means that one or more steps have been taken to remove at least some of the C6 sugars originally in the composition. For example, a C5-rich composition can include no more than about 50% C6 sugars, nor more than about 40% C6 sugars, no more

than about 30% C6 sugars, no more than about 20% C6 sugars, no more than about 10% C6 sugars, no more than about 5% C6 sugars, or it can include from about 2% to about 10% C6 sugars by weight. Likewise, a "C6-rich" composition is one in which at least some of the originally-present C5 sugars have been removed. For example, a C6-rich composition can include no more than about 50% C5 sugars, nor more than about 40% C5 sugars, no more than about 30% C5 sugars, no more than about 20% C5 sugars, no more than about 10% C5 sugars, no more than about 5% C5 sugars, or it can include from about 2% to about 10% C5 sugars by weight.

[00135] "Saccharide oligomer" is used herein to indicate a saccharide that contains two to ten saccharide residues or units or derivatives of saccharide units. In one embodiment, a saccharide oligomer can be soluble. In one embodiment, a saccharide oligomer can be soluble in an aqueous medium. In some embodiments, the saccharide oligomer comprise 2 to 10 or 2 to 9, 2 to 8, 2 to 7, 2 to 6, 2 to 5, 2 to 4, or 2 to 3 saccharide residues or units, or between 2 to 5 saccharide units. In some embodiments, the saccharide oligomer comprises more than 2 saccharide residues. In some embodiments, the saccharide oligomers comprise 2 saccharide residues. In some embodiments, the saccharide oligomers comprise less than 10 saccharide residues. In some embodiments, the saccharide polymers comprise 2, 3, 4, 5, 6, 7, 8, 9, or 10 saccharide residues or units.

[00136] "Saccharide polymer" is used herein to indicate a saccharide that contains two or more saccharide residues or units or derivatives of saccharide units. In one embodiment, a saccharide polymer can be soluble. In one embodiment, a saccharide polymer can be soluble in an aqueous medium. In some embodiments, the saccharide polymer comprises 2 to 10 saccharide residues or units. In some embodiments, the saccharide polymers comprise 2 to 10 or 2 to 20, 2 to 30, 2 to 40, 2 to 50, 2 to 60, 2 to 70, 2 to 80, 2 to 90, or 2 to 100 saccharide residues or units. In some embodiments, the saccharide polymers comprise more than 2 saccharide residues. In some embodiments, the saccharide polymers comprise 2 saccharide residues. In some embodiments, the saccharide polymers comprise less than 10 saccharide residues. In some embodiments, the saccharide polymers comprise more than 10 saccharide residues. In some embodiments, the saccharide polymers comprise 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 105, 110, 115, 120, 125, 130, 135, 140, 145, 150, 155, 160, 165, 170, 175, 180, 185, 190, 195, 200, 210, 220, 230, 240, 250, 260, 270, 280, 290, or 300 saccharide residues or units. In

some embodiments, the saccharide polymers comprise disaccharides, trisaccharides, tetrasaccharides, pentasaccharides, hexasaccharides, heptasaccharides, octasaccharides, enneasaccharides, and/or decasaccharides. In some embodiments, the saccharide polymers comprise less than 100 saccharide residues. In some embodiments, the saccharide polymers comprise less than 200 saccharide residues. In some embodiments, the saccharide polymers comprise less than 300 saccharide residues. In some embodiments, the saccharide polymers comprise more than 100 saccharide residues. In some embodiments, the saccharide polymers comprise more than 200 saccharide residues. In some embodiments, the saccharide polymers comprise more than 300 saccharide residues. In some embodiments, the saccharide polymers comprise more than 10 and less than 100 saccharide residues. In some embodiments, the saccharide polymers comprise from 10 to 100 saccharide residues. In some embodiments, the saccharide polymers comprise between 10 to 100 saccharide residues. In some embodiments, the saccharide polymers comprise 10 to 100 saccharide residues. In some embodiments, the saccharide polymers comprise more than 10 and less than 100 saccharide residues. In some embodiments, the saccharide polymers comprise from 10 to 100 saccharide residues. In some embodiments, the saccharide polymers comprise between 10 to 100 saccharide residues. In some embodiments, the saccharide polymers comprise 10 to 100 saccharide residues.

[00137] A "liquid" composition may contain solids and a "solids" composition may contain liquids. A liquid composition refers to a composition in which the material is primarily liquid, and a solids composition is one in which the material is primarily solid.

[00138] The terms "non-cellulosic" and "sugar- or starch- based" are used interchangeably and have the same meaning. For example "non-cellulosic fermentation process" is used interchangeably and means the same thing as "sugar- and starch-based fermentation process." Starch is a carbohydrate consisting of consisting of a large number of glucose units joined by glycosidic bonds. The glycosidic bonds are typically the easily hydrolysable alpha glycosidic bonds. This polysaccharide can be produced by all green plants as an energy store. There can be two types of starch molecules: the linear and helical amylose and the branched amylopectin, although amylase can also contain branches.

Description

[00139] The following description and examples illustrate some exemplary embodiments of the disclosure in detail. Those of skill in the art will recognize that there are numerous variations and modifications of this disclosure that are encompassed by its scope. Accordingly, the description of a certain exemplary embodiment should not be deemed to limit the scope of the present disclosure.

[00140] Introduction

[00141] Many of the methods used to make the hemicellulose and cellulose of biomass more accessible can generate inhibitor compounds that can negatively affect downstream processing, such as saccharification and/or fermentation. There is a need for pretreatment process that provides a biomass fraction that is accessible to effective enzymatic and/or other downstream hydrolysis reactions without the formation or release of large volumes of inhibitors.

[00142] Some methods used in pretreating biomass utilize high temperatures, pressure and/or steam without a highly satisfactory result to extract most or all the carbohydrate in biomass. Alkali pretreatment can be used, but can be costly because of the high volume of water that may be necessary to rinse the biomass. Acid hydrolysis can be used to extract and reduce the hemicellulose and cellulose to C5 and C6 saccharides. Because the process uses acid, process equipment such as pumps and pipes must be corrosion resistant and can be more expensive than those used to process grains. In addition, the process, especially under high temperatures and pressure, can release structural carbohydrates in cellulosic biomass and can expose crystalline cellulose to enzymatic degradation. The hydrolyzed sugars produced through this pretreatment process themselves can be labile to the harsh hydrolysis conditions and can be degraded to unwanted or toxic byproducts. If exposed to acid too long, especially under high temperatures, the glucose derived from cellulose can degrade into hydroxymethylfurfural, which can be further degraded into levulinic acid and formic acid. Xylose, a hemicellulose sugar, can be degraded into furfural and further to tars and other degradation products. The inhibitors produced can be difficult to remove and can negatively affect the fermentation process. This process can also generate neutralization byproducts, such as calcium sulfate or gypsum, which may need to be isolated and disposed of.

[00143] Methods of pretreating biomass to avoid acid processing have also been investigated. For example, U.S. Pat. No. 5,846,787 discloses a process in which cellulose-containing material is pretreated by combining the material with water in a reactor and heating the resultant combination to a temperature of 160°C to 220°C while maintaining the pH at 5 to 8. The resultant material may then be hydrolyzed using enzymes. This process, however, only works on herbaceous materials and biomass that has been preprocessed (municipal sewage waste, recycled materials, *etc.*) It may not work well on a woody biomass. Furthermore, the above methods only result in process slurries that must be significantly diluted to be manageable. And, prior acid and steam explosion processes may be limited to 8% to 15% by weight solids based on the total weight of the slurry.

[00144] The processes described above are designed to make the carbohydrate polymers accessible to enzymatic hydrolysis or other non-enzymatic hydrolysis (e.g., non-enzymatic polymer –based catalyst hydrolysis) to produce monomeric saccharides. The C5 and C6 sugars are naturally embedded in and cross-linked with lignin, extractives and phenolics. Hemicellulose has acetic ether bonds and its breakdown can lead to acid formation. High temperature and pressures during pretreatment and/or hydrolysis can result in the leaching of lignin and aromatics, which are dark brown, loading with mixed sugars, high ash, lignin aromatic fragments, inhibitors such as HMF, and acids in a resulting saccharide stream. To produce a higher saccahride concentration in the saccharide stream, and thus minimize evaporation cost, can require high solids concentration processing which can lead to increased phenolics and inhibitor levels. Recovered saccharides therefore can require expensive pretreatment and a costly refinement process to remove the substantial amount of inhibitors, saccharide breakdown products, and color. The refinement process can comprise multiple steps, including color removal, ion exchange and other expensive procedures performed on dilute saccharide streams, after which the streams need to be concentrated for customers.

[00145] Further, inhibitors released during pretreatment can interfere with enzymatic hydrolysis and simultaneous or subsequent fermentation, which can necessitate use of higher concentrations of enzymes in the polymeric saccharide streams. Some of these enzymes, such as hemicellulases, can be extremely expensive. In addition, enzymatic hydrolysis can take a long time, adding to the cost of sugars and increasing the chances of contamination.

[00146] Production of saccharide streams can comprise the use of polymeric catalysts. The use of polymeric acid catalysts can reduce the cost and time of producing saccharide streams from biomass in comparison to the use of chemical hydrolysis (e.g., acid-based or alkali-based) and/or enzymatic hydrolysis.

[00147] In some of the steps of the usual state-of-the-art sugar extraction of biomass, a great amount of water can be used. For example, washing biomass, steam treatments with or without acid or alkali solutions, and enzymatic hydrolysis can require large volumes of water. During some steps, such as washing, water can be recovered. It can be difficult to recover water from an enzymatic broth, however, and concentration of sugar solutions can be expensive.

[00148] These underlying complex challenges have been some of the key reasons that production of cellulosic-derived sugars can be expensive, which can make it economically challenging for the cellulosic sugar industry to compete with petroleum or starch-based sugar technology. Biochemical and bioplastics industries, due to their stringent process operations, demand the same, high level of refinement in use of cellulosic sugars as they require for other

sources. There is a need in the art to develop simple, scalable, and feedstock flexible solutions for cellulosic-based sugar platform technology to enable a higher concentration of cellulosic sugar hydrolysate to be rapidly processed, refined, and clarified in order to be competitive with starch-based sugar recovery and economics. To date, most of the work at research and processing centers such as the DOE, NREL and other laboratories developing cellulosic sugar platforms, are based on dilute streams of biomass hydrolysate and refinement of sugars. But dilute streams will need further evaporation, leading to higher energy and operating cost.

[00149] As described above, cellulosic sugar solutions produced by pretreatment and/or subsequent hydrolysis of pretreated biomass can have elevated levels of inhibitors such as acetic and formic acids. Removal of these inhibitors in a cost effective manner increases the usefulness of the sugar solutions as a feedstock for other processes such as biofuels, bioplastics, and industrial oils production. Evaporation can be used as a means to remove inhibitors from cellulosic sugar solutions.

[00150] Herein is described a novel process using polymeric catalysts to perform solid:solid catalysis on biomass comprising cellulose, hemicellulose and/or lignocellulose. Also provided herein is an evaporation:condensation based purification for the production of refined saccharide streams. The processes disclosed can minimize the use of enzymes and/or harsh chemical hydrolysis. The processed disclosed can also, or alternatively, produce saccharides in concentrated saccharide streams derived from pretreatment of cellulosic and lignocellulosic materials with reduced levels of fermentation inhibitors.

Feedstock and Pretreatment of Feedstock

[00151] Disclosed herein are methods of producing saccharide stream comprising C5 and/or C6 saccharides from a biomass composition comprising cellulose, hemicellulose, and/or lignocellulose. The methods can comprise pretreatment of the biomass composition and/or enzymatic hydrolysis of the pretreated biomass. The methods can comprise pretreatment of the biomass composition and/or non-enzymatic hydrolysis of the pretreated biomass (e.g., with polymeric catalysts). Pretreatment of the biomass composition can reduce solid particle size. Reducing the size of biomass solids can increase the efficiency of other processing steps such as chemical treatment, thermal treatment, enzymatic treatment. Increased efficiency can mean that less time is required in another processing step. Increased efficiency can mean that a higher yield of a desirable product such as C5 and/or C6 saccharides is produced in another processing step. Increased efficiency can mean that fewer inhibitors are produced in another processing step. The methods can comprise treatment of the pretreated biomass in order to remove inhibitors produced during pretreatment. The methods can comprise treatment of the C5 and/or C6

saccharide compositions in order to remove inhibitors produced during hydrolysis of the pretreated biomass.

[00152] Biomass (feedstock) can be derived from agricultural crops, crop residues, trees, woodchips, sawdust, paper, cardboard, grasses, algae, municipal waste and other sources as described *supra*. The biomass can comprise cellulosic, hemicellulosic, and/or lignocellulosic material. The biomass can comprise woody material (e.g., poplar, Eucalyptus, willow, pine, *etc.*). The biomass can comprise non-woody plant material, such as grasses, dicots, monocots, *etc.* The biomass can comprise algal biomass, nonvascular plant biomass, and/or processed materials derived from plants; *e.g.*, hulls, distiller's grains, municipal sewage waste, and the like.

[00153] A biomass composition comprising cellulose, hemicellulose, and/or lignocellulose can comprise alfalfa, algae, bagasse, bamboo, corn stover, corn cobs, corn kernels, corn mash, corn steep liquor, corn steep solids, distiller's grains, distiller's dried solubles, distiller's dried grains, condensed distiller's solubles, distiller's wet grains, distiller's dried grains with solubles, eucalyptus, food waste, fruit peels, garden residue, grass, grain hulls, modified crop plants, municipal waste, oat hulls, paper, paper pulp, prairie bluestem, poplar, rice hulls, seed hulls, silage, sorghum, straw, sugarcane, switchgrass, wheat, wheat straw, wheat bran, de-starched wheat bran, willows, wood, plant cells, plant tissue cultures, tissue cultures, or a combination thereof.

[00154] Cellulose is a linear polymer of glucose where the glucose units are connected via β(1→4) linkages. Hemicellulose is a branched polymer of a number of sugar monomers including glucose, xylose, mannose, galactose, rhamnose and arabinose, and can have sugar acids such as mannuronic acid and galacturonic acid present as well. Lignin is a cross-linked, racemic macromolecule of mostly *p*-coumaryl alcohol, conferyl alcohol and sinapyl alcohol. These three polymers occur together in lignocellusic materials in plant biomass. The different characteristics of the three polymers can make hydrolysis of the combination difficult as each polymer tends to shield the others from enzymatic attack.

[00155] Prior to pretreatment of a biomass composition, some processing can occur. For example, debris, such as soil, inert matter (rocks, pebbles) and other non-biological material can be removed by sifting or sorting in some manner. The biomass composition can be cleaned by washing with water or other chemicals. The biomass composition can be dried. The biomass composition can be mechanically processed (*e.g.*, coarse chopped or ground) to reduce the size of any solids prior to pretreatment. The amount of mechanical processing prior to pretreatment can depend upon the biomass. For example, woody materials can be chipped, cut, milled, ground prior or otherwise reduced in size prior to pretreatment. Woody materials can be reduced in size

to about a cm or less prior to pretreatment. Woody materials can be reduced to less than 0.5 cm prior to pretreatment. In another example, agricultural residues (*e.g.*, corn stover, wheat, straw, *etc.*) can be cut, chopped, shredded, or otherwise reduced in size prior to pretreatment. Agricultural residues can be reduced in size to less than 10 cm in length prior to pretreatment. Agricultural residues can be reduced in size to less than 5 cm in length prior to pretreatment.

[00156] See, *e.g.*, U.S. Patents No. 5,865,898, No. 8,110,383, No. 7,932,063, or No. 7,503,981, which are hereby incorporated by reference in their entireties.

[00157] The preferred particle size of solid materials in a biomass composition for pretreatment can vary according to a number of factors, including: the composition of the biomass material, the composition of the liquid hydrocarbon material, the velocity of the liquid hydrocarbon material, the temperature and pressure of the suspension, the material of the conduit (*e.g.* pipe or tank), holding the suspension, the amount of time the suspension is to remain together and the like considerations. In one embodiment, the suspension of the biomass material and liquid hydrocarbon material is contained within a pipe at a refinery and the biomass material may be considered efficiently carried by the liquid hydrocarbon material so long as the pipe does not substantially plug after continued use.

[00158] Consumers of saccharide streams produced from biomass have a variety of needs regarding the purity and concentration of the saccharides. In general, the more reduced the inhibitor concentration, the more fermentable the saccharides. Purified saccharides can be used to produce concentrated, clean end-products of fermentation such as succinic acid which can be used, for example, as a precursor for plastic manufacture. To satisfy a wide range of consumers of saccharides, the amount of C5 and C6 saccharides that go into each batch for distribution can be controlled.

[00159] Pretreatment processes that differentially solubilize hemicellulose and cellulose can enable the production of separate saccharide streams in order to produce C6-enriched saccharide streams and C5-enriched saccharide streams. A pretreatment that results in a fine, homogeneous (uniform) particle size can allow for solubilization of over 85% of the available hemicellulose while leaving the cellulose in solid form. The solubilized hemicellulose can be separated from the cellulose solids as a C5-enriched saccharide stream. The cellulose solids can then be hydrolyzed (e.g., with enzymes or polymeric catalysts) to produce a C6-enriched saccharide stream. Alternatively, the solubilized hemicellulose and cellulose solids can be hydrolyzed together (e.g., with enzymes or polymeric catalysts).

[00160] Reducing particle size during pretreatment can reduce the evaporation needed to achieve a concentrated C5 stream and, therefore reduces the phenolics and other inhibitors present in the

system making the C5 stream more fermentable than what could be achieved by poor solubilization of hemicellulose during pretreatment. When the particle size is reduced, the cooking of the material during pretreatment is much more uniform. With heterogeneous material, some particles are undercooked and some are overcooked. As the particle size becomes more homogenous or uniform, cooking can be optimized across the entire system. This even heating prevents charring of the material that can lead to significant losses in saccharides and higher production of inhibitors. Uniform heat throughout the biomass also prevents undercooking which can lead to unhydrolyzed cellulose during enzyme hydrolysis.

[00161] Pretreating a biomass composition can comprise mechanical, thermal, pressure, chemical, thermochemical, and/or biochemical processes. These processes can be performed individually or in combination. Pretreatment of the biomass composition can be performed such that any solids are reduced in size. Reducing the size of solids in the biomass composition can be advantageous because smaller particles have larger surface area to volume ratios. Increasing the ratio of surface area to volume can be advantageous because it can, for example, increase the rate of particle wetting (*e.g.*, with water or a chemical agent such as an acid or a base), increase the accessibility of enzymes to the polysaccharides in the biomass, increase the accessibility of polymeric catalysts to the polysaccharides in the biomass, enable the use of a smaller dose of enzymes during a hydrolysis of the biomass, enable the use of a smaller dose of polymeric catalyst during a hydrolysis of the biomass, enable the use of fewer or lower amounts of chemicals (*e.g.*, acids or bases) during a pretreatment and/or hydrolysis step, enable the use of weaker acids or bases in a pretreatment or hydrolysis step, enable the use of higher concentrations of solids in any further processing step (*e.g.*, during a hydrolysis step), and/or increase the yield of saccharides from the hydrolysis of the biomass.

[00162] Biomass compositions can be reduced in size to a mixture of particles having a uniform, or substantially uniform, size. Such mixtures can be referred to as homogeneous mixtures or uniform mixtures. Homogeneous mixtures of particles can have many advantages over mixtures of particles having heterogeneous sizes with respect to further pretreatment processes and/or during hydrolysis to produce saccharide streams. The size can refer to size dimensions. Size dimensions refer to the length, width, or height of a particle or solid particle. Size dimension also refers to the diameter of a particle or solid particle. For example, heterogeneous mixtures of particles can experience uneven heating during thermal and thermochemical processing steps. Uneven heating can lead to overcooking (*e.g.*, charring/burning) of particles and/or undercooking of particles. Charring or burning of particles can reduce the yield of saccharide from the hydrolysis of the particles; this can be due to degradation or denaturation of saccharide

polymers such as starch, hemicellulose, and/or cellulose. Undercooking of particles can lead to unhydrolyzed saccharide polymers (*e.g.*, starch, hemicellulose, cellulose) during enzymatic or chemical hydrolysis, which can also reduce the yield of saccharide. In contrast, uniform heating, wetting, chemical treatment (*e.g.*, acid or base treatment), and/or enzyme hydrolysis can be achieved with mixtures of particles having uniform sizes (*e.g.*, homogeneous mixtures). In one embodiment, the pretreatment of biomass compositions using the methods as described herein produce mixtures of particles with uniform or homogenous sizes. In one embodiment, the mixture of particles with uniform or homogenous sizes can be hydrolyzed using lower or reduced enzymes loads. In one embodiment, the mixture of particles with uniform or homogenous sizes can be hydrolyzed using polymeric catalysts. In one embodiment, the mixture of particles with uniform or homogenous sizes can be hydrolyzed using polymeric acid catalysts. In one embodiment, the mixture of particles with uniform or homogenous sizes can be hydrolyzed using lower or reduced polymeric catalyst loads. In one embodiment, the mixture of particles with uniform or homogenous sizes can be hydrolyzed using lower or reduced polymeric acid catalyst loads.

[00163] Methods are provided herein for the pretreatment of biomass used in the production of saccharide streams and/or production of fermentation end-products such as biofuels and chemicals.

[00164] Pretreatment can include mechanical, thermal, pressure, chemical, thermochemical, and/or biochemical tests pretreatment prior to being used in a bioprocess for the production of fuels and chemicals, but untreated biomass material can be used in the process as well. Mechanical processes can reduce the particle size of the biomass material so that it can be more conveniently handled in the bioprocess and can increase the surface area of the feedstock to facilitate contact with chemicals/biochemicals/biocatalysts. Mechanical processes can also separate one type of biomass material from another. The biomass material can also be subjected to thermal and/or chemical pretreatments to render plant polymers more accessible. Multiple steps of treatment can also be used.

[00165] Mechanical processes include, are not limited to, washing, soaking, milling, size reduction, screening, shearing, chopping, pressurization, and the like, as well as size classification and density classification processes. Any process can be used that reduces the size of the feedstock to a homogeneous or uniform mixture of particles of less than 50 mm, less than 40 mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, or 1 mm in a dimension (*e.g.*, diameter or length, width, or height). One such method is to use a vortex

generator and cutting system such as that found in U.S. Patent Applications Nos. 2002192774A1, 2012037325A1, and 2011275860A1.

[00166] In one embodiment, biomass is conveyed into a vortex mixer outfitted with blades. Water with or without one or more acids, bases, or other chemicals (*e.g.*, dilute sulfuric acid) is dispersed with these solids in a mix of 5% solids to 95% water at about 50°C. The vortex is intended to pull the materials through while the pH is adjusted and temperature maintained. The material is deposited in a second chamber where dewatering takes place until the feedstock is a plug. The feedstock plug then goes through other blades with microholes. Steam is added to maintain heat and pressure and the plug is subjected to even 160° C to 180° C temperatures and thorough cooking and mixing for a period of time as it is pushed through a pipe. At the end of the pipe, the material is subjected to steam explosion and is collected into a bin where water is added to a desired solid to liquid ratio. A polymeric catalyst can be added to the material to a desired solid:solid ratio, optionally followed by an adjustment of the solid to liquid ratio through the addition or removal of water. Polymeric catalysts suitable for such a process are disclosed herein.

[00167] A biomass composition can be conveyed into a vortex mixer outfitted with blades. Water with or without one or more acids, bases, or other chemicals (*e.g.*, dilute sulfuric acid) is dispersed with these solids in ratio of 5:1, 4:1, 3:1, 2:1, 1:1, 1:2, 1:3, 1:4, 1:5, or less than 1:5. In one embodiment, the water is at about 50°C. The vortex is intended to pull the materials through while the pH is adjusted and temperature maintained. The material is deposited in a second chamber where dewatering takes place until the biomass composition forms a plug. The biomass composition plug then goes through other blades with microholes. Steam is added to maintain heat and pressure and the plug is subjected to even 160° C to 180° C temperatures and thorough cooking and mixing for a period of time as it is pushed through a pipe. At the end of the pipe, the material is subjected to steam explosion and is collected into a bin where water is added to a desired solid to liquid ratio. A polymeric catalyst can be added to the biomass composition in a desired solid:solid ratio. Addition of the polymeric catalyst can be followed by an adjustment of the solid to liquid ratio through the addition or removal of water. The polymeric catalyst can be added at a number of points in this process. For example, one or more polymeric catalysts can be added with the biomass composition in the vortex mixer. The one or more polymeric catalysts can be added to the biomass composition in the form of a plug, before or after the blades with microholes. The one or more polymeric catalysts can be added after stream explosion.

[00168] Chemical pretreatment processes include, but are not limited to, bleaching, oxidation, reduction, acid treatment, base treatment, sulfite treatment, acid sulfite treatment, basic sulfite

treatment, ammonia treatment, hydrolysis, ionic liquid dissolution, or a combination thereof. Thermal pretreatment processes include, but are not limited to, sterilization, ammonia fiber expansion or explosion ("AFEX"), steam explosion, holding at elevated temperatures, pressurized or unpressurized, in the presence or absence of water, and freezing. Biochemical processes include, but are not limited to, treatment with enzymes, including enzymes produced by genetically-modified plants, and treatment with microorganisms. Various enzymes that can be utilized include cellulase, amylase, β-glucosidase, xylanase, gluconase, and other polysaccharases; lysozyme; laccase, and other lignin-modifying enzymes; lipoxygenase, peroxidase, and other oxidative enzymes; proteases; and lipases. Polymeric catalysts can be used as an enzyme substitute or in addition to the enzymes. One or more of the mechanical, chemical, thermal, thermochemical, and biochemical processes can be combined or used separately. Such combined processes can also include those used in the production of paper, cellulose products, microcrystalline cellulose, and cellulosics and can include pulping, kraft pulping, acidic sulfite processing. The feedstock can be a side stream or waste stream from a facility that utilizes one or more of these processes on a biomass material, such as cellulosic, hemicellulosic or lignocellulosic material. Examples include paper plants, cellulosics plants, distillation plants, cotton processing plants, and microcrystalline cellulose plants. The feedstock can also include cellulose-containing or cellulosic containing waste materials. The feedstock can also be biomass materials, such as wood, grasses, corn, starch, or saccharide, produced or harvested as an intended feedstock for production of ethanol or other products such as by biocatalysts.

[00169] In another embodiment, a method can utilize a pretreatment process disclosed in U.S. Patents and Patent Applications US20040152881, US20040171136, US20040168960, US20080121359, US20060069244, US20060188980, US20080176301, 5693296, 6262313, US20060024801, 5969189, 6043392, US20020038058, US5865898, US5865898, US6478965, 5986133, or US20080280338, each of which is incorporated by reference herein in its entirety

[00170] The AFEX process can be used for pretreatment of biomass. The AFEX process can be used in the preparation of cellulosic, hemicellulosic or lignocellulosic materials for fermentation to ethanol or other products. The process generally includes combining the feedstock with ammonia, heating under pressure, and suddenly releasing the pressure. Water can be present in various amounts. The AFEX process has been the subject of numerous patents and publications.

[00171] The pretreatment of biomass can comprise the addition of calcium hydroxide to a biomass to render the biomass susceptible to degradation. Pretreatment comprises the addition of calcium hydroxide and water to the biomass to form a mixture, and maintaining the mixture at a relatively high temperature. Alternatively, an oxidizing agent, selected from the group

consisting of oxygen and oxygen-containing gasses, can be added under pressure to the mixture. Examples of carbon hydroxide treatments are disclosed in U.S. Patent No. 5865898 to Holtzapple and S. Kim and M. T. Holtzapple, Bioresource Technology, 96, (2005) 1994, incorporated by reference herein in its entirety.

[00172] Pretreatment of biomass can comprise dilute acid hydrolysis. Example of dilute acid hydrolysis treatment are disclosed in T. A. Lloyd and C. E Wyman, Bioresource Technology, (2005) 96, 1967), incorporated by reference herein in its entirety.

[00173] Pretreatment of biomass can comprise pH controlled liquid hot water treatment. Examples of pH controlled liquid hot water treatments are disclosed in N. Mosier *et al.*, Bioresource Technology, (2005) 96, 1986, incorporated by reference herein in its entirety.

[00174] Pretreatment of biomass can comprise aqueous ammonia recycle process (ARP). Examples of aqueous ammonia recycle process are described in T. H. Kim and Y. Y. Lee, Bioresource Technology, (2005)96, 2007, incorporated by reference herein in its entirety.

[00175] Pretreatment of biomass compositions can comprise ionic liquid (IL) pretreatment. Pretreatment of biomass can comprise the use of ionic liquids to dissolute cellulose and/or hemicellulose. Biomass compositions can be pretreated by incubation with an ionic liquid, followed by IL extraction with a wash solvent such as alcohol or water. The treated biomass can then be separated from the ionic liquid/wash-solvent solution by centrifugation or filtration, and sent to the saccharification reactor or vessel. Examples of ionic liquid pretreatment are disclosed in US publication No. 2008/0227162, incorporated herein by reference in its entirety.

[00176] Suitable ionic liquids can include [bmim] 1-butyl-3-methylimidazolium, [emim] 1-ethyl-3-methylimidazolium, [amim] 1-allyl-3-methylimidazolium, [Ch] cholinium, [bzmim] 1-benzyl-3-methylimidazolium, [HEA] 2- hydroxyethylammonium, [bmpy] 1-butyl-3-methylpyridinium, [Me(OEt)3Et3N] triethyl-(2-(2-methoxyethoxy)ethoxy) ethylammonium, [DMEA] N,N-dimethylethanolammonium, [mmim] 1,3-dimethylimidazolium, [hmim] 1-hexyl-3-methylimidazolium, [pmim] 1-propyl-3-methylimidazolium, [abim] 1-allyl-3-butylimidazolium, [eMeOHpy] 1-ethyl-3-(hydroxymethyl)pyridine, [bHim] 1-butylimidazolium, [Cl] chloride, [CH3COO] acetate, [Et2PO4] diethylphosphate, [Me2PO4] dimethylphosphate, [MeOSO3] methylsulphate, [OTf] trifluoromethanesulphonate, [PrOO] propionate, [CF3COO] trifluoroacetate, [MeSO3] methanesulphonate, [HSO4] hydrogen sulphate, [PO(O)H2] phosphinate, [HCOO] formate, [BF4] tetrafluoroborate, [PF6] hexafluorophosphate, [Lys] lysinate, [Gly] glycinate, [Ala] alaninate, [Ser] serinate, [Thr] threoninate, [Met] methioninate, [Pro] prolinate, [Phe] phenylalaninate, [OHCH2COO] glycolate, [(CH2COO)2] succinate, [ABS] alkylbenzenesulphonate, [XS] xylenesulphonate, [MePO3] methylphosphonate, [EtPO3]

ethylphosphonate, [i-PrPO3] i-propylphosphonate, [BuPO3] butylphosphonate, [NTf2] bis(trifluoromethylsulfonyl)amide, [EtOSO3] ethylsulphate , or a combination thereof. Further details can be found in Costa Lopes et al. Sustainable Chemical Processes 2013, 1:3.

[00177] Pretreatment of biomass can comprise the use of a polymeric catalysts to hydrolyze cellulose or hemicelluloses into monosaccharides, disaccharides, oligosaccharides, or a combination thereof as described in US2012/0220740A1, US2013/0042859A1, and US2013/0042859A1, each of which is incorporated in its entirety.

[00178] The above mentioned methods can have two steps: a pretreatment step that leads to a wash stream, and an hydrolysis step of pretreated-biomass (e.g., with enzymes or polymeric catalysts) that produces a hydrolysate stream. In such methods, the pH at which the pretreatment step is carried out can include acid hydrolysis, hot water pretreatment, steam explosion or alkaline reagent based methods (AFEX, ARP, and lime pretreatments). Dilute acid and hot water treatment methods solubilize mostly hemicellulose, whereas methods employing alkaline reagents remove most lignin during the pretreatment step. As a result, the wash stream from the pretreatment step in the former methods contains mostly hemicellulose-based saccharides, whereas this stream has mostly lignin for the high-pH methods. The subsequent enzymatic hydrolysis of the residual biomass leads to mixed saccharides (C5 and C6) in the alkali based pretreatment methods, while glucose is the major product in the hydrolyzate from the low and neutral pH methods. In one embodiment, the treated material is additionally treated with catalase or another similar chemical chelating agents, surfactants, and other compounds to remove impurities or toxic chemicals or further release polysaccharides.

[00179] In another embodiment, a method can utilize a pretreatment process disclosed in U.S. Patent No. 4600590 to Dale, U.S. Patent No. 4644060 to Chou, U.S. Patent No. 5037663 to Dale. U.S. Patent No. 5171592 to Holtzapple, *et al.*, U.S. Patent No. 5939544 to Karstens, *et al.*, U.S. Patent No. 5473061 to Bredereck, *et al.*, U.S. Patent No. 6416621 to Karstens., U.S. Patent No. 6106888 to Dale, *et al.*, U.S. Patent No. 6176176 to Dale, *et al.*, PCT publication WO2008/020901 to Dale, *et al.*, Felix, A., *et al.*, Anim. Prod. 51, 47-61 (1990), Wais, A.C., Jr., *et al.*, Journal of Animal Science, 35, No. 1,109-112 (1972), which are incorporated herein by reference in their entireties.

[00180] Alteration of the pH of a pretreated feedstock can be accomplished by washing the feedstock (*e.g.*, with water) one or more times to remove an alkaline or acidic substance, or other substance used or produced during pretreatment. Washing can comprise exposing the pretreated feedstock to an equal volume of water 2, 3, 4, 5, 6, 7 , 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25 or more times. A pH modifier can be added. For example, an acid, a buffer,

or a material that reacts with other materials present can be added to modulate the pH of the feedstock. More than one pH modifier can be used, such as one or more bases, one or more bases with one or more buffers, one or more acids, one or more acids with one or more buffers, or one or more buffers. When more than one pH modifiers are utilized, they can be added at the same time or at different times. Other non-limiting exemplary methods for neutralizing feedstocks treated with alkaline substances have been described, for example in U.S. Patent Nos. 4,048,341; 4,182,780; and 5,693,296.

[00181] One or more acids can be combined, resulting in a buffer. Suitable acids and buffers that can be used as pH modifiers include any liquid or gaseous acid that is compatible with the microorganism. Non-limiting examples include peroxyacetic acid, sulfuric acid, lactic acid, citric acid, phosphoric acid, and hydrochloric acid. In some instances, the pH can be lowered to neutral pH or acidic pH, for example a pH of 7.0, 6.5, 6.0, 5.5, 5.0, 4.5, 4.0, or lower. In some embodiments, the pH is lowered and/or maintained within a range of about pH 4.5 to about 7.1, or about 4.5 to about 6.9, or about pH 5.0 to about 6.3, or about pH 5.5 to about 6.3, or about pH 6.0 to about 6.5, or about pH 5.5 to about 6.9 or about pH 6.2 to about 6.7.

[00182] A biomass composition can be pre-treated at an elevated temperature and/or pressure. For example, biomass can be pretreated at a temperature range of 20° C to 400° C. Biomass can be pretreated at a temperature of about 20°C, 25°C, 30°C, 35°C, 40°C, 45°C, 50°C, 55°C, 60°C, 65°C, 80°C, 90°C, 100°C, 120°C, 150°C, 200°C, 250°C, 300°C, 350°C, 400°C or higher. Elevated temperatures can be provided by the use of steam, hot water, or hot gases. Steam can be injected into a biomass containing vessel. The steam, hot water, or hot gas can be injected into a vessel jacket such that it heats, but does not directly contact the biomass.

[00183] A biomass can be treated at an elevated pressure. Biomass can be pretreated at a pressure range of about 1psi to about 30psi. For example, biomass can be pretreated at a pressure or about 1psi, 2psi, 3psi, 4psi, 5psi, 6psi, 7psi, 8psi, 9psi, 10psi, 12psi, 15psi, 18psi, 20psi, 22psi, 24psi, 26psi, 28psi, 30psi or more. In some embodiments, biomass can be treated with elevated pressures by the injection of steam into a biomass containing vessel. In one embodiment, the biomass can be treated to vacuum conditions prior or subsequent to alkaline or acid treatment or any other treatment methods provided herein.

[00184] Alkaline or acid pretreated biomass can be washed (*e.g.* with water (hot or cold) or other solvent such as alcohol (*e.g.* ethanol)), pH neutralized with an acid, base, or buffering agent (*e.g.* phosphate, citrate, borate, or carbonate salt) or dried prior to fermentation. The drying step can be performed under vacuum to increase the rate of evaporation of water or other solvents. Alternatively, or additionally, the drying step can be performed at elevated temperatures such as

about 20°C, 25°C, 30°C, 35°C, 40°C, 45°C, 50°C, 55°C, 60°C, 65°C, 80°C, 90°C, 100°C, 120°C, 150°C, 200°C, 250°C, 300°C or more.

[00185] The pretreatment step can include a step of solids recovery. The solids recovery step can be during or after pretreatment (*e.g.*, acid or alkali pretreatment), or before the drying step. In one embodiment, the solids recovery step provided by the methods of the present invention includes the use of a sieve, filter, screen, or a membrane for separating the liquid and solids fractions. In one embodiment, a suitable sieve pore diameter size ranges from about 0.001 microns to 8 mm, such as about 0.005 microns to 3 mm or about 0.01 microns to 1 mm. In one embodiment, a sieve pore size has a pore diameter of about 0.01 microns, 0.02 microns, 0.05 microns, 0.1 microns, 0.5 microns, 1 micron, 2 microns, 4 microns, 5 microns, 10 microns, 20 microns, 25 microns, 50 microns, 75 microns, 100 microns, 125 microns, 150 microns, 200 microns, 250 microns, 300 microns, 400 microns, 500 microns, 750 microns, 1mm or more. In one embodiment, biomass (*e.g.* corn stover) is processed or pretreated prior to fermentation. In one embodiment, a method of pre-treatment includes but is not limited to, biomass particle size reduction, such as for example shredding, milling, chipping, crushing, grinding, or pulverizing. In one embodiment, biomass particle size reduction can include size separation methods such as sieving, or other suitable methods known in the art to separate materials based on size. In one embodiment, size separation can provide for enhanced yields. In one embodiment, separation of finely shredded biomass (*e.g.* particles smaller than about 3 mm in diameter, such as, 3, 2.9, 2.7, 2.5, 2.3, 2, 1.9, 1.7, 1.5, 1.3, 1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, or 0.1 mm) from larger particles allows the recycling of the larger particles back into the size reduction process, thereby increasing the final yield of processed biomass. In one embodiment, a fermentative mixture is provided which comprises a pretreated lignocellulosic feedstock comprising less than about 50% of a lignin component present in the feedstock prior to pretreatment and comprising more than about 60% of a hemicellulose component present in the feedstock prior to pretreatment; and a microorganism capable of fermenting a five-carbon saccharide, such as xylose, arabinose or a combination thereof, and a six-carbon saccharide, such as glucose, galactose, mannose or a combination thereof. In some instances, pretreatment of the lignocellulosic feedstock comprises adding an alkaline substance which raises the pH to an alkaline level, for example NaOH. In one embodiment, NaOH is added at a concentration of about 0.5% to about 2% by weight of the feedstock. In one embodiment, pretreatment also comprises addition of a chelating agent.

[00186] Disclosed herein are methods of producing a composition comprising C5 and/or C6 saccharides and/or saccharide polymers from a biomass composition comprising cellulose, hemicellulose, and/or lignocellulose. In some embodiments, the methods comprise pretreating

the biomass composition to produce a pretreated biomass composition. Pretreating the biomass composition can comprise hydrating the biomass composition, mechanically reducing the size of solids in the biomass composition, heating the biomass composition, or a combination thereof. In some embodiments, the pretreated biomass composition comprises solid particles that are less than 50 mm, less than 40mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, or 1 mm in size (*e.g.*, diameter or length, width, or height). In some embodiments, the pretreated biomass composition further comprises a yield of C5 monosaccharides and/or disaccharides that is at least 50% of a theoretical maximum. In some embodiments, the pretreated biomass composition further comprises a yield of saccharide polymers that is at least 50% of a theoretical maximum. In some embodiments, the pretreated biomass composition further comprises a yield of saccharide polymers derived from hemicellulose that is at least 50% of a theoretical maximum. In some embodiments, the pretreated biomass composition further comprises a yield of saccharide polymers derived from cellulose that is at least 50% of a theoretical maximum.

[00187] Pretreatment of a biomass composition can comprise hydration of the biomass composition (e.g., to produce a hydrated biomass composition). Hydration of the biomass composition can comprise mixing or soaking the biomass composition in an aqueous medium. The aqueous medium can comprise water. The aqueous medium can be at a neutral pH. The aqueous medium can be a non-neutral aqueous medium. The non-neutral aqueous medium can comprise one or more acids or one or more bases. The one or more acids can be sulfuric acid, peroxyacetic acid, lactic acid, formic acid, acetic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, carbonic acid or a combination thereof. The one or more bases can be sodium hydroxide, calcium hydroxide, potassium hydroxide, ammonia, ammonia hydroxide, hydrogen peroxide or a combination thereof. Hydration of the biomass composition with one or more acids or one or more bases can precondition the biomass composition for thermochemical hydrolysis by impregnating the solids of the biomass composition with the one or more acids or the one or more bases. In some embodiments, the hydrolysis conditions are such that there is no or substantially no hydrolysis of cellulose, hemicellulose, and/or lignocellulose in the biomass composition.

[00188] In some embodiments, pretreatment of a biomass composition comprises hydration of the biomass composition in a non-neutral aqueous medium comprises from about 0.1% to about 50% w/w or v/w by dry biomass weight of one or more acids or one or more bases. For example,

the non-neutral aqueous medium can comprise about 25-50%, 10-50%, 10-25%, 5-50%, 5-25%, 5-10%, 4-50%, 4-25%, 4-10%, 4-5%, 3-50%, 3-25%, 3-10%, 3-5%, 3-4%, 2-50%, 2-25%, 2-10%, 2-5%, 2-4%, 2-3%, 1-50%, 1-25%, 1-10%, 1-5%, 1-4%, 1-3%, 1-2%, 0.5-50%, 0.5-25%, 0.5-10%, 0.5-5%, 0.5-4%, 0.5-3%, 0.5-2%, 0.5-1%, 0.5-%, 0.1-50%, 0.1-25%, 0.1-10%, 0.1-5%, 0.1-4%, 0.1-3%, 0.1-2%, 0.1-1%, 0.1-0.5%, 50%, 45%, 40%, 35%, 30%, 25%, 24%, 23%, 22%, 21%, 20%, 19%, 18%, 17%, 16%, 15%, 14%, 13%, 12%, 11%, 10%, 9.5%, 9%, 8.5%, 8%, 7.5%, 7%, 6.5%, 6%, 5.5%, 5%, 4.9%, 4.8%, 4.7%, 4.6%, 4.5%, 4.4%, 4.3%, 4.2%, 4.1%, 4%, 3.9%, 3.8%, 3.7%, 3.6%, 3.5%, 3.4%, 3.3%, 3.2%, 3.1%, 3%, 2.9%, 2.8%, 2.7%, 2.6%, 2.5%, 2.4%, 2.3%, 2.2%, 2.1%, 2%, 1.9%, 1.8%, 1.7%, 1.6%, 1.5%, 1.4%, 1.3%, 1.2%, 1.1%, 1%, 0.9%, 0.8%, 0.7%, 0.6%, 0.5%, 0.4%, 0.3%, 0.2%, or 0.1% of the one or more acids or the one or more bases. The one or more acids can be sulfuric acid, sulfurous acid, peroxyacetic acid, lactic acid, formic acid, acetic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, carbonic acid, or a combination thereof. The one or more bases can be sodium hydroxide, calcium hydroxide, potassium hydroxide, ammonia, ammonia hydroxide, hydrogen peroxide or a combination thereof. In some embodiments, the non-neutral aqueous medium comprises the one or more acids or the one or more bases at from about 0.1% to about 5% v/w by dry biomass weight. In some embodiments, the non-neutral aqueous medium comprises sulfuric acid at from about 0.1% to about 5% v/w by dry biomass weight. In some embodiments, the non-neutral aqueous medium comprises sulfuric acid at about 1.8% v/w by dry biomass weight. In some embodiments, the non-neutral aqueous medium comprises sulfuric acid at about 1% v/w by dry biomass weight. In some embodiments, the non-neutral aqueous medium comprises a weak acid (i.e. acetic acid, formic acid, oxalic acid, carbonic acid or any other weak acid or any acid that is not a strong acid) at from about 0.1% to about 5% v/w by dry biomass weight. In some embodiments, the non-neutral aqueous medium comprises a weak acid(i.e. acetic acid, formic acid, oxalic acid, carbonic acid or any other weak acid or any acid that is not a strong acid) at about 1.8% v/w by dry biomass weight. In some embodiments, the non-neutral aqueous medium comprises a weak acid(i.e. acetic acid, formic acid, oxalic acid, carbonic acid or any other weak acid or any acid that is not a strong acid) at about 1% v/w by dry biomass weight.

[00189] In some embodiments, pretreatment of the biomass composition comprises hydration of the biomass composition in a non-neutral aqueous medium having a pH that is less than 7. For example, the non-neutral aqueous medium can have a pH that is less than 7, 6.5, 6, 5.5, 5, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, or 1. For example, the non-neutral aqueous medium can have a pH that is

about 6.5, 6.4, 6.3, 6.2, 6.1, 6, 5.9, 5.8, 5.7, 5.6, 5.5, 5.4, 5.3, 5.2, 5.1, 5, 4.9, 4.8, 4.7, 4.6, 4.5, 4.4, 4.3, 4.2, 4.1, 4, 3.9, 3.8, 3.7, 3.6, 3.5, 3.4, 3.3, 3.2, 3.1, 3, 2.9, 2.8, 2.7, 2.6, 2.5, 2.4, 2.3, 2.2, 2.1, 2, 1.9, 1.8, 1.7, 1.6, 1.5, 1.4, 1.3, 1.2, 1.1, 1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, or lower. The non-neutral aqueous medium having a pH that is less than 7 can comprise one or more acids such as sulfuric acid, sulfurous acid, peroxyacetic acid, lactic acid, formic acid, acetic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, carbonic acid or a combination thereof. The one or more acids can be at any suitable concentration, such as any of the concentrations disclosed herein.

[00190] In some embodiments, pretreatment of the biomass composition comprises hydration of the biomass composition in a non-neutral aqueous medium having a pH that is greater than 7. For example, the non-neutral aqueous medium can have a pH that is greater than 7, 7.5, 8, 8.5, 9, 9.5, 10, 10.5, 11, 11.5, 12, 12.5, 13, 13.5 or higher. For example, the non-neutral aqueous medium can have a pH that is about 7.5, 7.6, 7.7, 7.8, 7.9, 8, 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 9, 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, 10, 10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 10.7, 10.8, 10.9, 11, 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 11.7, 11.8, 11.9, 12, 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 13, 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, or higher. The non-neutral aqueous medium having a pH greater than 7 can comprise one or more bases such as sodium hydroxide, calcium hydroxide, potassium hydroxide, ammonia, ammonia hydroxide, hydrogen peroxide or a combination thereof. The one or more bases can be at any suitable concentration, such as any of the concentrations disclosed herein.

[00191] In some embodiments, hydration of a biomass composition in an aqueous medium, such as any of the aqueous media disclosed herein, can be performed at a temperature that is from about 10 °C to about 100 °C. For example, the hydration temperature can be about 10-100 °C, 20-80 °C, 30-70 °C, 40-60 °C, 10 °C, 15 °C, 20 °C, 25 °C, 30 °C, 35 °C, 40 °C, 45 °C, 50 °C, 55 °C, 60 °C, 65 °C, 70 °C, 75 °C, 80 °C, 85 °C, 90 °C, 95 °C, or 100 °C. In one embodiment, the temperature is from about 30 °C to about 70 °C. In another embodiment, the temperature is from about 40 °C to about 60 °C. In another embodiment, the temperature is about 50 °C.

[00192] In some embodiments, hydration of a biomass composition in an aqueous medium, such as any of the aqueous media disclosed herein, is for a hydration time of from about 1 minute to about 24 hours. For example, the hydration time can be about 1-24 hr, 1-18 hr, 1-12 hr, 1-6 hr, 6-24 hr, 6-18 hr, 6-12 hr, 12-24 hr, 12-18 hr, 18-24 hr, 1 hr, 2 hr, 3 hr, 4 hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr, 11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr. In another example, the hydration time can be about 1-60 min, 1-45 min, 1-30 min, 1-15 min,

1-10 min, 1-5 min, 5-45 min, 5-30 min, 5-15 min, 5-10 min, 10-30 min, 10-15 min, 1 min, 2 min, 3 min, 4 min, 5 min, 6 min, 7 min, 8 min, 9 min, 10 min, 11 min, 12 min, 13 min, 14 min, 15 min, 16 min, 17 min, 18 min, 19 min, 20 min, 21 min, 22 min, 23 min, 24 min, 25 min, 26 min, 27 min, 28 min, 29 min, 30 min, 31 min, 32 min, 33 min, 34 min, 35 min, 36 min, 37 min, 38 min, 39 min, 40 min, 41 min, 42 min, 43 min, 44 min, 45 min, 46 min, 47 min, 48 min, 49 min, 50 min, 51 min, 52 min, 53 min, 54 min, 55 min, 56 min, 57 min, 58 min, 59 min, or 60 min. In one embodiment, hydration of the biomass composition is for about 1 minute to about 60 minutes. In another embodiment, hydration of the biomass composition is for about 5 minutes to about 30 minutes. In another embodiment, hydration of the biomass is for about 15 minutes to about 20 minutes.

[00193] In some embodiments, hydration of a biomass composition in an aqueous medium produces a hydrated biomass composition comprising from about 1% to about 40% solids by dry biomass weight. For example, the hydrated biomass composition can comprise about 1-40%, 1-30%, 1-20%, 1-10%, 1-5%, 1-2.5%, 2.5-20%, 2.5-10%, 2.5-5%, 5-20%, 5-10%, 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9%, 10%, 11%, 12%, 13%, 14%, 15%, 16%, 17%, 18%, 19%, 20%, 25%, 30%, 35%, 40% solids by dry biomass weight. In some embodiments, the hydrated biomass composition comprises from about 1% to about 20 % solids by dry biomass weight. In some embodiments, the hydrated biomass composition comprises about 5% solids by biomass weight.

[00194] In some embodiments, a biomass composition is pretreated to produce a pretreated biomass composition, wherein pretreatment comprises mechanical size reduction of solids in the biomass composition. In some embodiments, the biomass composition is a hydrated biomass composition. In some embodiments, the pretreated biomass composition comprises solid particles that are less than 50 mm, less than 40 mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, 1 mm, or 0.5 mm in size, or less (*e.g.*, diameter or length, width, or height). Mechanical size reduction can comprise cutting, chipping, grinding, milling, shredding, screening, shearing, steam injection, steam explosion, acid-catalyzed steam explosion, ammonia fiber/freeze explosion (AFEX), or a combination thereof. In some embodiments, mechanical size reduction comprises milling that is hammer milling, ball milling, bead milling, pan milling, colloid milling, or a combination thereof. In some embodiments, mechanical size reduction does not comprise milling. In some embodiments, mechanical size reduction comprises simultaneous cutting and steam injection. In some embodiments, mechanical size reduction comprises steam injection, cutting, and steam explosion. In some embodiments, mechanical size reduction comprises simultaneous cutting and steam injection using a rotating cutter with a plurality of

cutting blades and a plurality of steam-injection holes. In some embodiments, mechanical size reduction comprises cutting with a first rotating cutter and a second rotating cutter. In some embodiments, the second rotating cutter comprises a plurality of cutting blades and a plurality of steam-injection holes.

[00195] In some embodiments, a biomass composition is pretreated to produce a pretreated biomass composition, wherein pretreatment comprises mechanical size reduction of solids in the biomass composition. In some embodiments, the biomass composition is a hydrated biomass composition. In some embodiments, the pretreated biomass composition comprises solid particles that are less than about 50 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, the pretreated biomass composition comprises solid particles that are less than about 45 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, the pretreated biomass composition comprises solid particles that are less than about 40 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, the pretreated biomass composition comprises solid particles that are less than about 35 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, the pretreated biomass composition comprises solid particles that are less than about 30 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, the pretreated biomass composition comprises solid particles that are less than about 25 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, the pretreated biomass composition comprises solid particles that are less than about 20 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, the pretreated biomass composition comprises solid particles that are less than about 17.5 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, the pretreated biomass composition comprises solid particles that are less than about 15 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, the pretreated biomass composition comprises solid particles that are less than about 12.5 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, the pretreated biomass composition comprises solid particles that are less than about 10 mm in size (*e.g.*, length, width, height, or diameter). For example, the pretreated biomass composition can comprise solid particles having a size of less than about 0.01 mm, 0.02 mm, 0.03 mm, 0.04 mm, 0.05 mm, 0.06 mm, 0.07 mm, 0.08 mm, 0.09 mm, 0.1 mm, 0.15 mm, 0.2 mm, 0.25 mm, 0.3 mm, 0.35 mm, 0.4 mm, 0.45 mm, 0.5 mm, 0.55 mm, 0.6 mm, 0.65 mm, 0.7 mm, 0.75 mm, 0.8 mm, 0.85 mm, 0.9 mm, 0.95 mm, 1 mm, 1.1 mm, 1.2 mm, 1.3 mm, 1.4 mm, 1.5 mm, 1.6 mm, 1.7 mm, 1.8 mm, 1.9 mm, 2 mm, 2.5 mm, 3 mm, 3.5 mm, 4 mm, 4.5 mm, 5 mm, 6 mm, 7 mm, 8 mm, 9 mm, 10 mm, 11 mm, 12 mm, 13 mm, 14 mm, 15 mm, 16 mm, 17 mm, 18 mm, 19 mm, 20 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, or 50 mm. In one

embodiment, the pretreated biomass composition comprises solid particles that are less than about 7.5 mm in size (*e.g.*, length, width, height, or diameter).. In another embodiment, the pretreated biomass composition comprises solid particles that are less than about 5 mm in size (*e.g.*, length, width, height, or diameter).. In another embodiment, the pretreated biomass composition comprises solid particles that are less than about 1.5 mm in size (*e.g.*, length, width, height, or diameter).. In another embodiment, the pretreated biomass composition comprises solid particles that are less than about 1 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, all of the solid particles in the pretreated biomass composition comprises solid particles that are less than 50 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, all of the solid particles in the pretreated biomass composition comprises solid particles that are less than 45 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, all of the solid particles in the pretreated biomass composition comprises solid particles that are less than 40 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, all of the solid particles in the pretreated biomass composition comprises solid particles that are less than 35 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, all of the solid particles in the pretreated biomass composition comprises solid particles that are less than 30 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, all of the solid particles in the pretreated biomass composition comprises solid particles that are less than 25 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, all of the solid particles in the pretreated biomass composition comprises solid particles that are less than 20 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, all of the solid particles in the pretreated biomass composition comprises solid particles that are less than 17.5 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, all of the solid particles in the pretreated biomass composition comprises solid particles that are less than 15 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, all of the solid particles in the pretreated biomass composition comprises solid particles that are less than 12.5 mm in size (*e.g.*, length, width, height, or diameter). In some embodiments, all of the solid particles in the pretreated biomass composition comprises solid particles that are less than 10 mm in size (*e.g.*, length, width, height, or diameter). In one embodiment, all of the solid particles in the pretreated biomass are less than 7.5 mm in size (*e.g.*, length, width, height, or diameter). In another embodiment, all of the solid particles in the pretreated biomass are less than 5 mm in size(*e.g.*, length, width, height, or diameter). In another embodiment, all of the solid particles in the pretreated biomass are less than 2.5 mm in size(*e.g.*, length, width, height, or diameter). In another embodiment, all of the solid particles in the

pretreated biomass are less than 2 mm in size(*e.g.*, length, width, height, or diameter). In another embodiment, all of the solid particles in the pretreated biomass are less than 1.5 mm in size(*e.g.*, length, width, height, or diameter). In another embodiment, all of the solid particles in the pretreated biomass are less than 1 mm in size(*e.g.*, length, width, height, or diameter). In some embodiments, the particles in the pretreated biomass composition have uniform or substantially uniform sizes.

[00196] In some embodiments, a biomass composition is pretreated to produce a pretreated biomass composition, wherein pretreatment comprises mechanical size reduction of solids in the biomass composition. In some embodiments, the biomass composition is a hydrated biomass composition. In some embodiments, the pretreated biomass composition comprises solid particles having an average size (*e.g.*, length, width, height, or diameter) of from about 0.01 mm to about 50 mm. In some embodiments, the pretreated biomass composition comprises solid particles having an average size (*e.g.*, length, width, height, or diameter) of from about 0.01 mm to about 45 mm. In some embodiments, the pretreated biomass composition comprises solid particles having an average size (*e.g.*, length, width, height, or diameter) of from about 0.01 mm to about 40 mm. In some embodiments, the pretreated biomass composition comprises solid particles having an average size (*e.g.*, length, width, height, or diameter) of from about 0.01 mm to about 35 mm. In some embodiments, the pretreated biomass composition comprises solid particles having an average size (*e.g.*, length, width, height, or diameter) of from about 0.01 mm to about 30 mm. In some embodiments, the pretreated biomass composition comprises solid particles having an average size (*e.g.*, length, width, height, or diameter) of from about 0.01 mm to about 25 mm. In some embodiments, the pretreated biomass composition comprises solid particles having an average size (*e.g.*, length, width, height, or diameter) of from about 0.01 mm to about 20 mm. In some embodiments, the pretreated biomass composition comprises solid particles having an average size (*e.g.*, length, width, height, or diameter) of from about 0.01 mm to about 17.5 mm. In some embodiments, the pretreated biomass composition comprises solid particles having an average size (*e.g.*, length, width, height, or diameter) of from about 0.01 mm to about 15 mm. In some embodiments, the pretreated biomass composition comprises solid particles having an average size (*e.g.*, length, width, height, or diameter) of from about 0.01 mm to about 12.5 mm. In some embodiments, the pretreated biomass composition comprises solid particles having an average size (*e.g.*, length, width, height, or diameter) of from about 0.01 mm to about 10 mm. For example, the mixture of particles can have an average particle size (*e.g.*, length, width, height, or diameter) of about 0.01-50 mm, 0.01-45 mm, 0.01-40 mm, 0.01-35 mm, 0.01-30 mm, 0.01-25 mm, 0.01-20 mm, 0.01-17.5 mm, 0.01-15 mm, 0.01-12.5 mm, 0.01-10 mm,

0.01-7.5 mm, 0.01-5 mm, 0.01-2.5 mm, 0.01-2 mm, 0.01-1.5 mm, 0.01-1 mm, 0.01-0.5 mm, 0.01-0.1 mm, 0.1-10 mm, 0.1-7.5 mm, 0.1-5 mm, 0.1-2.5 mm, 0.1-2 mm, 0.1-1.5 mm, 0.1-1 mm, 0.1-0.5 mm, 0.5-10 mm, 0.5-7.5 mm, 0.5-5 mm, 0.5-2.5 mm, 0.5-2 mm, 0.5-1.5 mm, 0.5-1 mm, 1-10 mm, 1-7.5 mm, 1-5 mm, 1-2.5 mm, 1-2 mm, 1-1.5 mm, 1.5-10 mm, 1.5-7.5 mm, 1.5-5 mm, 1.5-2.5 mm, 1.5-2 mm, 2-10 mm, 2-7.5 mm, 2-5 mm, 2-2.5 mm, 2.5-10 mm, 2.5-7.5 mm, 2.5-5 mm, 5-10 mm, 5-7.5 mm, 7.5-10 mm, 0.01 mm, 0.05 mm, 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 0.6 mm, 0.7 mm, 0.8 mm, 0.9 mm, 1 mm, 1.1 mm, 1.2 mm, 1.3 mm, 1.4 mm, 1.5 mm, 1.6 mm, 1.7 mm, 1.8 mm, 1.9 mm, 2 mm, 2.1 mm, 2.2 mm, 2.3 mm, 2.4 mm, 2.5 mm, 2.75 mm, 3 mm, 3.25 mm, 3.5 mm, 3.75 mm, 4 mm, 4.25 mm, 4.5 mm, 4.75 mm, 5 mm, 5.25 mm, 5.5 mm, 5.75 mm, 6 mm, 6.25 mm, 6.5 mm, 6.75 mm, 7 mm, 7.25 mm, 7.5 mm, 8 mm, 8.5 mm, 9 mm, 9.5 mm, 10 mm, 10.5 mm, 11 mm, 11.5 mm, 12 mm, 12.5 mm, 13 mm, 13.5 mm, 14 mm, 14.5 mm, 15 mm, 15.5 mm, 16 mm, 16.5 mm, 17 mm, 17.5 mm, 18 mm, 18.5 mm, 19 mm, 19.5 mm, 20 mm, 21 mm, 22 mm, 23 mm, 24 mm, 25 mm, 30 mm, 35 mm, 40 mm, 45 mm, or 50 mm. In one embodiment, the pretreated biomass composition comprises solid particles having an average size of from about 0.1 mm to about 7.5 mm. In another embodiment, the pretreated biomass composition comprises solid particles having an average size of from about 0.1 mm to about 5 mm. In another embodiment, the pretreated biomass composition comprises solid particles having an average size of from about 0.1 mm to about 1.5 mm. In another embodiment, the pretreated biomass composition comprises solid particles having an average size of from about 0.1 mm to about 1 mm. In another embodiment, the pretreated biomass composition comprises solid particles having an average size of from about 0.5 mm to about 1 mm. In some embodiments, the particles in the pretreated biomass composition have uniform or substantially uniform sizes.

[00197] In some embodiments, a biomass composition is pretreated to produce a pretreated biomass composition, wherein pretreatment comprises mechanical size reduction of solids in the biomass composition. In some embodiments, the biomass composition is a hydrated biomass composition. In some embodiments, the solid particles in the pretreated biomass composition are homogenous or uniform in size or substantially homogenous or uniform in size. The solid particles in the pretreated biomass composition can be considered to be homogenous or substantially homogeneous if greater than about 50% of the particles fall within a given size range. For example, the mixture of particles can be considered homogeneous or uniform or substantially homogeneous or substantially uniform if about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100% of the solid particles falls within a given size range. The given size range can be from about 0.01 mm to about 50 mm. The given

size range can be from about 0.01 mm to about 45 mm. The given size range can be from about 0.01 mm to about 40 mm. The given size range can be from about 0.01 mm to about 35 mm. The given size range can be from about 0.01 mm to about 30 mm. The given size range can be from about 0.01 mm to about 25 mm. The given size range can be from about 0.01 mm to about 20 mm. The given size range can be from about 0.01 mm to about 17.5 mm. The given size range can be from about 0.01 mm to about 15 mm. The given size range can be from about 0.01 mm to about 12.5 mm. The given size range can be from about 0.01 mm to about 10 mm; for example, about 0.01-50 mm, 0.01-45 mm, 0.01-40 mm, 0.01-35 mm, 0.01-30 mm, 0.01-25 mm, 0.01-20 mm, 0.01-17.5 mm, 0.01-15 mm, 0.01-12.5 mm,0.01-10 mm, 0.01-7.5 mm, 0.01-5 mm, 0.01-2.5 mm, 0.01-2 mm, 0.01-1.5 mm, 0.01-1 mm, 0.01-0.5 mm, 0.01-0.1 mm, 0.1-10 mm, 0.1-7.5 mm, 0.1-5 mm, 0.1-2.5 mm, 0.1-2 mm, 0.1-1.5 mm, 0.1-1 mm, 0.1-0.5 mm, 0.5-50 mm, 0.5-45 mm, 0.5-40 mm, 0.5-35 mm, 0.5-30 mm, 0.5-25 mm, 0.5-20 mm, 0.5-17.5 mm, 0.5-15 mm, 0.5-12.5 mm,0.5-10 mm, 0.5-7.5 mm, 0.5-5 mm, 0.5-2.5 mm, 0.5-2 mm, 0.5-1.5 mm, 0.5-1 mm, 1-50 mm, 1-45 mm, 1-40 mm, 1-35 mm, 1-30 mm, 1-25 mm, 1-20 mm, 1-17.5 mm, 1-15 mm, 1-12.5 mm,1-10 mm, 1-7.5 mm, 1-5 mm, 1-2.5 mm, 1-2 mm, 1-1.5 mm, 1.5-50 mm, 1.5-45 mm, 1.5-40 mm, 1.5-35 mm, 1.5-30 mm, 1.5-25 mm, 1.5-20 mm, 1.5-17.5 mm, 1.5-15 mm, 1.5-12.5 mm,1.5-10 mm, 1.5-7.5 mm, 1.5-5 mm, 1.5-2.5 mm, 1.5-2 mm, 2-50 mm, 2-45 mm, 2-40 mm, 2-35 mm, 2-30 mm, 2-25 mm, 2-20 mm, 2-17.5 mm, 2-15 mm, 2-12.5 mm,2-10 mm, 2-7.5 mm, 2-5 mm, 2-2.5 mm, 2.5-50 mm, 2.5-45 mm, 2.5-40 mm, 2.5-35 mm, 2.5-30 mm, 2.5-25 mm, 2.5-20 mm, 2.5-17.5 mm, 2.5-15 mm, 2.5-12.5 mm,2.5-10 mm, 2.5-7.5 mm, 2.5-5 mm, 5-50 mm, 5-45 mm, 5-40 mm, 5-35 mm, 5-30 mm, 5-25 mm, 5-20 mm, 5-17.5 mm, 5-15 mm, 5-12.5 mm,5-10 mm, 5-7.5 mm, or 7.5-10 mm. In one embodiment, the given size range is from about 0.1 mm to about 7.5 mm. In another embodiment, the given size range is from about 0.1 mm to about 5 mm. In another embodiment, the given size range is from about 0.1 mm to about 2.5 mm. In another embodiment, the given size range is from about 0.1 mm to about 2 mm. In another embodiment, the given size range is from about 0.1 mm to about 1.5 mm. In another embodiment, the given size range is from about 0.1 mm to about 1 mm.

[00198] In some embodiments, a biomass composition is pretreated to produce a pretreated biomass composition, wherein pretreatment comprises mechanical size reduction of solids in the biomass composition. In some embodiments, the biomass composition is a hydrated biomass composition. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about

0.01 to about 50 mm. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 45 mm. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 40 mm. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 35 mm. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 30 mm. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 25 mm. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 20 mm. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 17.5 mm. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 15 mm. In one embodiment, a homogeneous or uniform mixture of particles is

produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 12.5 mm. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 10 mm. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 7.5 mm. In another embodiment, a homogeneous mixture of particles is produced during pretreatment of biomass wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.1 to about 5 mm. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 2.5 mm. In another embodiment, a homogeneous mixture of particles is produced during pretreatment of biomass wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.1 to about 1.5 mm. In one embodiment, a homogeneous mixture of particles is produced during pretreatment of biomass wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.1 mm to about 1 mm. In one embodiment, a homogeneous or uniform mixture of particles is produced during pretreatment of a biomass composition wherein greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in the mixture have a size (*e.g.*, diameter or length, width, or height) that is from about 0.01 to about 0.5 mm. In one embodiment, a homogeneous mixture of particles is produced during pretreatment of biomass wherein the surface area to volume ratio is increased several fold. For example, the fold-change in surface area to volume ratio can be increased about 100-

fold, 75-fold, 50-fold, 40-fold, 30-fold, 25- fold, 20-fold, 19-fold, 18-fold, 17-fold, 16-fold, 15-fold, 11-fold, 10-fold, 9-fold, 8-fold, 7-fold, 6-fold, 5-fold, 4-fold, 3-fold, 2-fold or 1-fold. In another embodiment, homogeneous mixture of particles is produced during pretreatment of biomass wherein the surface area to volume ratio is increased about 1-5 fold, 5-10 fold, 10-15 fold, 15-20 fold, 20-25 fold, 25-30 fold, 30-35 fold, 35-40 fold, 40-45 fold, 45-50 fold, 50-55 fold, 55-60 fold, 60-65 fold, 65-70 fold, 70-75 fold, 75-80 fold, 80-85 fold, 85-90 fold, 90-95 fold, or 95-100 fold. In another embodiment, a homogeneous mixture of particles is produced during pretreatment of biomass wherein the surface area to volume ratio is increased more than 100-fold, 75-fold, 50-fold, 40-fold, 30-fold, 25- fold, 20-fold, 19-fold, 18-fold, 17-fold, 16-fold, 15-fold, 11-fold, 10-fold, 9-fold, 8-fold, 7-fold, 6-fold, 5-fold, 4-fold, 3-fold, 2-fold or 1-fold. In one embodiment, a homogeneous mixture of particles is produced during pretreatment of biomass wherein the surface area to volume ratio is higher than solids in the biomass composition.

[00199] In some embodiments, where pretreatment comprises hydration of a biomass composition to produce a hydrated biomass composition and mechanical size reduction of the hydrated biomass composition to produce solid particles less than 50 mm, less than 40 mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, 1 mm, or 0.5 mm in size, the surface area to volume ratio of the solid particles can be increased about 100-fold, 75-fold, 50-fold, 40-fold, 30-fold, 25- fold, 20-fold, 19-fold, 18-fold, 17-fold, 16-fold, 15-fold, 11-fold, 10-fold, 9-fold, 8-fold, 7-fold, 6-fold, 5-fold, 4-fold, 3-fold, 2-fold or 1-fold. In another embodiment, a homogeneous mixture of particles is produced during pretreatment of biomass wherein the surface area to volume ratio is increased about 1-5 fold, 5-10 fold, 10-15 fold, 15-20 fold, 20-25 fold, 25-30 fold, 30-35 fold, 35-40 fold, 40-45 fold, 45-50 fold, 50-55 fold, 55-60 fold, 60-65 fold, 65-70 fold, 70-75 fold, 75-80 fold, 80-85 fold, 85-90 fold, 90-95 fold, or 95-100 fold. In another embodiment, a homogeneous mixture of particles is produced during pretreatment of biomass wherein the surface area to volume ratio is increased more than 100-fold, 75-fold, 50-fold, 40-fold, 30-fold, 25- fold, 20-fold, 19-fold, 18-fold, 17-fold, 16-fold, 15-fold, 11-fold, 10-fold, 9-fold, 8-fold, 7-fold, 6-fold, 5-fold, 4-fold, 3-fold, 2-fold or 1-fold. In one embodiment, a homogeneous mixture of particles is produced during pretreatment of biomass wherein the surface area to volume ratio is higher than solids in the biomass composition.

[00200] In some embodiments, where pretreatment comprises hydration of a biomass composition to product a hydrated biomass composition and mechanical size reduction of the

hydrated biomass composition to produce solid particles less than 50 mm, less than 40 mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, or 1 mm in size, further comprise dewatering the hydrated biomass composition to a solids content of from about 5% to about 40% by dry biomass weight. For example, the solids content can be about 5-40%, 5-35%, 5-30%, 5-25%, 5-20%, 5-15%, 5-10%, 10-40%, 10-35%, 10-30%, 10-25%, 10-20%, 10-15%, 15-40%, 15-35%, 15-30%, 15-25%, 15-20%, 20-40%, 20-35%, 20-30%, 20-25%, 25-40%, 25-35%, 25-30%, 30-40%, 30-35%, 35-40%, 5%, 6%, 7%, 8%, 9%, 10%, 11%, 12%, 13%, 14%, 15%, 16%, 17%, 18%, 19%, 20%, 21%, 22%, 23%, 24%, 25%, 26%, 27%, 28%, 29%, 30%, 31%, 32%, 33%, 34%, 35%, 36%, 37%, 38%, 39%, or 40% by dry biomass weight. In one embodiment, the hydrated biomass is dewatered to a solids content of about 30% by dry biomass weight. Dewatering can be performed before, during, and/or after mechanical size reduction. Dewatering can be performed with a filter, a filter press, a centrifuge, or any other suitable apparatus. In some embodiments, the hydrated biomass can be dewatered subjected to mechanical size reduction and hydrated following mechanical size reduction. In some embodiments, the hydrated biomass can be dewatered subjected to mechanical size reduction and hydrated following mechanical size reduction in a non-neutral aqueous medium.

[00201] In some embodiments, pretreatment of a biomass composition comprises heating the biomass composition. The pretreatment can further comprises hydrating the biomass composition and/or mechanically reducing the size of the solids in the biomass composition. In some embodiments, the pretreatment can further comprise hydrolyzing the biomass composition. In some embodiments, the pretreatment can further comprise hydrolyzing the biomass composition with one or more enzymes. In some embodiments, the pretreatment can further comprise hydrolyzing the biomass with one or more polymeric catalysts. In some embodiments, the pretreatment can further comprise hydrolyzing the biomass with one or more polymeric acid catalysts. In some embodiments, the pretreatment can further comprise hydrolyzing the biomass composition by altering the pH of the aqueous medium such that the pH is non-neutral. Heating, hydrating, and/or mechanically reducing the size of the biomass composition during pretreatment can be performed in any order. Heating, hydrating, and/or mechanically reducing the size of the biomass composition can be performed sequentially, at the same time, or can partially overlap in time. Heating, hydrating, mechanically reducing the size of the biomass composition and/or hydrolyzing the biomass composition during pretreatment can be performed in any order. Heating, hydrating, mechanically reducing the size of the biomass composition, and/or

hydrolyzing the biomass composition can be performed sequentially, at the same time, or can partially overlap in time.

[00202] In some embodiments, heating the biomass composition hydrolyzes a portion of the hemicellulose of the biomass composition to C5 monosaccharides and disaccharides. In some embodiments, a yield of C5 monosaccharides and/or disaccharides is at least 50% of the theoretical maximum. In some embodiments, the yield of C5 monosaccharides and/or disaccharides is at least 60%, 65%, 70%, 75%, 80%, 85%, or 90% of the theoretical maximum. In some embodiments, the C5 monosaccharides and/or disaccharides are monosaccharides. In some embodiments, the biomass composition is a hydrated biomass composition. In some embodiments, the hydrated composition is impregnated with one or more acids or one or more bases.

[00203] In some embodiments, treating the biomass composition with a polymeric acid catalyst hydrolyzes a portion of the hemicellulose of the biomass composition to C5 monosaccharides and disaccharides. In some embodiments, a yield of C5 monosaccharides and/or disaccharides is at least 50% of the theoretical maximum. In some embodiments, the yield of C5 monosaccharides and/or disaccharides is at least 60%, 65%, 70%, 75%, 80%, 85%, or 90% of the theoretical maximum. In some embodiments, the C5 monosaccharides and/or disaccharides are monosaccharides. In some embodiments, the biomass composition is a hydrated biomass composition. In some embodiments, the hydrated composition is impregnated with one or more acids or one or more bases.

[00204] In some embodiments, heating the biomass composition hydrolyzes a portion of the hemicellulose of the biomass composition to saccharide polymers. In some embodiments, heating the biomass composition hydrolyzes a portion of the hemicellulose of the biomass composition to saccharide polymers that are soluble. In some embodiments, heating the biomass composition hydrolyzes a portion of the hemicellulose of the biomass composition to saccharide polymers that are soluble in an aqueous medium. In some embodiments, pretreatment comprises hydrating the biomass composition in an aqueous medium and/or mechanically reducing the size of the biomass composition, and/or heating the biomass composition to hydrolyze a portion of the hemicellulose of the biomass composition to saccharide polymers derived from hemicellulose. In some embodiments, pretreatment comprises hydrating the biomass composition in an aqueous medium and/or mechanically reducing the size of the biomass composition, and/or mixing the biomass composition with a polymeric catalyst to hydrolyze a portion of the hemicellulose of the biomass composition to saccharides or saccharide polymers derived from hemicellulose. In some embodiments, pretreatment comprises hydrating the

biomass composition in an aqueous medium and/or mechanically reducing the size of the biomass composition, and/or mixing the biomass composition with a polymeric acid catalyst to hydrolyze a portion of the hemicellulose of the biomass composition to saccharides or saccharide polymers derived from hemicellulose. In some embodiments, a yield of saccharide polymers is at least 50% of the theoretical maximum. In some embodiments, the yield of saccharide polymers is at least 60%, 65%, 70%, 75%, 80%, 85%, or 90% of the theoretical maximum. In some embodiments, the saccharide polymers derived from hemicellulose comprise oligosaccharides. In some embodiments, the saccharide polymers derived from hemicellulose comprise disaccharides, trisaccharides, tetrasaccharides, pentasaccharides, hexasaccharides, heptasaccharides, octasaccharides, enneasaccharides, and/or decasaccharides. In some embodiments, the biomass composition is a hydrated biomass composition. In some embodiments, the hydrated composition is impregnated with one or more acids or one or more bases. In some embodiments, the hydrated composition is not impregnated with one or more acids or one or more bases. In some embodiments, the hydrated composition is hydrated in water. . In some embodiments, the hydrated composition is hydrated in water and heated. In some embodiments, the hydrated biomass composition is impregnated with one or more polymeric catalysts. In some embodiments, the hydrated biomass composition is impregnated with one or more polymeric acid catalysts.

[00205] In some embodiments, heating a biomass composition does not, or does not substantially hydrolyze the cellulose of the biomass composition. In some embodiments, a yield of glucose after heating the biomass composition is less than 20% of a theoretical maximum. In some embodiments, the yield of glucose is less than 15%, 10%, 5%, 2.5%, or 1% of the theoretical maximum. In some embodiments, a yield of saccharide polymers derived from cellulose after heating the biomass composition is less than 20% of a theoretical maximum. In some embodiments, the yield of saccharide polymers derived from cellulose is less than 15%, 10%, 5%, 2.5%, or 1% of the theoretical maximum.

[00206] In some embodiments, heating the biomass composition (that was optionally hydrated, mechanically reduced in size, and/or dewatered) is performed at a temperature of from about 100 °C to about 250 °C. For example, the temperature can be about 100-250 °C, 100-200 °C, 100-180 °C, 100-160 °C, 100-140 °C, 100-120 °C, 120-200 °C, 120-180 °C, 120-160 °C, 120-140 °C, 140-180 °C, 140-160 °C, 160-180 °C, 100 °C, 110 °C, 120 °C, 130 °C, 140 °C, 150 °C, 155 °C, 160 °C, 165 °C, 170 °C, 175 °C, 180 °C, 185 °C, 190 °C, 200 °C, 210 °C, 220 °C, 230 °C, 240 °C, or 250 °C. In one embodiment, heating of the biomass composition is at a temperature of from about 100 °C to about 250 °C. In another embodiment, heating of the biomass composition

is at a temperature of from about 150 °C to about 200 °C. In another embodiment, heating of the biomass composition is at a temperature of from about 160 °C to about 180 °C.

[00207] In some embodiments, heating the biomass composition (that was optionally hydrated, mechanically reduced in size, and/or dewatered) is performed at a pressure higher than atmospheric. The pressure can be from about 25 PSIG to about 250 PSIG. For example, the pressure can be about 25-250 PSIG, 25-225 PSIG, 25-200 PSIG, 25-175 PSIG, 25-150 PSIG, 25-125 PSIG, 25-100 PSIG, 25-75 PSIG, 25-50 PSIG, 50-225 PSIG, 50-200 PSIG, 50-175 PSIG, 50-150 PSIG, 50-125 PSIG, 50-100 PSIG, 50-75 PSIG, 75-200 PSIG, 75-175 PSIG, 75-150 PSIG, 75-125 PSIG, 75-100 PSIG, 100-175 PSIG, 100-150 PSIG, 100-125 PSIG, 125-150 PSIG, 25 PSIG, 30 PSIG, 35 PSIG, 40 PSIG, 45 PSIG, 50 PSIG, 55 PSIG, 60 PSIG, 65 PSIG, 70 PSIG, 75 PSIG, 80 PSIG, 85 PSIG, 90 PSIG, 95 PSIG, 100 PSIG, 105 PSIG, 110 PSIG, 115 PSIG, 120 PSIG, 125 PSIG, 130 PSIG, 135 PSIG, 140 PSIG, 145 PSIG, 150 PSIG, 155 PSIG, 160 PSIG, 165 PSIG, 170 PSIG, 175 PSIG, 180 PSIG, 185 PSIG, 190 PSIG, 195 PSIG, 200 PSIG, 205 PSIG, 210 PSIG, 215 PSIG, 220 PSIG, 225 PSIG, 230 PSIG, 235 PSIG, 240 PSIG, 245 PSIG, 250 PSIG. In one embodiment, the pressure is from about 25 PSIG to about 250 PSIG. In another embodiment, the pressure is from about 75 PSIG to about 200 PSIG. In another embodiment, the pressure is from about 100 PSIG to about 150 PSIG.

[00208] In some embodiments, pretreatment comprises heating a biomass composition (that was optionally hydrated, mechanically reduced in size, and/or dewatered) under any of the conditions disclosed herein for a time sufficient to produce a yield of C5 monosaccharides and/or disaccharides that is at least 50% of a theoretical maximum. The time sufficient to produce the yield of C5 monosaccharides and/or disaccharides can be from about 1 minute to about 120 minutes. For example, the time can be about 1-120 min, 1-90 min, 1-60 min, 1-30 min, 1-15 min, 1-10 min, 1-5 min, 5-60 min, 5-30 min, 5-15 min, 5-10 min, 120 min, 110 min, 100 min, 90 min, 80 min, 70 min, 60 min, 50 min, 45 min, 40 min, 35 min, 30 min, 25 min, 20 min, 19 min, 18 min, 17 min, 16 min, 15 min, 14 min, 13 min, 12 min, 11 min, 10 min, 9 min, 8 min, 7 min, 6 min, 5 min, 4 min, 3 min, 2 min, 1 min. In one embodiment, the time sufficient to produce the yield of C5 monosaccharides and/or disaccharides is from about 1 minute to about 60 minutes. In another embodiment, the time sufficient to produce the yield of C5 monosaccharides and/or disaccharides is from about 5 minutes to about 30 minutes. In another embodiment, the time sufficient to produce the yield of C5 monosaccharides and/or disaccharides is from about 7.5 minutes to about 12.5 minutes.

[00209] In some embodiments, pretreatment comprises treating a biomass composition with a polymeric catalyst (that was optionally hydrated, mechanically reduced in size, heated, and/or

dewatered) under any of the conditions disclosed herein for a time sufficient to produce a yield of C5 monosaccharides and/or disaccharides that is at least 50% of a theoretical maximum. In one embodiment, the polymeric catalyst is a polymeric acid catalyst. The time sufficient to produce the yield of C5 monosaccharides and/or disaccharides can be from about 1 minute to about 120 minutes. For example, the time can be about 1-120 min, 1-90 min, 1-60 min, 1-30 min, 1-15 min, 1-10 min, 1-5 min, 5-60 min, 5-30 min, 5-15 min, 5-10 min, 120 min, 110 min, 100 min, 90 min, 80 min, 70 min, 60 min, 50 min, 45 min, 40 min, 35 min, 30 min, 25 min, 20 min, 19 min, 18 min, 17 min, 16 min, 15 min, 14 min, 13 min, 12 min, 11 min, 10 min, 9 min, 8 min, 7 min, 6 min, 5 min, 4 min, 3 min, 2 min, 1 min. In one embodiment, the time sufficient to produce the yield of C5 monosaccharides and/or disaccharides is from about 1 minute to about 60 minutes. In another embodiment, the time sufficient to produce the yield of C5 monosaccharides and/or disaccharides is from about 5 minutes to about 30 minutes. In another embodiment, the time sufficient to produce the yield of C5 monosaccharides and/or disaccharides is from about 7.5 minutes to about 12.5 minutes. In some embodiments, pretreatment comprises treating a biomass composition with a polymeric catalyst (that was optionally hydrated, mechanically reduced in size, heated, and/or dewatered) under any of the conditions disclosed herein for a time sufficient to produce a yield of saccharide polymers that is at least 50% of a theoretical maximum. In some embodiments, the saccharide polymers can be derived from hemicelluloses. The time sufficient to produce the yield of saccharide polymers can be from about 1 minute to about 120 minutes. For example, the time can be about 1-120 min, 1-90 min, 1-60 min, 1-30 min, 1-15 min, 1-10 min, 1-5 min, 5-60 min, 5-30 min, 5-15 min, 5-10 min, 120 min, 110 min, 100 min, 90 min, 80 min, 70 min, 60 min, 50 min, 45 min, 40 min, 35 min, 30 min, 25 min, 20 min, 19 min, 18 min, 17 min, 16 min, 15 min, 14 min, 13 min, 12 min, 11 min, 10 min, 9 min, 8 min, 7 min, 6 min, 5 min, 4 min, 3 min, 2 min, 1 min. In one embodiment, the time sufficient to produce the yield of saccharide polymers is from about 1 minute to about 60 minutes. In another embodiment, the time sufficient to produce the yield of saccharide polymers is from about 5 minutes to about 30 minutes. In another embodiment, the time sufficient to produce the yield of saccharide polymers is from about 7.5 minutes to about 12.5 minutes.

[00210] In some embodiments, the method disclosed herein are for industrial scale production of compositions comprising C5 and C6 saccharides. In one embodiment, industrial scale production comprises pretreating greater than 1 metric ton (MT) in 24 hours. In another embodiment, industrial scale production comprises pretreating greater than 20 MT in 24 hours. In another embodiment, industrial scale production comprises pretreating greater than 50 MT in 24 hours.

In another embodiment, industrial scale production comprises pretreating greater than 100 MT in 24 hours.

[00211] In some embodiments, the methods disclosed herein are for production of compositions comprising saccharide polymers. In some embodiments, pretreatment of a biomass composition comprising cellulose, hemicellulose, and/or lignocellulose according to any of the methods disclosed herein can comprise heating, hydrating, mechanically reducing the size of the biomass composition, and/or hydrolyzing the biomass composition and can be performed sequentially, at the same time, or can partially overlap in time. In one embodiment, the hydrolyzing is performed using a polymeric acid catalyst.

[00212] In some embodiments, the method disclosed herein are for industrial scale production of compositions comprising saccharide polymers.

[00213] Hydrolysis

[00214] Disclosed herein are methods of producing a saccharide stream comprising C5 and/or C6 saccharides from a biomass composition comprising cellulose, hemicellulose, and/or lignocellulose. The methods can comprise pretreating the biomass composition according to any of the methods disclosed herein. In some embodiments, the biomass composition is pretreated to produce a pretreated biomass composition, wherein pretreatment comprises mechanical size reduction of solids in the biomass composition. In some embodiments, the (pretreated) biomass composition comprises solid particles that are less than 50 mm, less than 40 mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, 1 mm, or 0.5 mm in size, or less. The pretreated biomass composition can further comprise a yield of C5 monosaccharides and/or disaccharides that is at least 50%, 60%, 65%, 70%, 75%, 80%, 85%, or 90% of a theoretical maximum. The methods of producing a composition can further comprise hydrolyzing the biomass composition or pretreated biomass composition with one or more enzymes for a time sufficient to produce the composition comprising C5 and C6 saccharides. The methods of producing a composition can further comprise hydrolyzing the biomass composition or pretreated biomass composition with one or more polymeric catalysts for a time sufficient to produce the composition comprising C5 and C6 saccharides. The methods of producing a composition can further comprise hydrolyzing the biomass composition or pretreated biomass composition with one or more polymeric acid catalysts for a time sufficient to produce the composition comprising C5 and C6 saccharides. The C5 and C6 saccharides can comprise glucose, xylose, mannose, galactose, rhamnose, arabinose, or a combination thereof. The composition comprising C5 and/or C6 saccharides can be an aqueous composition.

[00215] In one embodiment, the methods disclosed herein are methods of producing a composition comprising saccharide polymers from a biomass composition comprising cellulose, hemicellulose, and/or lignocellulose. In one embodiment, the methods for producing a composition comprising saccharide polymers comprises a two step process. In a first step, a biomass composition comprising cellulose, hemicellulose, and/or lignocellulose can be hydrated in an aqueous medium, heated, and/or mechanically size reduced according to any of the methods disclosed herein to produce a pretreated biomass composition. In one embodiment, the biomass composition can be heated to a temperature and for a time according to any of the methods disclosed herein. In one embodiment, the biomass composition can be heated at 50°C for 1-30 minutes. In one embodiment, the aqueous medium can be water. In one embodiment, the pretreated biomass composition comprises solids and saccharide polymers. In one embodiment, the solids in the pretreated biomass comprise solid particles. In some embodiments, the pretreated biomass composition comprises saccharide polymers and solid particles that are less than 50 mm, less than 40 mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, 1 mm, or 0.5 mm in size, or less. In some embodiments, the saccharide polymers in the pretreated biomass composition can be derived from hemicellulose. The pretreated biomass composition can comprise a yield of saccharide polymers that is at least 50%, 60%, 65%, 70%, 75%, 80%, 85%, or 90% of a theoretical maximum. In some embodiments, the saccharide polymers of the pretreated biomass composition can comprise a first population of saccharide polymers. In some embodiments, the saccharide polymers of the pretreated biomass composition can be separated from the solids of the pretreated biomass composition. In some embodiments, the first population of saccharide polymers can be further hydrolyzed and/or fermented. In a second step, the solids from the pretreated biomass composition can be hydrolyzed to produce saccharide polymers. In a second step, the solids from the pretreated biomass composition can be separated from the first population of saccharide polymers and can be hydrolyzed to produce a second population of saccharide polymers. In one embodiment, the solids from the pretreated biomass composition can be adjusted to a solids content of 8%-25% w/v in water. In one embodiment, the solids from the pretreated biomass composition can be adjusted to a solids content of 20-25% (w/v) in water. In one embodiment, the solids from the pretreated biomass composition can be hydrolyzed to produce a second population of saccharide polymers. In one embodiment, the solids can be hydrolyzed by one or more polymeric catalysts. In one embodiment, the solids can be hydrolyzed by one or more polymeric acid catalysts. In one embodiment, the solids can be hydrolyzed by one or more enzymes. The one or more enzymes

can comprise enzymes that hydrolyze polysaccharides to yield saccharide polymers. In one embodiment, the one or more enzymes comprise one or more endocellulases, one or more exocellulases, one or more endo-hemicellulases, one or more exo-hemicellulases, or a combination thereof. The one or more enzymes can be present at a total level of about 0.1% w/w to about 20% w/w by dry biomass weight. In one embodiment, the solids can be hydrolyzed by being treated in a non-neutral aqueous medium. The non-neutral aqueous medium can be at a pH above 7 or a pH below 7. For example, the non-neutral aqueous medium can have a pH that is less than 7, 6.5, 6, 5.5, 5, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, or 1. For example, the non-neutral aqueous medium can have a pH that is greater than 7, 7.5, 8, 8.5, 9, 9.5, 10, 10.5, 11, 11.5, 12, 12.5, 13, 13.5 or higher. In one embodiment, the solids from the pretreated biomass composition can be hydrolyzed with an acid. The acid can comprise one or more acids such as those described herein. The one or more acids can be at any suitable concentration, such as any of the concentrations disclosed herein. In one embodiment, the solids of the pretreated biomass can be hydrolyzed in 1% v/w sulfuric acid based on the dry weight of the solids. In one embodiment, the solids of the pretreated biomass can be hydrolyzed in 1% -3% v/w of a weak acid (i.e. formic acid or oxalic acid) based on the dry weight of the solids. In one embodiment, the solids of the pretreated biomass can be hydrolyzed in an acid and heated. In one embodiment, the solids of the pretreated biomass can be hydrolyzed in an acid and heated at a temperature of about 140°C to 220°C. In one embodiment, the solids of the pretreated biomass can be hydrolyzed in an acid and heated at a pressure of about 135-260 PSIG. In one embodiment, the solid particles of the pretreated biomass can be hydrolyzed in an acid for 10-30 minutes. The hydrolysis of the solids of the pretreated biomass can comprise a yield of saccharide polymers that is at least 50%, 60%, 65%, 70%, 75%, 80%, 85%, or 90% of a theoretical maximum. In one embodiment, the first step and the second step can be combined. In one embodiment, the first step and second step can be sequential. In one embodiment, the first step and second step can be simultaneous.

[00216] In some embodiments, the first population of saccharide polymers comprises saccharide polymers derived from hemicellulose. In one embodiment, the first population of saccharide polymers comprises glucose residues, xylose residues, mannose residues, galactose residues, rhamnose residues, arabinose residues, or a combination thereof. In one embodiment, the first population of saccharide polymers comprises oligosaccharides. In some embodiments, the second population of saccharide polymers comprises saccharide polymers derived from cellulose. In one embodiment, the second population of saccharide polymers comprises glucose residues. In one embodiment, the second population of saccharide polymers comprises 95-100% glucose residues. In one embodiment, the second population of saccharide polymers comprises

50-55%, 55-60%, 60-65%, 65-70%, 70-75%, 75-80%, 80-85%, 85-90%, 90-95%, or 95-100% glucose residues. In one embodiment, the second population of saccharide polymers comprises 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100% glucose residues. In one embodiment, the second population of saccharide polymers comprises oligosaccharides. In one embodiment, the first and second populations of saccharide polymers can be further hydrolyzed and/or fermented. In one embodiment, the first and second populations of saccharide polymers can be further hydrolyzed and/or fermented separately. In one embodiment, the first and second populations of saccharide polymers can be combined to make a composition comprising saccharide polymers. The saccharide polymers can be further hydrolyzed and/or fermented. In one embodiment, the first and second populations of saccharide polymers can be further hydrolyzed and/or fermented by one or more biocatalysts.

[00217] In some embodiments, hydrolysis of the pretreated biomass composition and/or solid particles of the pretreated biomass to produce saccharide polymers can comprise hydrating in a non-neutral aqueous medium. The non-neutral aqueous medium can comprise one or more acids or one or more bases. The one or more acids can be sulfuric acid, peroxyacetic acid, lactic acid, formic acid, acetic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, carbonic acid or a combination thereof. The one or more bases can be sodium hydroxide, calcium hydroxide, potassium hydroxide, ammonia, ammonia hydroxide, hydrogen peroxide or a combination thereof.

[00218] In some embodiments, hydrolysis of the pretreated biomass composition and/or solids of the pretreated biomass to produce saccharide polymers comprises hydration of the pretreated biomass composition in a non-neutral aqueous medium comprising from about 0.1% to about 50% w/w or v/w by dry biomass weight of one or more acids or one or more bases. For example, the non-neutral aqueous medium can comprise about 25-50%, 10-50%, 10-25%, 5-50%, 5-25%, 5-10%, 4-50%, 4-25%, 4-10%, 4-5%, 3-50%, 3-25%, 3-10%, 3-5%, 3-4%, 2-50%, 2-25%, 2-10%, 2-5%, 2-4%, 2-3%, 1-50%, 1-25%, 1-10%, 1-5%, 1-4%, 1-3%, 1-2%, 0.5-50%, 0.5-25%, 0.5-10%, 0.5-5%, 0.5-4%, 0.5-3%, 0.5-2%, 0.5-1%, 0.5-%, 0.1-50%, 0.1-25%, 0.1-10%, 0.1-5%, 0.1-4%, 0.1-3%, 0.1-2%, 0.1-1%, 0.1-0.5%, 50%, 45%, 40%, 35%, 30%, 25%, 24%, 23%, 22%, 21%, 20%, 19%, 18%, 17%, 16%, 15%, 14%, 13%, 12%, 11%, 10%, 9.5%, 9%, 8.5%, 8%, 7.5%, 7%, 6.5%, 6%, 5.5%, 5%, 4.9%, 4.8%, 4.7%, 4.6%, 4.5%, 4.4%, 4.3%, 4.2%, 4.1%, 4%, 3.9%, 3.8%, 3.7%, 3.6%, 3.5%, 3.4%, 3.3%, 3.2%, 3.1%, 3%, 2.9%, 2.8%, 2.7%, 2.6%, 2.5%, 2.4%, 2.3%, 2.2%, 2.1%, 2%, 1.9%, 1.8%, 1.7%, 1.6%, 1.5%, 1.4%, 1.3%, 1.2%, 1.1%, 1%, 0.9%, 0.8%, 0.7%, 0.6%, 0.5%, 0.4%, 0.3%, 0.2%, or 0.1% of the one or more acids or the one

or more bases. The one or more acids can be sulfuric acid, sulfurous acid, peroxyacetic acid, lactic acid, formic acid, acetic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, carbonic acid, or a combination thereof. The one or more bases can be sodium hydroxide, calcium hydroxide, potassium hydroxide, ammonia, ammonia hydroxide, hydrogen peroxide or a combination thereof. In some embodiments, the non-neutral aqueous medium comprises the one or more acids or the one or more bases at from about 0.1% to about 5% v/w by dry biomass weight. In some embodiments, the non-neutral aqueous medium comprises sulfuric acid at from about 0.1% to about 5% v/w by dry biomass weight. In some embodiments, the non-neutral aqueous medium comprises sulfuric acid at about 1.8% v/w by dry biomass weight. In some embodiments, the non-neutral aqueous medium comprises sulfuric acid at about 1% v/w by dry biomass weight. In some embodiments, the non-neutral aqueous medium comprises a weak acid (i.e. acetic acid, formic acid, oxalic acid, carbonic acid or any other weak acid or any acid that is not a strong acid) at from about 0.1% to about 5% v/w by dry biomass weight. In some embodiments, the non-neutral aqueous medium comprises a weak acid(i.e. acetic acid, formic acid, oxalic acid, carbonic acid or any other weak acid or any acid that is not a strong acid) at about 1.8% v/w by dry biomass weight. In some embodiments, the non-neutral aqueous medium comprises a weak acid(i.e. acetic acid, formic acid, oxalic acid, carbonic acid or any other weak acid or any acid that is not a strong acid) at about 1% v/w by dry biomass weight.

[00219] In some embodiments, hydrolysis of the pretreated biomass composition and/or solids of the pretreated biomass to produce saccharide polymers comprises hydration of the biomass composition in a non-neutral aqueous medium having a pH that is less than 7. For example, the non-neutral aqueous medium can have a pH that is less than 7, 6.5, 6, 5.5, 5, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, or 1. For example, the non-neutral aqueous medium can have a pH that is about 6.5, 6.4, 6.3, 6.2, 6.1, 6, 5.9, 5.8, 5.7, 5.6, 5.5, 5.4, 5.3, 5.2, 5.1, 5, 4.9, 4.8, 4.7, 4.6, 4.5, 4.4, 4.3, 4.2, 4.1, 4, 3.9, 3.8, 3.7, 3.6, 3.5, 3.4, 3.3, 3.2, 3.1, 3, 2.9, 2.8, 2.7, 2.6, 2.5, 2.4, 2.3, 2.2, 2.1, 2, 1.9, 1.8, 1.7, 1.6, 1.5, 1.4, 1.3, 1.2, 1.1, 1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, or lower. The non-neutral aqueous medium having a pH that is less than 7 can comprise one or more acids such as sulfuric acid, sulfurous acid, peroxyacetic acid, lactic acid, formic acid, acetic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, carbonic acid or a combination thereof. The one or more acids can be at any suitable concentration, such as any of the concentrations disclosed herein. In some embodiments, acid hydrolysis of the pretreated

biomass composition hydrolyzes saccharide polymers derived from hemicelluloses down to monosaccharides and/or disaccharides.

[00220] In some embodiments, hydrolysis of the pretreated biomass composition and/or solids of the pretreated biomass to produce saccharide polymers comprises hydration of the biomass composition in a non-neutral aqueous medium having a pH that is greater than 7. For example, the non-neutral aqueous medium can have a pH that is greater than 7, 7.5, 8, 8.5, 9, 9.5, 10, 10.5, 11, 11.5, 12, 12.5, 13, 13.5 or higher. For example, the non-neutral aqueous medium can have a pH that is about 7.5, 7.6, 7.7, 7.8, 7.9, 8, 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 9, 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, 10, 10.1, 10.2, 10.3, 10.4, 10.5, 10.6, 10.7, 10.8, 10.9, 11, 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 11.7, 11.8, 11.9, 12, 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 13, 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, or higher. The non-neutral aqueous medium having a pH greater than 7 can comprise one or more bases such as sodium hydroxide, calcium hydroxide, potassium hydroxide, ammonia, ammonia hydroxide, hydrogen peroxide or a combination thereof. The one or more bases can be at any suitable concentration, such as any of the concentrations disclosed herein.

[00221] In some embodiments, hydrolysis of the pretreated biomass composition and/or solids of the pretreated biomass to produce saccharide polymers comprises heating the pretreated biomass composition and/or solid particles of the pretreated biomass In some embodiments, heating of the pretreated biomass composition and/or solids of the pretreated biomass is performed at a temperature of from about 100 °C to about 250 °C. For example, the temperature can be about 100-250 °C, 100-200 °C, 100-180 °C, 100-160 °C, 100-140 °C, 100-120 °C, 120-200 °C, 120-180 °C, 120-160 °C, 120-140 °C, 140-180 °C, 140-160 °C, 160-180 °C, 140-220 °C 100 °C, 110 °C, 120 °C, 130 °C, 140 °C, 150 °C, 155 °C, 160 °C, 165 °C, 170 °C, 175 °C, 180 °C, 185 °C, 190 °C, 200 °C, 210 °C, 220 °C, 230 °C, 240 °C, or 250 °C. In one embodiment, heating of the biomass composition is at a temperature of from about 100 °C to about 250 °C. In another embodiment, heating of the pretreated biomass composition and/or solid particles of the pretreated biomass is at a temperature of from about 140 °C to about 220 °C. In another embodiment, heating of the biomass composition is at a temperature of from about 160 °C to about 180 °C.

[00222] In some embodiments, heating the pretreated biomass composition and/or solids of the pretreated biomass is performed at a pressure higher than atmospheric. The pressure can be from about 25 PSIG to about 250 PSIG. For example, the pressure can be about 25-250 PSIG, 25-225 PSIG, 25-200 PSIG, 25-175 PSIG, 25-150 PSIG, 25-125 PSIG, 25-100 PSIG, 25-75 PSIG, 25-50 PSIG, 50-225 PSIG, 50-200 PSIG, 50-175 PSIG, 50-150 PSIG, 50-125 PSIG, 50-100 PSIG,

50-75 PSIG, 75-200 PSIG, 75-175 PSIG, 75-150 PSIG, 75-125 PSIG, 75-100 PSIG, 100-175 PSIG, 100-150 PSIG, 100-125 PSIG, 125-150 PSIG, 25 PSIG, 30 PSIG, 35 PSIG, 40 PSIG, 45 PSIG, 50 PSIG, 55 PSIG, 60 PSIG, 65 PSIG, 70 PSIG, 75 PSIG, 80 PSIG, 85 PSIG, 90 PSIG, 95 PSIG, 100 PSIG, 105 PSIG, 110 PSIG, 115 PSIG, 120 PSIG, 125 PSIG, 130 PSIG, 135 PSIG, 140 PSIG, 145 PSIG, 150 PSIG, 155 PSIG, 160 PSIG, 165 PSIG, 170 PSIG, 175 PSIG, 180 PSIG, 185 PSIG, 190 PSIG, 195 PSIG, 200 PSIG, 205 PSIG, 210 PSIG, 215 PSIG, 220 PSIG, 225 PSIG, 230 PSIG, 235 PSIG, 240 PSIG, 245 PSIG, 250 PSIG. In one embodiment, the pressure is from about 25 PSIG to about 250 PSIG. In another embodiment, the pressure is from about 75 PSIG to about 200 PSIG. In another embodiment, the pressure is from about 100 PSIG to about 150 PSIG.

[00223] Some embodiments comprise adjusting the water content of the pretreated biomass composition and/or solids of a pretreated biomass composition prior to hydrolyzing with a non-neutral aqueous medium.

[00224] The water content of solids of a pretreated biomass composition can be adjusted to from about 5% to about 40% solids by dry biomass weight prior to hydrolyzing with a non-neutral aqueous medium. For example, the water content can be adjusted to about 4-40%, 5-30%, 5-25%, 5-20%, 5-15%, 5-12%, 5-10%, 5-8%, 8-30%, 8-25%, 8-20%, 8-15%, 8-12%, 8-10%, 10-40%, 10-30%, 10-25%, 10-20%, 10-15%, 10-12%, 12-30%, 12-25%, 12-20%, 12-15%, 15-30%, 15-25%, 15-20%, 20-30%, 20-25%, 25-30%, 5%, 6%, 7%, 8%, 9%, 10%, 11%, 12%, 13%, 14%, 15%, 16%, 17%, 18%, 19%, 20%, 21%, 22%, 23%, 24%, 25%, 26%, 27%, 28%, 29%, 30%, 31%, 32%, 33%, 34%, 35%, 36%, 37%, 38%, 39%, or 40% solids by dry biomass weight. In one embodiment, the water content of the pretreated biomass composition and/or solids of a pretreated biomass composition is adjusted to about 5% to about 30% solids by dry biomass weight. In another embodiment, the water content of the pretreated biomass composition and/or solids of a pretreated biomass composition is adjusted to about 5% to about 20% solids by dry biomass weight.

[00225] In some embodiments, hydrolysis of the pretreated biomass composition and/or solids of the pretreated biomass to produce saccharide polymers comprises treating with one or more enzymes. The one or more enzymes can comprise enzymes that hydrolyze polysaccharides to yield saccharide polymers. In one embodiment, the one or more enzymes comprise one or more endocellulases, one or more exocellulases, one or more endo-hemicellulases, one or more exo-hemicellulases, or a combination thereof. A saccharide polymer can comprise glucose residues, xylose residues, mannose residues, galactose residues, rhamnose residues, or a combination thereof. The composition comprising saccharide polymers can be an aqueous composition. In

some embodiments, the one or more enzymes are at a total level from about 1% to about 20% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level from about 1% to about 10% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level from about 1% to about 5% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of less than 15% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of less than 10% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of less than 5% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of less than 1% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of less than 0.5% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of about 0.1% to about 1.0% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of less than 0.1% by dry biomass weight.

[00226] In another embodiment, the methods disclosed herein are methods of producing a composition comprising saccharide polymers from a biomass composition comprising cellulose, hemicellulose, and/or lignocellulose. In this embodiment, the methods can comprise pretreating the biomass composition according to any of the methods disclosed herein. In some embodiments, the biomass composition is pretreated to produce a pretreated biomass composition, wherein pretreatment comprises hydration and mechanical size reduction of solids in the biomass composition. In some embodiments, the biomass can be hydrated in water .and subsequently pretreated according to any of the methods described herein. In some embodiments, the pretreated biomass composition comprises solid particles that are less than 50 mm, less than 40 mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, 1 mm, or 0.5 mm in size, or less. In some embodiments, the hydrated and mechanically size reduced biomass composition can be heated for any time or temperature disclosed herein. The pretreated biomass composition can comprise a yield of saccharide polymers that is at least 50%, 60%, 65%, 70%, 75%, 80%, 85%, or 90% of a theoretical maximum. The methods of producing a composition can further comprise hydrolyzing the biomass composition or pretreated biomass composition with one or more enzymes for a time sufficient to produce the composition comprising saccharide polymers. The levels of the one or more enzymes can be any of the levels described herein for any enzyme described herein. The one or more enzymes can comprise enzymes that hydrolyze polysaccharides to yield saccharide polymers. In one embodiment, the

one or more enzymes comprise one or more endocellulases, one or more exocellulases, one or more endo-hemicellulases, one or more exo-hemicellulases, or a combination thereof. The saccharide polymers can comprise glucose polymers residues, xylose residues polymers, mannose residues polymers, galactose residues polymers, rhamnose residues polymers, arabinose residues polymers, or a combination thereof. A saccharide polymer can comprise glucose residues, xylose residues, mannose residues, galactose residues, rhamnose residues, or a combination thereof. The composition comprising saccharide polymers can be an aqueous composition.

[00227] In another embodiment, the methods disclosed herein are methods of producing a composition comprising saccharide polymers from a biomass composition comprising cellulose, hemicellulose, and/or lignocellulose. In this embodiment, the methods can comprise pretreating the biomass composition according to any of the methods disclosed herein. In some embodiments, the biomass composition is pretreated to produce a pretreated biomass composition, wherein pretreatment comprises mechanical size reduction of solids in the biomass composition. In some embodiments, the pretreated biomass composition comprises solid particles that are less than 50 mm, less than 40 mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, 1 mm, or 0.5 mm in size, or less. In some embodiments, the biomass can be hydrated in water and subsequently pretreated according to any of the methods described herein. The pretreated biomass composition can comprise a yield of saccharide polymers that is at least 50%, 60%, 65%, 70%, 75%, 80%, 85%, or 90% of a theoretical maximum. The methods of producing a composition can further comprise hydrolyzing the biomass composition or pretreated biomass composition by heating the biomass composition or pretreated biomass composition in a non-neutral aqueous medium for a time sufficient to produce the composition comprising saccharide polymers. The non-neutral aqueous medium can be at a pH above 7 or a pH below 7. For example, the non-neutral aqueous medium can have a pH that is less than 7, 6.5, 6, 5.5, 5, 4.5, 4, 3.5, 3, 2.5, 2, 1.5, or 1. For example, the non-neutral aqueous medium can have a pH that is about 6.5, 6.4, 6.3, 6.2, 6.1, 6, 5.9, 5.8, 5.7, 5.6, 5.5, 5.4, 5.3, 5.2, 5.1, 5, 4.9, 4.8, 4.7, 4.6, 4.5, 4.4, 4.3, 4.2, 4.1, 4, 3.9, 3.8, 3.7, 3.6, 3.5, 3.4, 3.3, 3.2, 3.1, 3, 2.9, 2.8, 2.7, 2.6, 2.5, 2.4, 2.3, 2.2, 2.1, 2, 1.9, 1.8, 1.7, 1.6, 1.5, 1.4, 1.3, 1.2, 1.1, 1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, 0.1, or lower. For example, the non-neutral aqueous medium can have a pH that is greater than 7, 7.5, 8, 8.5, 9, 9.5, 10, 10.5, 11, 11.5, 12, 12.5, 13, 13.5 or higher. For example, the non-neutral aqueous medium can have a pH that is about 7.5, 7.6, 7.7, 7.8, 7.9, 8, 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, 8.7, 8.8, 8.9, 9, 9.1, 9.2, 9.3, 9.4, 9.5, 9.6, 9.7, 9.8, 9.9, 10, 10.1, 10.2,

10.3, 10.4, 10.5, 10.6, 10.7, 10.8, 10.9, 11, 11.1, 11.2, 11.3, 11.4, 11.5, 11.6, 11.7, 11.8, 11.9, 12, 12.1, 12.2, 12.3, 12.4, 12.5, 12.6, 12.7, 12.8, 12.9, 13, 13.1, 13.2, 13.3, 13.4, 13.5, 13.6, 13.7, 13.8, 13.9, or higher. The non-neutral aqueous medium having a pH that is less than 7 can comprise one or more acids such as those described herein. The one or more acids can be at any suitable concentration, such as any of the concentrations disclosed herein. The non-neutral aqueous medium having a pH greater than 7 can comprise one or more bases such as those described herein. The one or more bases can be at any suitable concentration, such as any of the concentrations disclosed herein. The time sufficient to produce the yield of saccharide polymers can be from about 1 minute to about 120 minutes. For example, the time can be about 1-120 min, 1-90 min, 1-60 min, 1-30 min, 1-15 min, 1-10 min, 1-5 min, 5-60 min, 5-30 min, 5-15 min, 5-10 min, 120 min, 110 min, 100 min, 90 min, 80 min, 70 min, 60 min, 50 min, 45 min, 40 min, 35 min, 30 min, 25 min, 20 min, 19 min, 18 min, 17 min, 16 min, 15 min, 14 min, 13 min, 12 min, 11 min, 10 min, 9 min, 8 min, 7 min, 6 min, 5 min, 4 min, 3 min, 2 min, 1 min. In one embodiment, the time sufficient to produce the yield of saccharide polymers is from about 1 minute to about 60 minutes. In another embodiment, the time sufficient to produce the yield of saccharide polymers is from about 5 minutes to about 30 minutes. In another embodiment, the time sufficient to produce the yield of saccharide polymers is from about 7.5 minutes to about 12.5 minutes. Heating the biomass composition or pretreated biomass composition in a non-neutral aqueous medium can be performed at a temperature of from about 100 °C to about 250 °C. For example, the temperature can be about 100-250 °C, 100-200 °C, 100-180 °C, 100-160 °C, 100-140 °C, 100-120 °C, 120-200 °C, 120-180 °C, 120-160 °C, 120-140 °C, 140-180 °C, 140-160 °C, 160-180 °C, 100 °C, 110 °C, 120 °C, 130 °C, 140 °C, 150 °C, 155 °C, 160 °C, 165 °C, 170 °C, 175 °C, 180 °C, 185 °C, 190 °C, 200 °C, 210 °C, 220 °C, 230 °C, 240 °C, or 250 °C. In one embodiment, heating of the biomass composition or pretreated biomass composition is at a temperature of from about 100 °C to about 250 °C. In another embodiment, heating of the biomass composition or pretreated biomass composition is at a temperature of from about 150 °C to about 200 °C. In another embodiment, heating of the biomass composition or pretreated biomass composition is at a temperature of from about 160 °C to about 180 °C. In some embodiments, heating the biomass composition or pretreated biomass composition in a non-neutral aqueous medium is performed at a pressure higher than atmospheric. The pressure can be from about 25 PSIG to about 250 PSIG. For example, the pressure can be about 25-250 PSIG, 25-225 PSIG, 25-200 PSIG, 25-175 PSIG, 25-150 PSIG, 25-125 PSIG, 25-100 PSIG, 25-75 PSIG, 25-50 PSIG, 50-225 PSIG, 50-200 PSIG, 50-175 PSIG, 50-150 PSIG, 50-125 PSIG, 50-100 PSIG, 50-75 PSIG, 75-200 PSIG, 75-175 PSIG, 75-150 PSIG, 75-125 PSIG, 75-100 PSIG,

100-175 PSIG, 100-150 PSIG, 100-125 PSIG, 125-150 PSIG, 25 PSIG, 30 PSIG, 35 PSIG, 40 PSIG, 45 PSIG, 50 PSIG, 55 PSIG, 60 PSIG, 65 PSIG, 70 PSIG, 75 PSIG, 80 PSIG, 85 PSIG, 90 PSIG, 95 PSIG, 100 PSIG, 105 PSIG, 110 PSIG, 115 PSIG, 120 PSIG, 125 PSIG, 130 PSIG, 135 PSIG, 140 PSIG, 145 PSIG, 150 PSIG, 155 PSIG, 160 PSIG, 165 PSIG, 170 PSIG, 175 PSIG, 180 PSIG, 185 PSIG, 190 PSIG, 195 PSIG, 200 PSIG, 205 PSIG, 210 PSIG, 215 PSIG, 220 PSIG, 225 PSIG, 230 PSIG, 235 PSIG, 240 PSIG, 245 PSIG, 250 PSIG. In one embodiment, the pressure is from about 25 PSIG to about 250 PSIG. In another embodiment, the pressure is from about 75 PSIG to about 200 PSIG. In another embodiment, the pressure is from about 100 PSIG to about 150 PSIG. The saccharide polymer can comprise glucose polymers, xylose polymers, mannose polymers, galactose polymers, rhamnose polymers, arabinose polymers, or a combination thereof. A saccharide polymer can comprise glucose residues, xylose residues, mannose residues, galactose residues, rhamnose residues, or a combination thereof. The composition comprising saccharide polymers can be an aqueous composition.

[00228] In another embodiment, the methods disclosed herein are methods of producing a composition comprising saccharide polymers from a biomass composition comprising cellulose, hemicellulose, and/or lignocellulose. In this embodiment, the methods can comprise pretreating the biomass composition according to any of the methods disclosed herein. In some embodiments, the biomass composition is pretreated to produce a pretreated biomass composition, wherein pretreatment comprises mechanical size reduction of solids in the biomass composition to less than 50 mm, less than 40 mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, 1 mm, or 0.5 mm in size (*e.g.* diameter, or length, width, height), or less. In some embodiments, the biomass can be hydrated in water and subsequently pretreated according to any of the methods described herein. The pretreated biomass composition can comprise a yield of saccharide polymers that is at least 50%, 60%, 65%, 70%, 75%, 80%, 85%, or 90% of a theoretical maximum. The methods of producing a composition can further comprise hydrolyzing the biomass composition or pretreated biomass composition by heating the biomass composition or pretreated biomass composition in a non-neutral aqueous medium comprising one or more enzymes for a time sufficient to produce the composition comprising saccharide polymers. The pH, temperature, and pressure of the non-aqueous medium can be any of those described herein. The levels of the one or more enzymes can be any of the levels described herein for any enzyme described herein. The one or more enzymes can comprise enzymes that hydrolyze polysaccharides to yield saccharide polymers. In one embodiment, the one or more

enzymes comprise one or more endocellulases, one or more exocellulases, one or more endo-hemicellulases, one or more exo-hemicellulases, or a combination thereof.

[00229] In some embodiments, the one or more enzymes comprise one or more cellulase enzymes and optionally one or more hemicellulase enzymes. In one embodiment, the one or more enzymes is a cellulase and hemicellulase complex. In one embodiment, the cellulase and hemicellulase complex is not supplemented with additional hemicellulase enzymes. In some embodiments, the one or more enzymes comprise a commercially available enzyme cocktail (*e.g.*, Accellerase™ 1000, CelluSeb-TL, CelluSeb-TS, Cellic™, Ctec, Cellic™, CTec2, Cellic™, CTec3, STARGEN™, Maxalig™, Spezyme.R™, Distillase.R™, G-Zyme.R™, Fermenzyme.R™, Fermgen™, GC 212, or Optimash™, *etc.*). In some embodiments, the one or more enzymes comprise one or more endocellulases, one or more exocellulases, one or more endo-hemicellulases, one or more exo-hemicellulases, or a combination thereof.

[00230] In some embodiments, the one or more enzymes are at a total level from about 1% to about 20% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level from about 1% to about 10% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level from about 1% to about 5% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of less than 15% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of less than 10% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of less than 5% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of less than 1% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of less than 0.5% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of about 0.1% to about 1.0% w/w or v/w by dry biomass weight. In some embodiments, the one or more enzymes are at a total level of less than 0.1% by dry biomass weight.

[00231] In some embodiments, the time sufficient to produce the composition comprising C6 and C5 saccharides is from about 10 hours to about 100 hours. For example, the time can be about 10-100 hr, 10-75 hr, 10-50 hr, 10-20 hr, 20-100 hr, 20-75 hr, 20-50 hr, 50-100 hr, 50-75 hr, 75-100 hr, 10 hr, 11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr, 25 hr, 30 hr, 35 hr, 40 hr, 45 hr, 50 hr, 55 hr, 60 hr, 65 hr, 70 hr, 75 hr, 80 hr, 85 hr, 90 hr, 95 hr, or 100 hr. In one embodiment, the time sufficient to produce the composition comprising C6 and C5 saccharides is from about 21 hours to about 50 hours.

[00232] In some embodiments, the time sufficient to produce the composition comprising saccharide polymers is from about 1 hour to about 100 hours. In some embodiments, the time sufficient to produce the composition comprising saccharide polymers is from about 10 hours to about 100 hours. In some embodiments, the time sufficient to produce the composition comprising saccharide polymers is more than 100 hours. For example, the time can be about 10-100 hr, 10-75 hr, 10-50 hr, 10-20 hr, 20-100 hr, 20-75 hr, 20-50 hr, 50-100 hr, 50-75 hr, 75-100 hr, 1 hr, 2 hr, 3 hr, 4, hr, 5 hr, 6 hr, 7 hr, 8 hr, 9 hr, 10 hr, 11 hr, 12 hr, 13 hr, 14 hr, 15 hr, 16 hr, 17 hr, 18 hr, 19 hr, 20 hr, 21 hr, 22 hr, 23 hr, 24 hr, 25 hr, 30 hr, 35 hr, 40 hr, 45 hr, 50 hr, 55 hr, 60 hr, 65 hr, 70 hr, 75 hr, 80 hr, 85 hr, 90 hr, 95 hr, or 100 hr. In some embodiments, the time can be about 100-200 hr, 100-175 hr, 100-150 hr, 100-125 hr. In one embodiment, the time sufficient to produce the composition comprising saccharide polymers is from about 21 hours to about 50 hours.

[00233] In some embodiments, the time sufficient to produce the composition comprising saccharide polymers is from about 1 minute to about 100 minutes. In some embodiments, the time sufficient to produce the composition comprising saccharide polymers is from about 10 minutes to about 100 minutes. In some embodiments, the time sufficient to produce the composition comprising saccharide polymers is more than 100 minutes. For example, the time can be about 10-100 minutes, 10-75 minutes, 10-50 minutes, 10-20 minutes, 20-100 minutes, 20-75 minutes, 20-50 minutes, 50-100 minutes, 50-75 minutes, 75-100 minutes, 1, minute, 2 minutes, 3 minutes, 4 minutes, 5 minutes, 6 minutes, 7 minutes, 8 minutes, 9 minutes, 10 minutes, 11 minutes, 12 minutes, 13 minutes, 14 minutes, 15 minutes, 16 minutes, 17 minutes, 18 minutes, 19 minutes, 20 minutes, 21 minutes, 22 minutes, 23 minutes, 24 minutes, 25 minutes, 30 minutes, 35 minutes, 40 minutes, 45 minutes, 50 minutes, 55 minutes, 60 minutes, 65 minutes, 70 minutes, 75 minutes, 80 minutes, 85 minutes, 90 minutes, 95 minutes, or 100 minutes. In some embodiments, the time can be about 100-200 minutes, 100-175 minutes, 100-150 minutes, 100-125 minutes. In one embodiment, the time sufficient to produce the composition comprising saccharide polymers is from about 21 minutes to about 50 minutes. In one embodiment, the composition comprising C6 and C5 saccharides comprises glucose in a yield that is greater than 55% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the composition comprising C6 and C5 saccharides comprises glucose in a yield that is greater than 60% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the composition comprising C6 and C5 saccharides comprises glucose in a yield that is greater than 70% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the composition comprising C6 and C5 saccharides comprises glucose in a yield

that is greater than 80% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the composition comprising C6 and C5 saccharides comprises glucose in a yield that is greater than 90% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the composition comprising C6 and C5 saccharides comprises glucose in a yield that is greater than 70% of a theoretical maximum at 48 hours of hydrolysis. In another embodiment, the composition comprising C6 and C5 saccharides comprises glucose in a yield that is greater than 80% of a theoretical maximum at 48 hours of hydrolysis. In another embodiment, the composition comprising C6 and C5 saccharides comprises glucose in a yield that is greater than 90% of a theoretical maximum at 48 hours of hydrolysis. In another embodiment, the composition comprising C6 and C5 saccharides comprises glucose in a yield that is greater than 95% of a theoretical maximum at 48 hours of hydrolysis. In another embodiment, the composition comprising C6 and C5 saccharides comprises xylose in a yield that is greater than 60% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the composition comprising C6 and C5 saccharides comprises xylose in a yield that is greater than 70% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the composition comprising C6 and C5 saccharides comprises xylose in a yield that is greater than 80% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the composition comprising C6 and C5 saccharides comprises xylose in a yield that is greater than 90% of a theoretical maximum at 21 hours of hydrolysis. In one embodiment, the composition comprising C6 and C5 saccharides is produced by hydrolysis with one or more enzymes. In one embodiment, the composition comprising C6 and C5 saccharides is produced by hydrolysis with one or more polymeric catalysts. In one embodiment, the composition comprising C6 and C5 saccharides is produced by hydrolysis with one or more polymeric acid catalysts.

[00234] In one embodiment, the composition comprises saccharide polymers wherein the saccharide polymers comprise glucose residues. In one embodiment, the composition comprises saccharide polymers wherein the saccharide polymers comprise xylose residues. In one embodiment, the composition comprises saccharide polymers wherein the saccharide polymers comprise galactose residues. In one embodiment, the composition comprises saccharide polymers wherein the saccharide polymers comprise arabinose residues. In one embodiment, the composition comprises saccharide polymers wherein the saccharide polymers comprise mannose residues. In one embodiment, the composition comprises saccharide polymers wherein the saccharide polymers comprise rhamnose residues. In one embodiment, the composition comprises saccharide polymers wherein the saccharide polymers comprise a mixture of saccharide polymers comprising glucose residues, xylose residues, mannose residues, galactose

residues, rhamnose residues, and/or arabinose residues. In one embodiment, the yield of saccharide polymers is greater than 55% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 60% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 70% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 80% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 90% of a theoretical maximum at 21 hours of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 70% of a theoretical maximum at 48 hours of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 80% of a theoretical maximum at 48 hours of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 90% of a theoretical maximum at 48 hours of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 95% of a theoretical maximum at 48 hours of hydrolysis. In one embodiment, the yield of saccharide polymers is greater than 55% of a theoretical maximum at 21 minutes of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 60% of a theoretical maximum at 21 minutes of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 70% of a theoretical maximum at 21 minutes of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 80% of a theoretical maximum at 21 minutes of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 90% of a theoretical maximum at 21 minutes of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 70% of a theoretical maximum at 48 minutes of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 80% of a theoretical maximum at 48 minutes of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 90% of a theoretical maximum at 48 minutes of hydrolysis. In another embodiment, the yield of saccharide polymers is greater than 95% of a theoretical maximum at 48 minutes of hydrolysis.

[00235] Some embodiments comprise adjusting the water content and/or the pH of a pretreated biomass prior to hydrolyzing with one or more enzymes.

[00236] The water content of a pretreated biomass composition can be adjusted to from about 5% to about 30% solids by dry biomass weight prior to hydrolyzing with one or more enzymes. For example, the water content can be adjusted to about 5-30%, 5-25%, 5-20%, 5-15%, 5-12%, 5-10%, 5-8%, 8-30%, 8-25%, 8-20%, 8-15%, 8-12%, 8-10%, 10-30%, 10-25%, 10-20%, 10-15%, 10-12%, 12-30%, 12-25%, 12-20%, 12-15%, 15-30%, 15-25%, 15-20%, 20-30%, 20-25%, 25-30%, 5%, 6%, 7%, 8%, 9%, 10%, 11%, 12%, 13%, 14%, 15%, 16%, 17%, 18%, 19%, 20%,

21%, 22%, 23%, 24%, 25%, 26%, 27%, 28%, 29%, or 30% solids by dry biomass weight. In one embodiment, the water content of the pretreated biomass composition is adjusted to about 5% to about 30% solids by dry biomass weight. In another embodiment, the water content of the pretreated biomass composition is adjusted to about 5% to about 20% solids by dry biomass weight.

[00237] The pH of a pretreated biomass composition can be adjusted to from about 3 to about 8 prior to hydrolyzing with one or more enzymes. For example, the pH can be adjusted to about 3-8, 3-7, 3-6, 3-5.5, 3-4.5, 3-4, 4-7, 4-6, 4-5.5, 4-4.5, 4.5-6, 4.5-5.5, 3, 3.5, 3.6, 3.7, 3.8, 3.9, 4, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6, 6.5, 7, 7.5, or 8. In one embodiment, the pH of the pretreated biomass composition is adjusted to about 4 to about 7. In another embodiment, the pH of the pretreated biomass composition is adjusted to about 4.5 to about 5.5.

[00238] Hydrolysis of a pretreated biomass composition with one or more enzymes can be done at a temperature of from about 30 °C to about 70 °C. For example, the temperature of hydrolysis can be about 30-70 °C, 30-65 °C, 30-60 °C, 30-55 °C, 30-50 °C, 30-45 °C, 30-40 °C, 40-65 °C, 40-60 °C, 40-55 °C, 40-50 °C, 40-45 °C, 45-60 °C, 45-55 °C, 45-50 °C, 50-60 °C, 50-55 °C. In one embodiment, the temperature of hydrolysis is from about 45 °C to about 60 °C.

[00239] Some embodiments comprise adjusting the water content and/or the pH of solids of a pretreated biomass composition prior to hydrolyzing with one or more enzymes.

[00240] The water content of solids of a pretreated biomass composition can be adjusted to from about 5% to about 30% solids by dry biomass weight prior to hydrolyzing with one or more enzymes. For example, the water content can be adjusted to about 5-30%, 5-25%, 5-20%, 5-15%, 5-12%, 5-10%, 5-8%, 8-30%, 8-25%, 8-20%, 8-15%, 8-12%, 8-10%, 10-30%, 10-25%, 10-20%, 10-15%, 10-12%, 12-30%, 12-25%, 12-20%, 12-15%, 15-30%, 15-25%, 15-20%, 20-30%, 20-25%, 25-30%, 5%, 6%, 7%, 8%, 9%, 10%, 11%, 12%, 13%, 14%, 15%, 16%, 17%, 18%, 19%, 20%, 21%, 22%, 23%, 24%, 25%, 26%, 27%, 28%, 29%, or 30% solids by dry biomass weight. In one embodiment, the water content of the solids of a pretreated biomass composition is adjusted to about 5% to about 30% solids by dry biomass weight. In another embodiment, the water content of the solids of a pretreated biomass composition is adjusted to about 5% to about 20% solids by dry biomass weight.

[00241] The pH of solids of a pretreated biomass composition can be adjusted to from about 3 to about 8 prior to hydrolyzing with one or more enzymes. For example, the pH can be adjusted to about 3-8, 3-7, 3-6, 3-5.5, 3-4.5, 3-4, 4-7, 4-6, 4-5.5, 4-4.5, 4.5-6, 4.5-5.5, 3, 3.5, 3.6, 3.7, 3.8, 3.9, 4, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5, 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 6, 6.5, 7,

7.5, or 8. In one embodiment, the pH of the pretreated biomass composition is adjusted to about 4 to about 7. In another embodiment, the pH of the pretreated biomass composition is adjusted to about 4.5 to about 5.5.

[00242] Hydrolysis of solids of a pretreated biomass composition with one or more enzymes can be done at a temperature of from about 30 °C to about 70 °C. For example, the temperature of hydrolysis can be about 30-70 °C, 30-65 °C, 30-60 °C, 30-55 °C, 30-50 °C, 30-45 °C, 30-40 °C, 40-65 °C, 40-60 °C, 40-55 °C, 40-50 °C, 40-45 °C, 45-60 °C, 45-55 °C, 45-50 °C, 50-60 °C, 50-55 °C. In one embodiment, the temperature of hydrolysis is from about 45 °C to about 60 °C.

[00243] In one embodiment, the biomass hydrolyzing unit provides useful advantages for the conversion of biomass to biofuels and chemical products. One advantage of this unit is its ability to produce monomeric saccharides from multiple types of biomass, including mixtures of different biomass materials, and is capable of hydrolyzing polysaccharides and higher molecular weight saccharides to lower molecular weight saccharides. In one embodiment, the hydrolyzing unit utilizes a pretreatment process and a hydrolytic enzyme which facilitates the production of a saccharide stream containing a concentration of a monomeric saccharide or several monomeric saccharides derived from cellulosic and/or hemicellulosic polymers. Examples of biomass material that can be pretreated and hydrolyzed to manufacture saccharide monomers include, but are not limited to, cellulosic, hemicellulosic, lignocellulosic materials; pectins; starches; wood; paper; agricultural products; forest waste; tree waste; tree bark; leaves; grasses; sawgrass; woody plant matter; non-woody plant matter; carbohydrates; starch; inulin; fructans; glucans; corn; sugar cane; sorghum, other grasses; bamboo, algae, and material derived from these materials. This ability to use a very wide range of pretreatment methods and hydrolytic enzymes gives distinct advantages in biomass fermentations. Various pretreatment conditions and enzyme hydrolysis can enhance the extraction of saccharides from biomass, resulting in higher yields, higher productivity, greater product selectivity, and/or greater conversion efficiency.

[00244] In one embodiment, the enzyme treatment is used to hydrolyze various higher saccharides (higher molecular weight) present in biomass to lower saccharides (lower molecular weight), such as in preparation for fermentation by biocatalysts such as yeasts to produce ethanol, hydrogen, or other chemicals such as organic acids including succinic acid, formic acid, acetic acid, and lactic acid. These enzymes and/or the hydrolysate can be used in fermentations to produce various products including fuels, and other chemicals.

[00245] In one embodiment, the polymeric acid catalyst treatment is used to hydrolyze various higher saccharides (higher molecular weight) present in biomass to lower saccharides (lower molecular weight), such as in preparation for fermentation by biocatalysts such as yeasts to

produce ethanol, hydrogen, or other chemicals such as organic acids including succinic acid, formic acid, acetic acid, and lactic acid.

[00246] In one example, the process for converting biomass material into ethanol includes pretreating the biomass material (*e.g.*, "feedstock"), hydrolyzing the pretreated biomass to convert polysaccharides to oligosaccharides, further hydrolyzing the oligosaccharides to monosaccharides, and converting the monosaccharides to biofuels and chemical products. In one embodiment, enzymes such as cellulases, polysaccharases, lipases, proteases, ligninases, and hemicellulases, help produce the monosaccharides that can be used in the biosynthesis of fermentation end-products. In one embodiment, polymeric acid catalysts help produce the monosaccharides that can be used in the biosynthesis of fermentation end-products. Biomass material that can be utilized includes woody plant matter, non-woody plant matter, cellulosic material, lignocellulosic material, hemicellulosic material, carbohydrates, pectin, starch, inulin, fructans, glucans, corn, algae, sugarcane, other grasses, switchgrass, bagasse, wheat straw, barley straw, rice straw, corncobs, bamboo, citrus peels, sorghum, high biomass sorghum, seed hulls, and material derived from these. The final product can then be separated and/or purified, as indicated by the properties for the desired final product. In some instances, compounds related to saccharides such as sugar alcohols or sugar acids can be utilized as well.

[00247] Chemicals used in the methods of the present invention are readily available and can be purchased from a commercial supplier, such as Sigma-Aldrich. Additionally, commercial enzyme cocktails (*e.g.* Accellerase™ 1000, CelluSeb-TL, CelluSeb-TS, Cellic™, Ctec, Cellic™, CTec2, Cellic™, CTec3, STARGEN™, Maxalig™, Spezyme.R™, Distillase.R™, G-Zyme.R™, Fermenzyme.R™, Fermgen™, GC 212, or Optimash™) or any other commercial enzyme cocktail can be purchased from vendors such as Specialty Enzymes & Biochemicals Co., Genencor, or Novozymes. Alternatively, enzyme cocktails can be prepared by growing one or more organisms such as for example a fungi (*e.g.* a *Trichoderma*, a *Saccharomyces*, a *Pichia*, a White Rot Fungus *etc.*), a bacteria (*e.g.* a *Clostridium*, or a coliform bacterium, a *Zymomonas* bacterium, *Sacharophagus degradans etc.*) in a suitable medium and harvesting enzymes produced therefrom. In some embodiments, the harvesting can include one or more steps of purification of enzymes.

[00248] In one embodiment, treatment of biomass comprises enzyme hydrolysis. In one embodiment, a biomass is treated with an enzyme or a mixture of enzymes, *e.g.*, endoglucanases, exoglucanases, cellobiohydrolases, cellulase, beta-glucosidases, glycoside hydrolases, glycosyltransferases, lyases, esterases and proteins containing carbohydrate-binding modules. In one embodiment, the enzyme or mixture of enzymes is one or more individual enzymes with

distinct activities. In another embodiment, the enzyme or mixture of enzymes can be enzyme domains with a particular catalytic activity. For example, an enzyme with multiple activities can have multiple enzyme domains, including for example glycoside hydrolases, glycosyltransferases, lyases and/or esterases catalytic domains.

[00249] As used herein, a multi-enzyme product is one that can be obtained from or derived from a microbial, plant, or other source or combination thereof, and will contain enzymes capable of degrading lignocellulosic material. Examples of enzymes comprising the multi-enzyme products of the invention include cellulases (such as cellobiohydrolases, endoglucanase, β-glucosidases, hemicellulases (such as xylanases, including endoxylanases, exoxylanase, and β-xylosidase), ligninases, amylases, α-arabinofuranosidases, α-glucuronidases, α-glucuronidases, arabinases, glucuronidases, proteases, esterases (including ferulic acid esterase and acetylxylan esterase), lipases, glucomannanases, and xylogluconases.

[00250] In some embodiments, the multi-enzyme product comprises a hemicellulase. Hemicellulose is a complex polymer, and its composition often varies widely from organism to organism, and from one tissue type to another. In general, a main component of hemicellulose is beta-1,4-linked xylose, a five carbon saccharide. However, this xylose is often branched as beta-1,3 linkages, and can be substituted with linkages to arabinose, galactose, mannose, glucuronic acid, or by esterification to acetic acid. Hemicellulose can also contain glucan, which is a general term for beta-linked six carbon saccharides. Those hemicelluloses include xyloglucan, glucomannan, and galactomannan.

[00251] The composition, nature of substitution, and degree of branching of hemicellulose is very different in dicotyledonous plants (dicots, *e.g.*, plant whose seeds have two cotyledons or seed leaves such as lima beans, peanuts, almonds, peas, kidney beans) as compared to monocotyledonous plants (monocots; *e.g.*, plants having a single cotyledon or seed leaf such as corn, wheat, rice, grasses, barley). In dicots, hemicellulose is comprised mainly of xyloglucans that are 1,4-beta-linked glucose chains with 1,6-beta-linked xylosyl side chains. In monocots, including most grain crops, the principal components of hemicellulose are heteroxylans. These are primarily comprised of 1,4-beta-linked xylose backbone polymers with 1,3-beta linkages to arabinose, galactose and mannose as well as xylose modified by ester-linked acetic acids. Also present are branched beta glucans comprised of 1,3- and 1,4-beta-linked glucosyl chains. In monocots, cellulose, heteroxylans and beta glucans are present in roughly equal amounts, each comprising about 15-25% of the dry matter of cell walls.

[00252] Hemicellulolytic enzymes, *e.g.* hemicellulases, include includes both exohydrolytic and endohydrolytic enzymes, such as xylanase, β-xylosidase and esterases, which actively cleave

hemicellulosic material through hydrolysis. These xylanase and esterase enzymes cleave the xylan and acetyl side chains of xylan and the remaining xylo-oligomers are unsubstituted and can thus be hydrolyzed with xylosidase only. In addition, several less known side activities have been found in enzyme preparations which hydrolyze hemicellulose. While the multi-enzyme product may contain many types of enzymes, mixtures comprising enzymes that increase or enhance saccharide release from biomass are preferred, including hemicellulases. In one embodiment, the hemicellulase is a xylanase, an arabinofuranosidase, an acetyl xylan esterase, a glucuronidase, an endo-galactanase, a mannanase, an endo arabinase, an exo arabinase, an exo-galactanase, a ferulic acid esterase, a galactomannanase, a xylogluconase, or mixtures of any of these. In particular, the enzymes can include glucoamylase, β-xylosidase and/or β-glucosidase. The enzymes of the multi-enzyme product can be provided by a variety of sources. In one embodiment, the enzymes can be produced by growing microorganisms or plants that produce the enzymes naturally or by virtue of being genetically modified to express the enzyme or enzymes. In another embodiment, at least one enzyme of the multi-enzyme product is commercially available.

[00253] In one embodiment, enzymes that degrade polysaccharides are used for the hydrolysis of biomass and can include enzymes that degrade cellulose, namely, cellulases. Examples of some cellulases include endocellulases and exo-cellulases that hydrolyze beta-1,4-glucosidic bonds.

[00254] In one embodiment, enzymes that degrade polysaccharides are used for the hydrolysis of biomass and can include enzymes that have the ability to degrade hemicellulose, namely, hemicellulases. Hemicellulose can be a major component of plant biomass and can contain a mixture of pentoses and hexoses, for example, D-xylopyranose, L-arabinofuranose, D-mannopyranose, D-glucopyranose, D-galactopyranose, D-glucopyranosyluronic acid and other saccharides. In one embodiment, enzymes that degrade polysaccharides are used for the hydrolysis of biomass and can include enzymes that have the ability to degrade pectin, namely, pectinases. In plant cell walls, the cross-linked cellulose network can be embedded in a matrix of pectins that can be covalently cross-linked to xyloglucans and certain structural proteins. Pectin can comprise homogalacturonan (HG) or rhamnogalacturonan (RH).

[00255] In one embodiment, hydrolysis of biomass includes enzymes that can hydrolyze starch. Enzymes that hydrolyze starch include alpha-amylase, glucoamylase, beta-amylase, exo-alpha-1,4-glucanase, and pullulanase.

[00256] In one embodiment, hydrolysis of biomass comprises hydrolases that can include enzymes that hydrolyze chitin. In another embodiment, hydrolases can include enzymes that hydrolyze lichen, namely, lichenase.

[00257] In one embodiment, after pretreatment and/or hydrolysis by any of the above methods the feedstock contains cellulose, hemicellulose, soluble oligomers, saccharide polymers, simple saccharides, lignin, volatiles and ash. The parameters of the hydrolysis can be changed to vary the concentration of the components of the pretreated feedstock. For example, In one embodiment, a hydrolysis is chosen so that the concentration of soluble C5 saccharides is high and the concentration of lignin is low after hydrolysis. For example, in another embodiment a pretreatment and/or hydrolysis is chosen so that the concentration of saccharide polymers is high and the concentration of lignin is low after hydrolysis. Examples of parameters of the hydrolysis include temperature, pressure, time, concentration, composition and pH.

[00258] In one embodiment, the parameters of the pretreatment and hydrolysis are changed to vary the concentration of the components of the pretreated feedstock such that concentration of the components in the pretreated and hydrolyzed feedstock is optimal for fermentation with a microbe such as a yeast or bacterium microbe.

[00259] In one embodiment, the parameters of the pretreatment are changed to encourage the release of the components of a genetically modified feedstock such as enzymes stored within a vacuole to increase or complement the enzymes synthesized by biocatalyst to produce optimal release of the fermentable components during hydrolysis and fermentation.

[00260] In one embodiment, the parameters of the pretreatment and hydrolysis are changed such that concentration of accessible cellulose in the pretreated feedstock is 1%, 5%, 10%, 12%, 13%, 14%, 15%, 16%, 17%, 19%, 20%, 30%, 40% or 50%. In one embodiment, the parameters of the pretreatment are changed such that concentration of accessible cellulose in the pretreated feedstock is 5% to 30%. In one embodiment, the parameters of the pretreatment are changed such that concentration of accessible cellulose in the pretreated feedstock is 10% to 20%.

[00261] In one embodiment, the parameters of the pretreatment are changed such that concentration of hemicellulose in the pretreated feedstock is 1%, 5%, 10%, 12%, 13%, 14%, 15%, 16%, 17%, 19%, 20%, 21%, 22%, 23%, 24%, 25%, 26%, 27%, 28%, 29%, 30%, 40% or 50%. In one embodiment, the parameters of the pretreatment are changed such that concentration of hemicellulose in the pretreated feedstock is 5% to 40%. In one embodiment, the parameters of the pretreatment are changed such that concentration of hemicellulose in the pretreated feedstock is 10% to 30%.

[00262] In one embodiment, the parameters of the pretreatment and hydrolysis are changed such that concentration of soluble oligomers in the pretreated feedstock is 1%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, or 99%. Examples of soluble oligomers include, but are not limited to, cellobiose and xylobiose. In one

embodiment, the parameters of the pretreatment are changed such that concentration of soluble oligomers in the pretreated feedstock is 30% to 90%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration of soluble oligomers in the pretreated feedstock is 45% to 80%.

[00263] In one embodiment, the parameters of the pretreatment and hydrolysis are changed such that concentration of simple saccharides in the pretreated feedstock is 1%, 5%, 10%, 12%, 13%, 14%, 15%, 16%, 17%, 19%, 20%, 30%, 40% or 50%. In one embodiment, the parameters of the pretreatment and hydrolysis are changed such that concentration of simple saccharides in the pretreated feedstock is 0% to 20%. In one embodiment, the parameters of the pretreatment and hydrolysis are changed such that concentration of simple saccharides in the pretreated feedstock is 0% to 5%. Examples of simple saccharides include, but are not limited to, C5 and C6 monomers and dimers.

[00264] In one embodiment, the parameters of the pretreatment and hydrolysis are changed such that the concentration of saccharide polymers in the pretreated feedstock is 1%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, or 99%. In one embodiment, the parameters of the pretreatment and hydrolysis are changed such that concentration of saccharide polymers in the pretreated feedstock is 0% to 20%. In one embodiment, the parameters of the pretreatment and hydrolysis are changed such that concentration of saccharide polymers in the pretreated feedstock is 0% to 5%. In one embodiment, the parameters of the pretreatment and hydrolysis are changed such that concentration of saccharide polymers in the pretreated feedstock is 30% to 90%. In one embodiment, the parameters of the pretreatment and hydrolysis are changed such that concentration of saccharide polymers in the pretreated feedstock is 45% to 80%. Examples of saccharide polymers can include, but are not limited to, C5 and C6 oligomers or polymers.

[00265] In one embodiment, the parameters of the pretreatment are changed such that concentration of lignin in the pretreated and/or hydrolyzed feedstock is 1%, 5%, 10%, 12%, 13%, 14%, 15%, 16%, 17%, 19%, 20%, 30%, 40% or 50%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration of lignin in the pretreated feedstock is 0% to 20%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration of lignin in the pretreated feedstock is 0% to 5%. In one embodiment, the parameters of the pretreatment and hydrolysis are changed such that concentration of lignin in the pretreated and/or hydrolyzed feedstock is less than 1% to 2%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration of phenolics is minimized.

[00266] Pretreatment and/or hydrolysis of biomass comprising cellulose, hemicelluloses and/or lignocelluloses as described herein can produce a number of compounds that are potent fermentation inhibitors. These include organic acids such as acetic acid and formic acid, furan compounds (furfural and 5-hydroxy methyl furfural), and several products of lignin oxidation and degradation (e.g., phenolics). In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration or amount of furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids in the pretreated and/or hydrolyzed feedstock is less than 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.5%, 0.4%, 0.3%, 0.2%, 0.1%, 0.05%, 0.025%, 0.01%, 0.005%, 0.0025%, 0.001%, 0.0005%, 0.00025%, 0.0001% , 0.00005%, 0.000025%, or 0.00001% w/v. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural is undetectable or substantially undetectable. In one embodiment, the pretreatment and/or hydrolysis of the biomass as described herein reduces the levels of fermentation inhibitors wherein the amount of fermentation inhibitors is undetectable or substantially undetectable. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration (w/v) of fermentation inhibitors in the pretreated and/or hydrolyzed feedstock is less than 1% to 2%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of fermentation inhibitors is less than 10%, less than 5%, less than 2.5%, less than 2%, less than 1.5%, less than 1% ,less than 0.5%, less than 0.4%, less than 0.3%, less than 0.2%, less than 0.1%, less than 0.05%, less than 0.025%, less than 0.01%, less than 0.005%, less than 0.0025%, less than 0.001%, less than 0.0005%, less than 0.00025%, less than 0.0001%, less than 0.00005%, less than 0.000025%, or less than 0.00001% in the pretreated and/or hydrolyzed feedstock. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of fermentation inhibitors is about 10%, about 5%, about 2.5%, about 2%, about 1.5%, about 1% , about 0.5%, about 0.4%, about 0.3%, about 0.2%, about 0.1%, about 0.05%, about 0.025%, about 0.01%, about 0.005%, about 0.0025%, about 0.001%, about 0.0005%, about 0.00025%, about 0.0001%, about 0.00005%, about 0.000025%, or about 0.00001%. in the pretreated and/or hydrolyzed feedstock. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of fermentation inhibitors is about 0.00001% -10%, 0.00001% -5%, 0.00001% - 2.5%, 0.00001% - 2%, 0.00001% - 1.5%, 0.00001% - 1%, 0.00001% - 0.5%, 0.00001% - 0.4%, 0.00001% - 0.3%, 0.00001% - 0.2%, 0.00001% - 0.1%, 0.00001% -0.05%, 0.00001% - 0.025%, 0.00001% - 0.01%, 0.00001% - 0.005%, 0.00001% - 0.0025%, 0.00001% - 0.001%, 0.00001% - 0.0005%, 0.00001% -0.00025%, 0.00001% - 0.0001%, 0.00001% -

0.00005%, or 0.00001% - 0.000025% in the pretreated and/or hydrolyzed feedstock. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of fermentation inhibitors is 0% or substantially 0% in the pretreated and/or hydrolyzed feedstock. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of fermentation inhibitors is undetectable or substantially undetectable. In one embodiment, the fermentation inhibitors comprise furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids. In one embodiment, the one or more organic acids is acetic acid. In one embodiment, the one or more organic acids is formic acid.

[00267] In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration (w/v) or amount of fermentation inhibitors produced during pretreatment and/or hydrolysis is less than 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.5%, 0.4%, 0.3%, 0.2%, 0.1%, 0.05%, 0.025%, 0.01%, 0.005%, 0.0025%, 0.001%, 0.0005%, 0.00025%, 0.0001% , 0.00005%, 0.000025%, or 0.00001%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration (w/v) of fermentation inhibitors produced during pretreatment and/or hydrolysis is less than 1% to 2%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of fermentation inhibitors produced during pretreatment and/or hydrolysis is less than 10%, less than 5%, less than 2.5%, less than 2%, less than 1.5%, less than 1% ,less than 0.5%, less than 0.4%, less than 0.3%, less than 0.2%, less than 0.1%, less than 0.05%, less than 0.025%, less than 0.01%, less than 0.005%, less than 0.0025%, less than 0.001%, less than 0.0005%, less than 0.00025%, less than 0.0001%, less than 0.00005%, less than 0.000025%, or less than 0.00001%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of fermentation inhibitors produced during pretreatment and/or hydrolysis is about 10%, about 5%, about 2.5%, about 2%, about 1.5%, about 1% , about 0.5%, about 0.4%, about 0.3%, about 0.2%, about 0.1%, about 0.05%, about 0.025%, about 0.01%, about 0.005%, about 0.0025%, about 0.001%, about 0.0005%, about 0.00025%, about 0.0001%, about 0.00005%, about 0.000025%, or about 0.00001%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of fermentation inhibitors produced during pretreatment and/or hydrolysis is about 0.00001% -10%, 0.00001% -5%, 0.00001% - 2.5%, 0.00001% - 2%, 0.00001% - 1.5%, 0.00001% - 1%, 0.00001% - 0.5%, 0.00001% - 0.4%, 0.00001% - 0.3%, 0.00001% - 0.2%, 0.00001% - 0.1%, 0.00001% -0.05%, 0.00001% - 0.025%, 0.00001% - 0.01%, 0.00001% - 0.005%, 0.00001% - 0.0025%, 0.00001% - 0.001%, 0.00001% - 0.0005%, 0.00001% -

0.00025%, 0.00001% - 0.0001%, 0.00001% - 0.00005%, or0.00001% - 0.000025% . In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of fermentation inhibitors produced during pretreatment and/or hydrolysis is 0% or substantially 0%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of fermentation inhibitors produced during pretreatment and/or hydrolysis is undetectable or substantially undetectable. In one embodiment, the fermentation inhibitors comprise furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids. In one embodiment, the one or more organic acids is acetic acid. In one embodiment, the one or more organic acids is formic acid.

[00268] In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration or amount of furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids in the pretreated and/or hydrolyzed feedstock is less than 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.5%, 0.4%, 0.3%, 0.2%, 0.1%, 0.05%, 0.025%, 0.01%, 0.005%, 0.0025%, 0.001%, 0.0005%, 0.00025%, 0.0001% , 0.00005%, 0.000025%, or 0.00001% w/v. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration or amount of acetic acid in the pretreated and/or hydrolyzed feedstock is less than 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.5%, 0.4%, 0.3%, 0.2%, 0.1%, 0.05%, 0.025%, 0.01%, 0.005%, 0.0025%, 0.001%, 0.0005%, 0.00025%, 0.0001% , 0.00005%, 0.000025%, or 0.00001% w/v. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural is undetectable or substantially undetectable. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the amount of furfural is undetectable or substantially undetectable. In one embodiment, the pretreatment and/or hydrolysis of the biomass as described herein reduces the levels of furfural, hydroxymethyl furfural (HMF), and/or one or more organic acids wherein the amount of furfural, hydroxymethyl furfural (HMF), and/or one or more organic acids is undetectable or substantially undetectable. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration (w/v) of furfural, hydroxymethyl furfural (HMF), and/or one or more organic acids in the pretreated and/or hydrolyzed feedstock is less than 1% to 2%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural, hydroxymethyl furfural (HMF), and/or one or more organic acids is less than 10%, less than 5%, less than 2.5%, less than 2%, less than 1.5%, less than 1% ,less than 0.5%, less than 0.4%, less than 0.3%, less than 0.2%, less than 0.1%, less than 0.05%, less than 0.025%, less than 0.01%, less than 0.005%, less than 0.0025%, less than 0.001%, less than 0.0005%, less than 0.00025%,

less than 0.0001%, less than 0.00005%, less than 0.000025%, or less than 0.00001% in the pretreated and/or hydrolyzed feedstock. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of acetic acid is less than 10%, less than 5%, less than 2.5%, less than 2%, less than 1.5%, less than 1% ,less than 0.5%, less than 0.4%, less than 0.3%, less than 0.2%, less than 0.1%, less than 0.05%, less than 0.025%, less than 0.01%, less than 0.005%, less than 0.0025%, less than 0.001%, less than 0.0005%, less than 0.00025%, less than 0.0001%, less than 0.00005%, less than 0.000025%, or less than 0.00001% in the pretreated and/or hydrolyzed feedstock. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural, hydroxymethyl furfural (HMF), and/or one or more organic acids is about 10%, about 5%, about 2.5%, about 2%, about 1.5%, about 1% , about 0.5%, about 0.4%, about 0.3%, about 0.2%, about 0.1%, about 0.05%, about 0.025%, about 0.01%, about 0.005%, about 0.0025%, about 0.001%, about 0.0005%, about 0.00025%, about 0.0001%, about 0.00005%, about 0.000025%, or about 0.00001% in the pretreated and/or hydrolyzed feedstock. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of acetic acid is about 10%, about 5%, about 2.5%, about 2%, about 1.5%, about 1% , about 0.5%, about 0.4%, about 0.3%, about 0.2%, about 0.1%, about 0.05%, about 0.025%, about 0.01%, about 0.005%, about 0.0025%, about 0.001%, about 0.0005%, about 0.00025%, about 0.0001%, about 0.00005%, about 0.000025%, or about 0.00001% in the pretreated and/or hydrolyzed feedstock. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural, hydroxymethyl furfural (HMF), and/or one or more organic acids is about 0.00001% -10%, 0.00001% -5%, 0.00001% - 2.5%, 0.00001% - 2%, 0.00001% - 1.5%, 0.00001% - 1%, 0.00001% - 0.5%, 0.00001% - 0.4%, 0.00001% - 0.3%, 0.00001% - 0.2%, 0.00001% - 0.1%, 0.00001% -0.05%, 0.00001% - 0.025%, 0.00001% - 0.01%, 0.00001% - 0.005%, 0.00001% - 0.0025%, 0.00001% - 0.001%, 0.00001% - 0.0005%, 0.00001% -0.00025%, 0.00001% - 0.0001%, 0.00001% - 0.00005%, or 0.00001% - 0.000025% in the pretreated and/or hydrolyzed feedstock. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural, hydroxymethyl furfural (HMF), and/or one or more organic acids is 0% or substantially 0% in the pretreated and/or hydrolyzed feedstock. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural, hydroxymethyl furfural (HMF), and/or one or more organic acids is undetectable or substantially undetectable. In one embodiment, the one or more organic acids is acetic acid. In one embodiment, the one or more organic acids is formic acid. In one embodiment, the parameters

of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of acetic acid is about 0.00001% -10%, 0.00001% -5%, 0.00001% - 2.5%, 0.00001% - 2%, 0.00001% - 1.5%, 0.00001% - 1%, 0.00001% - 0.5%, 0.00001% - 0.4%, 0.00001% - 0.3%, 0.00001% - 0.2%, 0.00001% - 0.1%, 0.00001% -0.05%, 0.00001% - 0.025%, 0.00001% - 0.01%, 0.00001% - 0.005%, 0.00001% - 0.0025%, 0.00001% - 0.001%, 0.00001% - 0.0005%, 0.00001% - 0.00025%, 0.00001% - 0.0001%, 0.00001% - 0.00005%, or 0.00001% - 0.000025% in the pretreated and/or hydrolyzed feedstock. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of acetic acid is 0% or substantially 0% in the pretreated and/or hydrolyzed feedstock. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of acetic acid is undetectable or substantially undetectable.

[00269] In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration (w/v) or amount of furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids produced during pretreatment and/or hydrolysis is less than 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.5%, 0.4%, 0.3%, 0.2%, 0.1%, 0.05%, 0.025%, 0.01%, 0.005%, 0.0025%, 0.001%, 0.0005%, 0.00025%, 0.0001% , 0.00005%, 0.000025%, or 0.00001%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural produced during pretreatment and/or hydrolysis is undetectable or substantially undetectable. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the amount of furfural produced during pretreatment and/or hydrolysis is undetectable or substantially undetectable. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration (w/v) of furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids produced during pretreatment and/or hydrolysis is less than 1% to 2%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids produced during pretreatment and/or hydrolysis is less than 10%, less than 5%, less than 2.5%, less than 2%, less than 1.5%, less than 1% ,less than 0.5%, less than 0.4%, less than 0.3%, less than 0.2%, less than 0.1%, less than 0.05%, less than 0.025%, less than 0.01%, less than 0.005%, less than 0.0025%, less than 0.001%, less than 0.0005%, less than 0.00025%, less than 0.0001%, less than 0.00005%, less than 0.000025%, or less than 0.00001%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids produced during pretreatment and/or hydrolysis is about 10%, about 5%, about 2.5%, about 2%, about 1.5%, about 1% , about 0.5%,

about 0.4%, about 0.3%, about 0.2%, about 0.1%, about 0.05%, about 0.025%, about 0.01%, about 0.005%, about 0.0025%, about 0.001%, about 0.0005%, about 0.00025%, about 0.0001%, about 0.00005%, about 0.000025%, or about 0.00001%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids produced during pretreatment and/or hydrolysis is about 0.00001% -10%, 0.00001% -5%, 0.00001% - 2.5%, 0.00001% - 2%, 0.00001% - 1.5%, 0.00001% - 1%, 0.00001% - 0.5%, 0.00001% - 0.4%, 0.00001% - 0.3%, 0.00001% - 0.2%, 0.00001% - 0.1%, 0.00001% -0.05%, 0.00001% - 0.025%, 0.00001% - 0.01%, 0.00001% - 0.005%, 0.00001% - 0.0025%, 0.00001% - 0.001%, 0.00001% - 0.0005%, 0.00001% -0.00025%, 0.00001% - 0.0001%, 0.00001% - 0.00005%, or 0.00001% - 0.000025%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids produced during pretreatment and/or hydrolysis is 0% or substantially 0%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids produced during pretreatment and/or hydrolysis is undetectable or substantially undetectable. In one embodiment, the one or more organic acids is acetic acid. In one embodiment, the one or more organic acids is formic acid. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration (w/v) or amount of acetic acid produced during pretreatment and/or hydrolysis is less than 10%, 9%, 8%, 7%, 6%, 5%, 4%, 3%, 2%, 1%, 0.5%, 0.4%, 0.3%, 0.2%, 0.1%, 0.05%, 0.025%, 0.01%, 0.005%, 0.0025%, 0.001%, 0.0005%, 0.00025%, 0.0001%, 0.00005%, 0.000025%, or 0.00001%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that concentration (w/v) of acetic acid produced during pretreatment and/or hydrolysis is less than 1% to 2%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of acetic acid produced during pretreatment and/or hydrolysis is less than 10%, less than 5%, less than 2.5%, less than 2%, less than 1.5%, less than 1% ,less than 0.5%, less than 0.4%, less than 0.3%, less than 0.2%, less than 0.1%, less than 0.05%, less than 0.025%, less than 0.01%, less than 0.005%, less than 0.0025%, less than 0.001%, less than 0.0005%, less than 0.00025%, less than 0.0001%, less than 0.00005%, less than 0.000025%, or less than 0.00001%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of acetic acid produced during pretreatment and/or hydrolysis is about 10%, about 5%, about 2.5%, about 2%, about 1.5%, about 1% , about 0.5%, about 0.4%, about 0.3%, about 0.2%, about 0.1%, about 0.05%, about 0.025%, about 0.01%,

about 0.005%, about 0.0025%, about 0.001%, about 0.0005%, about 0.00025%, about 0.0001%, about 0.00005%, about 0.000025%, or about 0.00001%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of acetic acid produced during pretreatment and/or hydrolysis is about 0.00001% -10%, 0.00001% -5%, 0.00001% - 2.5%, 0.00001% - 2%, 0.00001% - 1.5%, 0.00001% - 1%, 0.00001% - 0.5%, 0.00001% - 0.4%, 0.00001% - 0.3%, 0.00001% - 0.2%, 0.00001% - 0.1%, 0.00001% -0.05%, 0.00001% - 0.025%, 0.00001% - 0.01%, 0.00001% - 0.005%, 0.00001% - 0.0025%, 0.00001% - 0.001%, 0.00001% - 0.0005%, 0.00001% -0.00025%, 0.00001% - 0.0001%, 0.00001% - 0.00005%, or 0.00001% - 0.000025%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of acetic acid produced during pretreatment and/or hydrolysis is 0% or substantially 0%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of acetic acid produced during pretreatment and/or hydrolysis is undetectable or substantially undetectable. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of formic acid produced during pretreatment and/or hydrolysis is 0% or substantially 0%. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration (w/v) of formic acid produced during pretreatment and/or hydrolysis is undetectable or substantially undetectable.

[00270] In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that less of one or more of fermentation inhibitors are produced. The fermentation inhibitors comprise furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids. In one embodiment, the organic acid comprises acetic acid. In one embodiment, the organic acid comprises formic acid. In one embodiment, the temperature used for the hydration of the biomass composition during the pretreatment and/or hydrolysis produces less of one or more fermentation inhibitors than if the temperature were higher. In one embodiment, the hydration of the biomass composition is in an aqueous medium. In one embodiment, the hydration of the biomass composition is in a non-neutral aqueous medium. In one embodiment, the temperature used for hydration of the biomass composition is from about 30 °C to about 70 °C, about 40 °C to about 60 °C, or at about 50 °C. In one embodiment, the time or duration of the hydration of the biomass composition during the pretreatment and/or hydrolysis produces less of one or more fermentation inhibitors than if the time or duration were longer. In one embodiment, the time or duration of hydration of the biomass composition is from about 1 minute to about 60 minutes, about 5 minutes to about 30 minutes, or about 15 minutes to about 20 minutes. In one embodiment, the temperature used for heating a hydrated biomass composition during the

pretreatment and/or hydrolysis produces less of one or more fermentation inhibitors than if the temperature was higher. In one embodiment, the temperature used for heating a hydrated biomass composition is from about 100 °C to about 250 °C , about 150 °C to about 200 °C, or about 160 °C to about 180 °C. In one embodiment, the pressure used for heating a hydrated biomass composition during the pretreatment and/or hydrolysis produces less of one or more fermentation inhibitors than if the pressure was higher. In one embodiment, the pressure used for heating a hydrated biomass composition is higher than atmospheric pressure. In one embodiment, the pressure used for heating a hydrated biomass composition is from about 25 PSIG to about 250 PSIG, about 75 PSIG to about 200 PSIG, or about 100 PSIG to about 150 PSIG. In one embodiment, the temperature of hydration of the biomass composition is from about 30 °C to about 70 °C, about 40 °C to about 60 °C, or at about 50 °C. In one embodiment, the total time or duration of the pretreatment of the biomass composition produces less of one or more fermentation inhibitors than if the total time or duration were longer. In one embodiment, the total time or duration of the pretreatment of the biomass composition is from about 1 minute to about 3 hours, from about 5 minutes to about 90 minutes, or from about 15 minutes to about 45 minutes. In one embodiment, heating of a hydrated biomass composition comprising particle sizes as described herein during the pretreatment produce less of one or more fermentation inhibitors than if the particle sizes were larger. In one embodiment, heating of the hydrated biomass composition comprising particle size ranges as described herein during the pretreatment produce less of one or more fermentation inhibitors than if the particle size ranges were larger. In one embodiment, the pretreatment and/or hydrolysis of the biomass composition produce one or more of fermentation inhibitors, wherein the one or more fermentation inhibitors can be removed by a humidification-dehumidification process. The fermentation inhibitors comprise furfural, 5-hydroxymethyl furfural (HMF), and/or one or more organic acids. In one embodiment, the organic acid comprises acetic acid. In one embodiment, the organic acid comprises formic acid.

[00271] In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed such that the concentration of simple saccharides is at least 75% to 85%, and the concentration of lignin is 0% to 5% and the concentration of furfural and low molecular weight lignin in the pretreated feedstock is less than 1% to 2%.

[00272] In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed to obtain a high concentration of hemicellulose and a low concentration of lignin. In one embodiment, the parameters of the pretreatment and/or hydrolysis are changed to obtain a high concentration of hemicellulose and a low concentration of lignin such that concentration of the

components in the pretreated stock is optimal for fermentation with a microbe such as biocatalyst.

[00273] In one embodiment, more than one of these steps can occur at any given time. For example, hydrolysis of the pretreated feedstock and hydrolysis of the oligosaccharides can occur simultaneously, and one or more of these can occur simultaneously to the conversion of monosaccharides to a fuel or chemical.

[00274] In another embodiment, an enzyme can directly convert the polysaccharide to monosaccharides. In some instances, an enzyme can hydrolyze the polysaccharide to oligosaccharides and the enzyme or another enzyme can hydrolyze the oligosaccharides to monosaccharides.

[00275] In another embodiment, a polymeric catalyst can directly convert the polysaccharide to monosaccharides. In another embodiment, a polymeric acid catalyst can directly convert the polysaccharide to monosaccharides. In one embodiment, very low levels of furfural and/or hydroxymethylfurfural are produced by the use of polymeric catalyst or polymeric acid catalyst. In one embodiment, substantially no furfural and/or hydroxymethylfurfural are produced by the use of polymeric catalyst or polymeric acid catalyst. . In one embodiment, the levels of furfural and/or hydroxymethylfurfural are reduced compared to methods that do not use polymeric catalyst or polymeric acid catalyst. In one embodiment, the levels of furfural and/or hydroxymethylfurfural are substantially reduced compared to methods that do not use polymeric catalyst or polymeric acid catalyst.

[00276] In another embodiment, the enzymes can be added to the fermentation or they can be produced by microorganisms present in the fermentation. In one embodiment, the microorganism present in the fermentation produces some enzymes. In another embodiment, enzymes are produced separately and added to the fermentation.

[00277] For the overall conversion of pretreated biomass to final product to occur at high rates, it is generally necessary for each of the necessary enzymes for each conversion step to be present with sufficiently high activity. If one of these enzymes is missing or is present in insufficient quantities, the production rate of an end product will be reduced. The production rate can also be reduced if the microorganisms responsible for the conversion of monosaccharides to product only slowly take up monosaccharides and/or have only limited capability for translocation of the monosaccharides and intermediates produced during the conversion to end product. Additions of fractions obtained from pretreatment and/or pretreatment and hydrolysis can increase initial or overall growth rates. In another embodiment, oligomers are taken up slowly by a biocatalyst,

necessitating an almost complete conversion of polysaccharides and oligomers to monomeric saccharides.

[00278] In another embodiment, the enzymes of the method are produced by a biocatalyst, including a range of hydrolytic enzymes suitable for the biomass materials used in the fermentation methods. In one embodiment, a biocatalyst is grown under conditions appropriate to induce and/or promote production of the enzymes needed for the saccharification of the polysaccharide present. The production of these enzymes can occur in a separate vessel, such as a seed fermentation vessel or other fermentation vessel, or in the production fermentation vessel where ethanol production occurs. When the enzymes are produced in a separate vessel, they can, for example, be transferred to the production fermentation vessel along with the cells, or as a relatively cell free solution liquid containing the intercellular medium with the enzymes. When the enzymes are produced in a separate vessel, they can also be dried and/or purified prior to adding them to the hydrolysis or the production fermentation vessel. The conditions appropriate for production of the enzymes are frequently managed by growing the cells in a medium that includes the biomass that the cells will be expected to hydrolyze in subsequent fermentation steps. Additional medium components, such as salt supplements, growth factors, and cofactors including, but not limited to phytate, amino acids, and peptides can also assist in the production of the enzymes utilized by the microorganism in the production of the desired products.

[00279] **Polymeric Catalyst Hydrolysis**

[00280] In one embodiment, treatment of biomass comprises polymeric catalyst based hydrolysis. In one embodiment, a biomass is treated with a polymeric acid catalyst or a mixture of polymeric acid catalysts. In one embodiment, the polymeric acid catalyst is a polymer having acidic monomers and ionic monomers that are connected to form a polymeric backbone, in which each acidic monomer has at least one Bronsted-Lowry acid, and each ionic monomer independently has at least one nitrogen-containing cationic group or phosphorous-containing cationic group. In some embodiments, each acidic monomer has one Bronsted-Lowry acid. In other embodiments, some of the acidic monomers have one Bronsted-Lowry acid, while others have two Bronsted-Lowry acids. In some embodiments, each ionic monomer has one nitrogen-containing cationic group or phosphorous-containing cationic group. In other embodiments, some of the ionic monomers have one nitrogen-containing cationic group or phosphorous-containing cationic group, while others have two nitrogen-containing cationic groups or phosphorous-containing cationic groups.

[00281] Also disclosed are methods of producing a saccharide stream from a biomass composition comprising cellulose, hemicellulose, or lignocellulose, the methods comprising: (a)

hydrating the biomass composition in an aqueous medium; (b) mechanical size reduction of the biomass composition to produce a mixture of solid particles, wherein at least 50% of the solid particles are less than 1.5 mm in a dimension; (c) heating the biomass composition; and (d) hydrolyzing the biomass composition with one or more polymeric catalysts to produce a saccharide stream.

[00282] The one or more polymeric catalysts can be, individually, a polymer comprising acidic monomers and ionic monomers connected to form a polymeric backbone. The polymer can be cross-linked.

[00283] Each acidic monomer can comprise, individually, at least one Bronsted-Lowry acid. In some embodiments, the Bronsted-Lowry acid at each occurrence is independently selected from the group consisting of sulfonic acid, phosphonic acid, acetic acid, isophthalic acid, boronic acid, and perfluorinated acid. In some embodiments, one or more of the Bronsted-Lowry acids are directly connected to the polymeric backbone. In some embodiments, one or more of the acidic monomers further comprise a linker connecting the Bronsted-Lowry acid to the polymeric backbone. In some embodiments, the linker at each occurrence is independently selected from the group consisting of unsubstituted or substituted alkylene, unsubstituted or substituted cycloalkylene, unsubstituted or substituted alkenylene, unsubstituted or substituted arylene, unsubstituted or substituted heteroarylene, unsubstituted or substituted alkylene ether, unsubstituted or substituted alkylene ester, and unsubstituted or substituted alkylene carbamate.

[00284] Each ionic monomer can comprise, individually, at least one nitrogen containing cationic group or phosphorous-containing cationic group.

[00285] The nitrogen-containing cationic group at each occurrence can be independently selected from the group consisting of pyrrolium, imidazolium, pyrazolium, oxazolium, thiazolium, pyridinium, pyrimidinium, pyrazinium, pyradizimium, thiazinium, morpholinium, piperidinium, piperizinium, and pyrollizinium.

[00286] The phosphorous-containing cationic group at each occurrence can be independently selected from the group consisting of triphenyl phosphonium, trimethyl phosphonium, triethyl phosphonium, tripropyl phosphonium, tributyl phosphonium, trichloro phosphonium, and trifluoro phosphonium.

[00287] One or more of the ionic monomers can be directly connected to form the polymeric backbone.

[00288] One or more of the ionic monomers can each further comprise a linker connecting the nitrogen-containing cationic group or the phosphorous-containing cationic group to the polymeric backbone. In some embodiments, the linker at each occurrence is independently

selected from the group consisting of unsubstituted or substituted alkylene, unsubstituted or substituted cycloalkylene, unsubstituted or substituted alkenylene, unsubstituted or substituted arylene, unsubstituted or substituted heteroarylene, unsubstituted or substituted alkylene ether, unsubstituted or substituted alkylene ester, and unsubstituted or substituted alkylene carbamate.

[00289] The polymeric backbone can be selected from the group consisting of polyethylene, polypropylene, polyvinyl alcohol, polystyrene, polyurethane, polyvinyl chloride, polyphenol-aldehyde, polytetrafluoroethylene, polybutylene terephthalate, polycaprolactam, poly(acrylonitrile butadiene styrene), polyalkyleneammonium, polyalkylenediammonium, polyalkylenepyrrolium, polyalkyleneimidazolium, polyalkylenepyrazolium, polyalkyleneoxazolium, polyalkylenethiazolium, polyalkylenepyridinium, polyalkylenepyrimidinium, polyalkylenepyrazinium, polyalkylenepyradizimium, polyalkylenethiazinium, polyalkylenemorpholinium, polyalkylenepiperidinium, polyalkylenepiperizinium, polyalkylenepyrollizinium, polyalkylenetriphenylphosphonium, polyalkylenetrimethylphosphonium, polyalkylenetriethylphosphonium, polyalkylenetripropylphosphonium, polyalkylenetributylphosphonium, polyalkylenetrichlorophosphonium, polyalkylenetrifluorophosphonium, and polyalkylenediazolium.

[00290] The polymer can further comprise hydrophobic monomers connected to form the polymeric backbone. In some embodiments, each hydrophobic monomer comprises a hydrophobic group, wherein the hydrophobic group at each occurrence is independently selected from an unsubstituted or substituted alkyl, an unsubstituted or substituted cycloalkyl, an unsubstituted or substituted aryl, or an unsubstituted or substituted heteroaryl.

[00291] The one or more polymeric catalysts can further comprise acidic-ionic monomers connected to form the polymeric backbone, wherein each acidic-ionic monomer comprises a Bronsted-Lowry acid and a cationic group.

[00292] The polymeric catalyst can have a total amount of Bronsted-Lowry acid of between 0.1 and 20 mmol per gram of polymer.

[00293] The polymeric catalyst can be coated on a solid core. In some embodiments, the solid core comprises an inert material or a magnetic material. In some embodiments, the solid core is iron. In some embodiments, the solid core is non-porous.

[00294] The one or more polymer catalysts and the biomass composition can be admixed in a ratio of about 3 : 1 to 1 : 3 polymer catalyst : biomass composition by dry weight. In some embodiments, the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 2 : 1 to 1 : 2 polymer catalyst : biomass composition by dry weight. In some

embodiments, the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 1.5 : 1 to 1 : 1.5 polymer catalyst : biomass composition by dry weight. In some embodiments, the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 1:1 polymer catalyst : biomass composition by dry weight.

[00295] Hydrolyzing the biomass composition with the one or more polymeric catalysts can be performed at a temperature of about 75°C-200°C. In some embodiments, hydrolyzing is performed at a temperature of about 100°C-175°C. In some embodiments, hydrolyzing is performed at a temperature of about 120°C-150°C.

[00296] Hydrolyzing the biomass composition with the one or more polymeric catalysts can be performed at a pressure of about 100 PSIG to about 150 PSIG.

[00297] Hydrolyzing the biomass composition with the one or more polymeric catalysts can be performed for a time of about 0.5 minutes to about 24 hours. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 12 hours. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 4 hours. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 1 hour. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 30 minutes. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 5 minutes.

[00298] The methods can further comprise: (e) recovering the one or more polymer catalysts from the saccharide stream and residual biomass. In some embodiments, recovering the one or more polymeric catalysts comprises the use of a cyclone press, worm press, filter press, mechanical press, a centrifuge press, or a gravity press. In some embodiments, recovering the one or more polymeric catalysts comprises differential sedimentation, wherein the residual biomass and the polymeric catalyst sediment into one or more separate phases from the saccharide stream.

[00299] The one or more polymeric catalysts can be selected from the group consisting of: poly[styrene-co-4-vinylbenzenesulfonic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium chloride-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium acetate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-3-ethyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium chloride-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-3-ethyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-3-ethyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium acetate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-1-(4-vinylbenzyl)-3H-

imidazol-1-ium chloride-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-1-(4-vinylbenzyl)-3H-imidazol-1-ium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-1-(4-vinylbenzyl)-3H-imidazol-1-ium acetate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-benzoimidazol-1-ium chloride-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-benzoimidazol-1-ium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-benzoimidazol-1-ium acetate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-1-(4-vinylbenzyl)-pyridinium-chloride-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-1-(4-vinylbenzyl)-pyridinium-bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-1-(4-vinylbenzyl)-pyridinium-acetate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-1-(4-vinylbenzyl)-pyridinium-chloride-co-3-methyl-1-(4-vinylbenzy- l)-3H-imidazol-1-ium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-1-(4-vinylbenzyl)-pyridinium-bisulfate-co-3-methyl-1-(4-vinylbenz- yl)-3H-imidazol-1-ium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-1-(4-vinylbenzyl)-pyridinium-acetate-co-3-methyl-1-(4-vinylbenzyl-)-3H-imidazol-1-ium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-4-methyl-4-(4-vinylbenzyl)-morpholin-4-ium chloride-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-4-methyl-4-(4-vinylbenzyl)-morpholin-4-ium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-4-methyl-4-(4-vinylbenzyl)-morpholin-4-ium acetate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-triphenyl-(4-vinylbenzyl)-phosphonium chloride-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-triphenyl-(4-vinylbenzyl)-phosphonium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-triphenyl-(4-vinylbenzyl)-phosphonium acetate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-1-methyl-1-(4-vinylbenzyl)-piperidin-1-ium chloride-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-1-methyl-1-(4-vinylbenzyl)-piperidin-1-ium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-1-methyl-1-(4-vinylbenzyl)-piperidin-1-ium acetate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-4-(4-vinylbenzyl)-morpholine-4-oxide-co-divinyl benzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-triethyl-(4-vinylbenzyl)-ammonium chloride-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-triethyl-(4-vinylbenzyl)-ammonium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-triethyl-(4-vinylbenzyl)-ammonium acetate-co-divinylbenzene]; poly[styrene-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium chloride-co-4-boronyl-1-(4-

vinylbenzyl)-pyridinium chloride-co-divinylbenzene]; poly[styrene-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium chloride-co-1-(4-vinylphenyl)methylphosphonic acid-co-divinylbenzene]; poly[styrene-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium bisulfate-co-1-(4-vinylphenyl)methylphosphonic acid-co-divinylbenzene]; poly[styrene-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium acetate-co-1-(4-vinylphenyl)methylphosphonic acid-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzylchloride-co-1-methyl-2-vinyl-pyridinium chloride-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzylchloride-co-1-methyl-2-vinyl-pyridinium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzylchloride-co-1-methyl-2-vinyl-pyridinium acetate-co-divinylbenzene]; poly[styrene-co-4-vinylbenzenesulfonic acid-co-4-(4-vinylbenzyl)-morpholine-4-oxide-co-divinyl benzene]; poly[styrene-co-4-vinylphenylphosphonic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium chloride-co-divinylbenzene]; poly[styrene-co-4-vinylphenylphosphonic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium bisulfate-co-divinylbenzene]; poly[styrene-co-4-vinylphenylphosphonic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium acetate-co-divinylbenzene]; poly[styrene-co-3-carboxymethyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium chloride-co-divinylbenzene]; poly[styrene-co-3-carboxymethyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium bisulfate-co-divinylbenzene]; poly[styrene-co-3-carboxymethyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium acetate-co-divinylbenzene]; poly[styrene-co-5-(4-vinylbenzylamino)-isophthalic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium chloride-co-divinylbenzene]; poly[styrene-co-5-(4-vinylbenzylamino)-isophthalic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium bisulfate-co-divinylbenzene]; poly[styrene-co-5-(4-vinylbenzylamino)-isophthalic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium acetate-co-divinylbenzene]; poly[styrene-co-(4-vinylbenzylamino)-acetic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium chloride-co-divinylbenzene]; poly[styrene-co-(4-vinylbenzylamino)-acetic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium bisulfate-co-divinylbenzene]; poly[styrene-co-(4-vinylbenzylamino)-acetic acid-co-3-methyl-1-(4-vinylbenzyl)-3H-imidazol-1-ium acetate-co-divinylbenzene]; poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzylmethylimidazolium chloride-co-vinylbenzylmethylmorpholinium chloride-co-vinylbenzyltriphenyl phosphonium chloride-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzylmethylimidazolium chloride-co-vinylbenzylmethylmorpholinium chloride-co-vinylbenzyltriphenyl phosphonium chloride-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzylmethylimidazolium bisulfate-co-vinylbenzylmethylmorpholinium bisulfate-co-

vinylbenzyltriphenyl phosphonium bisulfate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzylmethylimidazolium bisulfate-co-vinylbenzylmethylmorpholinium bisulfate-co-vinylbenzyltriphenyl phosphonium bisulfate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzylmethylimidazolium acetate-co-vinylbenzylmethylmorpholinium acetate-co-vinylbenzyltriphenyl phosphonium acetate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzylmethylimidazolium acetate-co-vinylbenzylmethylmorpholinium acetate-co-vinylbenzyltriphenyl phosphonium acetate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzylmethylmorpholinium chloride-co-vinylbenzyltriphenylphosphonium chloride-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzylmethylmorpholinium chloride-co-vinylbenzyltriphenylphosphonium chloride-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzylmethylmorpholinium bisulfate-co-vinylbenzyltriphenylphosphonium bisulfate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzylmethylmorpholinium bisulfate-co-vinylbenzyltriphenylphosphonium bisulfate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzylmethylmorpholinium acetate-co-vinylbenzyltriphenylphosphonium bisulfate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzylmethylmorpholinium acetate-co-vinylbenzyltriphenylphosphonium bisulfate-co-divinylbenzene) poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylmethylimidazolium chloride-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylmethylimidazolium bisulfate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylmethylimidazolium acetate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylmethylimidazolium chloride-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylmethylimidazolium bisulfate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylmethylimidazolium acetate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzyltriphenylphosphonium chloride-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzyltriphenylphosphonium bisulfate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzyltriphenylphosphonium acetate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzyltriphenylphosphonium chloride-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzyltriphenylphosphonium bisulfate-co-

divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzyltriphenylphosphonium acetate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzylmethylimidazolium chloride-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzylmethylimidazolium bisulfate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzylmethylimidazolium acetate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzylmethylimidazolium chloride-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzylmethylimidazolium bisulfate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzylmethylimidazolium acetate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzyltriphenylphosphonium chloride-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzyltriphenylphosphonium bisulfate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenesulfonic acid-co-vinylbenzyltriphenylphosphonium acetate-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzyltriphenylphosphonium chloride-co-divinylbenzene); poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzyltriphenylphosphonium bisulfate-co-divinylbenzene); and poly(styrene-co-4-vinylbenzenephosphonic acid-co-vinylbenzyltriphenylphosphonium acetate-co-divinylbenzene).

[00300] In some embodiments, the polymeric catalysts described herein can be used with biomass that has been pretreated by any of the methods described herein. In other embodiments, the polymeric catalysts described herein can be used concurrently with any of the pretreatment methods described herein. In other embodiments, the polymeric catalysts described herein can be used in combination with any of the pretreatment methods described herein. In other embodiments, the polymeric catalysts described herein can be in place of any of the pretreatment methods described herein. In other embodiments, the polymeric catalysts described herein can be used with biomass before pretreatment. In other embodiments, the polymeric catalysts described herein can be used with biomass that has not been pretreated. Further, the biomass can also be subjected to other processes instead of or in addition to pretreatment including, for example, particle size reduction, pre-soaking, wetting, washing, or conditioning by any of the methods described herein. In some embodiments, the biomass composition can be subjected to a one-step or a multi-step hydrolysis process using the polymeric catalysts described herein. In some embodiments, the biomass composition is first contacted with the polymeric catalyst, such as a polymeric acid catalyst, and then the resulting product is contacted with one or more enzymes in a second hydrolysis reaction. In one embodiment, pretreatment of a biomass

composition can comprise polymeric catalyst treatment. In one embodiment, pretreatment of a biomass composition comprising polymeric catalyst treatment, can be followed by enzymatic hydrolysis. In one embodiment, a biomass composition can be treated by any of the pretreatment methods described herein, followed by treatment with a polymeric catalyst as described, followed by enzymatic hydrolysis.

[00301] Hydrolysis of a biomass composition with one or more polymeric catalysts can be done at a temperature of from about 30 °C to about 170 °C. For example, the temperature of hydrolysis can be 30 °C, 35 °C, 40 °C, 45 °C, 50 °C, 55 °C, 60 °C, 65 °C, 70 °C, 75 °C, 80 °C, 85 °C, 90 °C, 95 °C, 100 °C, 105 °C, 110 °C, 115 °C, 120 °C, 125 °C, 130 °C, 135 °C, 140 °C, 145 °C, 150 °C, 155 °C, 160 °C, 165 °C, or 170 °C. For example, the temperature of hydrolysis can be from about 30-35 °C, 35-40 °C, 40-45 °C, 45-50 °C, 50-55 °C, 55-60 °C, 60-65 °C, 65-70 °C, 70-75 °C, 75-80 °C, 80-85 °C, 85-90 °C, 90-95 °C, 95-100 °C, 100-105 °C, 105 °C-110 °C, 110-115 °C, 115-120 °C, 120-125 °C, 125-130 °C, 130-135 °C, 135-140 °C, 140-145 °C, 145-150 °C, 150-155 °C, 155-160 °C, 160-165 °C, or 165-170 °C. For example, the temperature of hydrolysis can be from about 30-40 °C, 40-50 °C, 50-60 °C, 60-70 °C, 70-80 °C, 80-90 °C, 90-100 °C, 100-110 °C, 110-120 °C, 120-130 °C, 130-140 °C, 140-150 °C, 150-160 °C, or 160-170 °C. In one embodiment, the temperature of hydrolysis of the biomass during pretreatment is from about 135 °C to about 140 °C. In one embodiment, the temperature of hydrolysis of a pretreated biomass or solids of a pretreated biomass is from about 160 °C to about 170 °C. In one embodiment, the polymeric catalyst is a polymeric acid catalyst.

[00302] Hydrolysis of a biomass composition with one or more polymeric catalysts can be done at a pressure from about 25 PSIG to about 250 PSIG. For example, the pressure can be about 25-250 PSIG, 25-225 PSIG, 25-200 PSIG, 25-175 PSIG, 25-150 PSIG, 25-125 PSIG, 25-100 PSIG, 25-75 PSIG, 25-50 PSIG, 50-225 PSIG, 50-200 PSIG, 50-175 PSIG, 50-150 PSIG, 50-125 PSIG, 50-100 PSIG, 50-75 PSIG, 75-200 PSIG, 75-175 PSIG, 75-150 PSIG, 75-125 PSIG, 75-100 PSIG, 100-175 PSIG, 100-150 PSIG, 100-125 PSIG, 125-150 PSIG, 25 PSIG, 30 PSIG, 35 PSIG, 40 PSIG, 45 PSIG, 50 PSIG, 55 PSIG, 60 PSIG, 65 PSIG, 70 PSIG, 75 PSIG, 80 PSIG, 85 PSIG, 90 PSIG, 95 PSIG, 100 PSIG, 105 PSIG, 110 PSIG, 115 PSIG, 120 PSIG, 125 PSIG, 130 PSIG, 135 PSIG, 140 PSIG, 145 PSIG, 150 PSIG, 155 PSIG, 160 PSIG, 165 PSIG, 170 PSIG, 175 PSIG, 180 PSIG, 185 PSIG, 190 PSIG, 195 PSIG, 200 PSIG, 205 PSIG, 210 PSIG, 215 PSIG, 220 PSIG, 225 PSIG, 230 PSIG, 235 PSIG, 240 PSIG, 245 PSIG, 250 PSIG. In one embodiment, the pressure is from about 25 PSIG to about 250 PSIG. In another embodiment, the pressure is from about 75 PSIG to about 200 PSIG. In another embodiment, the pressure is from

about 100 PSIG to about 150 PSIG. In one embodiment, the polymeric catalyst is a polymeric acid catalyst.

[00303] Hydrolysis of a biomass composition with one or more polymeric catalysts can be performed for about 1-360 min, 1-300 min, 1-240 min, 1-180 min, 1-120 min, 1-90 min, 1-60 min, 1-30 min, 1-15 min, 1-10 min, 1-5 min, 5-60 min, 5-30 min, 5-15 min, 5-10 min, 360 min, 300 min, 240 min, 180 min, 120 min, 110 min, 100 min, 90 min, 80 min, 70 min, 60 min, 50 min, 45 min, 40 min, 35 min, 30 min, 25 min, 20 min, 19 min, 18 min, 17 min, 16 min, 15 min, 14 min, 13 min, 12 min, 11 min, 10 min, 9 min, 8 min, 7 min, 6 min, 5 min, 4 min, 3 min, 2 min, 1 min, or 0.5 min. In one embodiment, hydrolysis of solids of a biomass composition with one or more polymeric catalysts is from about 1 minute to about 60 minutes. In another embodiment, hydrolysis of solids of a biomass composition with one or more polymeric catalysts is from about 5 minutes to about 30 minutes. In another embodiment, hydrolysis of solids of a biomass composition with one or more polymeric catalysts is from about 7.5 minutes to about 12.5 minutes. In another embodiment, hydrolysis of solids of a biomass composition with one or more polymeric catalysts is from about 0.5 minutes to about 5 minutes. In another embodiment, hydrolysis of solids of a biomass composition with one or more polymeric catalysts is from about 0.5 minutes to about 20 minutes. In one embodiment, the polymeric catalyst is a polymeric acid catalyst.

[00304] The ability of the polymeric acid catalyst to hydrolyze the cellulose and hemicellulose components of biomass to soluble sugars can be measured by determining the effective first-order rate constant,

k_1 (species i) = - ln(1 - X_i)/ Δt ,

where Δt is the duration of the reaction and X_i is the extent of reaction for species i (e.g., glucan, xylan, arabinan). In some embodiments, the polymeric acid catalysts described herein are capable of degrading biomass into one or more sugars at a first-order rate constant of at least 0.001 per hour, at least 0.01 per hour, at least 0.1 per hour, at least 0.2 per hour, at least 0.3 per hour, at least 0.4 per hour, at least 0.5 per hour, or at least 0.6 per hour.

[00305] In one embodiment, the amount of the polymeric acid catalysts used may depend on several factors including, for example, the type of biomass, the concentration of the biomass, the type and number of pretreatment(s) applied to the biomass, and the reaction conditions (e.g., temperature, time, and pH). In one embodiment, the weight ratio of the polymeric acid catalyst to the biomass is about 0.1 g/g to about 50 g/g, about 0.1 g/g to about 25 g/g, about 0.1 g/g to about 10 g/g, about 0.1 g/g to about 5 g/g, about 0.1 g/g to about 2 g/g, about 0.1 g/g to about 1 g/g, or about 0.1 to about 1.0 g/g. In one embodiment, the amount of the polymeric acid catalysts used

in a mixture with the biomass before, during or after pre-treatment by any of the methods described herein is at a ratio of 1:2, 1:1, or 2:1 (wt/wt) of polymeric acid catalyst:biomass solids. In one embodiment, an aqueous medium is added to the polymeric acid catalyst:biomass solids at a 5:1, 4:1, 3:1, 2:1, 1:1, 1:2, 1:3, 1:4, 1:5, or less than 1:5 ratio. In one embodiment, the aqueous medium is water. In one embodiment, the aqueous medium is a non-neutral aqueous medium.

[00306] In some embodiments, the method for degrading biomass material using the polymeric acid catalysts described herein further includes recovering the sugars that are produced from the hydrolysis of the biomass material. In another embodiment, the method for degrading biomass material using the polymeric catalyst described herein further includes recovering the degraded or converted biomass material.

[00307] In one embodiment, the polymeric acid catalysts (along with residual insoluble biomass material) can be separated from soluble saccharide compositions using methods known in the art such as, for example, centrifugation, filtration, and gravity settling. Optionally, the polymeric acid catalysts and residual biomass solids may be separated by a cyclone. Suitable types of cyclones used for the separation may include, for example, hydro cyclones, tangential cyclones, spark and rotary separators, and axial and multi-cyclone units.

[00308] In another embodiment, separation of the polymeric acid catalysts (along with residual insoluble biomass material) can be performed by batch or continuous differential sedimentation. Over a period of time, residual treated biomass, the solid catalyst, and the saccharide-containing aqueous material can be separated by differential sedimentation into a plurality of phases (or layers). Generally, the catalyst layer may sediment to the bottom, and depending on the density of the residual biomass, the biomass phase may be on top of, or below, the aqueous phase. When the phase separation is performed in a batch mode, the phases are sequentially removed, either from the top of the vessel or an outlet at the bottom of the vessel. When the phase separation is performed in a continuous mode, the separation vessel contains one or more than one outlet means (e.g., two, three, four, or more than four), generally located at different vertical planes on a lateral wall of the separation vessel, such that one, two, or three phases are removed from the vessel. The removed phases are transferred to subsequent vessels or other storage means. By these processes, one of skill in the art would be able to capture (1) the catalyst layer and the aqueous layer or biomass layer separately, or (2) the catalyst, aqueous, and biomass layers separately, allowing efficient catalyst recycling, retreatment of biomass, and separation of sugars. Moreover, controlling rate of phase removal and other parameters allows for increased efficiency of catalyst recovery. Subsequent to removal of each of the separated phases, the

catalyst and/or biomass may be separately washed by the aqueous layer to remove adhered sugar molecules.

[00309] One aspect of this invention is the reduction in size and uniformity of biomass particles, whether a single feedstock or mixed feedstocks are used. Without being limited by theory, it is believed that an unexpected increase in the conversion of the feedstock to fermentable saccharides is achieved if the size of any feedstock subjected to polymeric acid catalysis is small and uniform, as long as sufficient catalyst is present for hydrolysis of the feedstock. If the cellulosic feedstock that is fed to a pretreatment process (i.e. hot water, acid, steam explosion, or polymeric acid catalysis) is not uniform and cannot be uniformly treated, then a smaller percentage of the available sites of the feedstock are activated and/or hydrolyzed than would be expected. Further, it is difficult to mix larger-sized particles and process a batch of heterogeneous material so that heat and moisture is evenly distributed; thus resulting in an uneven autohydrolysis reaction. Moreover, it is difficult to mix larger-sized particles and process a batch of heterogeneous material so that polymeric catalyst, such as polymeric acid catalyst, is evenly distributed; thus resulting in an uneven hydrolysis reaction. Even transfer of heat, chemicals, and moisture results in reduced processing time, less release of inhibitors, and improved release of hemicellulose and cellulose, especially microcrystalline cellulose. If the temperature in parts of the processing feedstock are too high, then some percentage of the hemicellulose saccharides are degraded to inhibitory compounds. Further, even heat prevents charring of the material that can lead to significant losses in saccharides. This also prevents undercooking which can lead to unhydrolyzed cellulose during polymeric acid catalyst based hydrolysis. In one embodiment, polymeric acid catalyst based hydrolysis is conducted on a homogenous mixture of particles produced by any of the pretreatment methods described herein such that greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles are kept at substantially the same temperature and/or pressure. In one embodiment, polymeric acid catalyst based hydrolysis is conducted on a homogenous mixture of particles produced by any of the pretreatment methods described herein such that substantially all of the particles are kept at substantially the same temperature and/or pressure. In one embodiment, a homogenous mixture of particles produced by any of the pretreatment methods described herein are uniformly exposed to treatment with a polymeric catalyst. In one embodiment, the polymeric catalyst is a polymeric acid catalyst. In one embodiment, greater than 50% (*e.g.*, about 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100%) of the particles in a homogenous mixture of particles produced by any of the pretreatment methods described herein are exposed to treatment

with a polymeric catalyst. In one embodiment, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100% of the particles in a homogenous mixture of particles produced by any of the pretreatment methods described herein are exposed to treatment with a polymeric catalyst. In one embodiment, 55%, 56%, 57%, 58%, 60%, 61%, 62%, 63%, 64%, 65%, 66%, 67%, 68%, 69%, 70%, 71%, 72%, 73%, 74%, 75%, 76%, 77%, 78%, 79%, 80%, 81%, 82%, 83%, 84%, 85%, 86%, 87%, 88%, 89%, 90%, 91%, 92%, 93%, 94%, 95%, 96%, 97%, 98%, 99%, 99.5%, or 100% of the particles in a homogenous mixture of particles produced by any of the pretreatment methods described herein are exposed to treatment with a polymeric catalyst. In one embodiment, 50-60%, 60-70%, 70-80%, 80-90%, or 90-100% of the particles in a homogenous mixture of particles produced by any of the pretreatment methods described herein are exposed to treatment with a polymeric catalyst. In one embodiment, substantially all of the particles in a homogenous mixture of particles produced by any of the pretreatment methods described herein are exposed to treatment with a polymeric catalyst.

[00310] Accordingly, disclosed herein are methods of producing a saccharide stream from a biomass composition comprising cellulose, hemicellulose, or lignocellulose, the methods comprising: (a) hydrating the biomass composition in an aqueous medium; (b) mechanical size reduction of the biomass composition to produce a mixture of solid particles, wherein at least 50% of the solid particles are less than 1.5 mm in a dimension; (c) heating the biomass composition; and (d) hydrolyzing the biomass composition with one or more polymeric catalysts to produce a saccharide stream.

[00311] The one or more polymeric catalysts can be, individually, a polymer comprising acidic monomers and ionic monomers connected to form a polymeric backbone. The polymer can be cross-linked.

[00312] Each acidic monomer can comprise, individually, at least one Bronsted-Lowry acid. In some embodiments, the Bronsted-Lowry acid at each occurrence is independently selected from the group consisting of sulfonic acid, phosphonic acid, acetic acid, isophthalic acid, boronic acid, and perfluorinated acid. In some embodiments, one or more of the Bronsted-Lowry acids are directly connected to the polymeric backbone. In some embodiments, one or more of the acidic monomers further comprise a linker connecting the Bronsted-Lowry acid to the polymeric backbone. In some embodiments, the linker at each occurrence is independently selected from the group consisting of unsubstituted or substituted alkylene, unsubstituted or substituted cycloalkylene, unsubstituted or substituted alkenylene, unsubstituted or substituted arylene, unsubstituted or substituted heteroarylene, unsubstituted or substituted alkylene ether, unsubstituted or substituted alkylene ester, and unsubstituted or substituted alkylene carbamate.

[00313] Each ionic monomer can comprise, individually, at least one nitrogen containing cationic group or phosphorous-containing cationic group.

[00314] The nitrogen-containing cationic group at each occurrence can be independently selected from the group consisting of pyrrolium, imidazolium, pyrazolium, oxazolium, thiazolium, pyridinium, pyrimidinium, pyrazinium, pyradizimium, thiazinium, morpholinium, piperidinium, piperizinium, and pyrollizinium.

[00315] The phosphorous-containing cationic group at each occurrence can be independently selected from the group consisting of triphenyl phosphonium, trimethyl phosphonium, triethyl phosphonium, tripropyl phosphonium, tributyl phosphonium, trichloro phosphonium, and trifluoro phosphonium.

[00316] One or more of the ionic monomers can be directly connected to form the polymeric backbone.

[00317] One or more of the ionic monomers can each further comprise a linker connecting the nitrogen-containing cationic group or the phosphorous-containing cationic group to the polymeric backbone. In some embodiments, the linker at each occurrence is independently selected from the group consisting of unsubstituted or substituted alkylene, unsubstituted or substituted cycloalkylene, unsubstituted or substituted alkenylene, unsubstituted or substituted arylene, unsubstituted or substituted heteroarylene, unsubstituted or substituted alkylene ether, unsubstituted or substituted alkylene ester, and unsubstituted or substituted alkylene carbamate.

[00318] The polymeric backbone can be selected from the group consisting of polyethylene, polypropylene, polyvinyl alcohol, polystyrene, polyurethane, polyvinyl chloride, polyphenol-aldehyde, polytetrafluoroethylene, polybutylene terephthalate, polycaprolactam, poly(acrylonitrile butadiene styrene), polyalkyleneammonium, polyalkylenediammonium, polyalkylenepyrrolium, polyalkyleneimidazolium, polyalkylenepyrazolium, polyalkyleneoxazolium, polyalkylenethiazolium, polyalkylenepyridinium, polyalkylenepyrimidinium, polyalkylenepyrazinium, polyalkylenepyradizimium, polyalkylenethiazinium, polyalkylenemorpholinium, polyalkylenepiperidinium, polyalkylenepiperizinium, polyalkylenepyrollizinium, polyalkylenetriphenylphosphonium, polyalkylenetrimethylphosphonium, polyalkylenetriethylphosphonium, polyalkylenetripropylphosphonium, polyalkylenetributylphosphonium, polyalkylenetrichlorophosphonium, polyalkylenetrifluorophosphonium, and polyalkylenediazolium.

[00319] The polymer can further comprise hydrophobic monomers connected to form the polymeric backbone. In some embodiments, each hydrophobic monomer comprises a

hydrophobic group, wherein the hydrophobic group at each occurrence is independently selected from an unsubstituted or substituted alkyl, an unsubstituted or substituted cycloalkyl, an unsubstituted or substituted aryl, or an unsubstituted or substituted heteroaryl.

[00320] The one or more polymeric catalysts can further comprise acidic-ionic monomers connected to form the polymeric backbone, wherein each acidic-ionic monomer comprises a Bronsted-Lowry acid and a cationic group.

[00321] The polymeric catalyst can have a total amount of Bronsted-Lowry acid of between 0.1 and 20 mmol per gram of polymer.

[00322] The polymeric catalyst can be coated on a solid core. In some embodiments, the solid core comprises an inert material or a magnetic material. In some embodiments, the solid core is iron. In some embodiments, the solid core is non-porous.

[00323] The one or more polymer catalysts and the biomass composition can be admixed in a ratio of about 3 : 1 to 1 : 3 polymer catalyst : biomass composition by dry weight. In some embodiments, the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 2 : 1 to 1 : 2 polymer catalyst : biomass composition by dry weight. In some embodiments, the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 1.5 : 1 to 1 : 1.5 polymer catalyst : biomass composition by dry weight. In some embodiments, the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 1:1 polymer catalyst : biomass composition by dry weight.

[00324] Hydrolyzing the biomass composition with the one or more polymeric catalysts can be performed at a temperature of about 75°C-200°C. In some embodiments, hydrolyzing is performed at a temperature of about 100°C-175°C. In some embodiments, hydrolyzing is performed at a temperature of about 120°C-150°C.

[00325] Hydrolyzing the biomass composition with the one or more polymeric catalysts can be performed at a pressure of about 100 PSIG to about 150 PSIG.

[00326] Hydrolyzing the biomass composition with the one or more polymeric catalysts can be performed for a time of about 0.5 minutes to about 24 hours. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 12 hours. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 4 hours. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 1 hour. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 30 minutes. In some embodiments, hydrolyzing is performed for a time of about 0.5 minutes to about 5 minutes.

[00327] The methods can further comprise: (e) recovering the one or more polymer catalysts from the saccharide stream and residual biomass. In some embodiments, recovering the one or

more polymeric catalysts comprises the use of a cyclone press, worm press, filter press, mechanical press, a centrifuge press, or a gravity press. In some embodiments, recovering the one or more polymeric catalysts comprises differential sedimentation, wherein the residual biomass and the polymeric catalyst sediment into one or more separate phases from the saccharide stream.

[00328] At least 50% of the mixture of solid particles in the pretreated biomass composition can be from about 0.1 mm to about 1 mm in a dimension. All of the solid particles in the pretreated biomass can be less than 7.5 mm in a dimension. In some embodiments, all of the solid particles in the pretreated biomass are less than 1 mm in a dimension. The dimension can be diameter, length, or width.

[00329] Heating the biomass composition can solubilize at least 50% of the hemicellulose in the biomass composition. In some embodiments, heating the biomass composition solubilizes at least 75% of the hemicellulose in the biomass composition. In some embodiments, heating the biomass composition solubilizes at least 95% of the hemicellulose in the biomass composition.

[00330] The hemicellulose can be solubilized as polysaccharides.

[00331] The hemicellulose can be solubilized as monosaccharides, disaccharides, or a combination thereof.

[00332] Heating the biomass composition can produce a yield of glucose that is less than about 20% of a theoretical maximum. In some embodiments, the yield of glucose is less than 15%, 10%, 5%, 2.5%, or 1% of the theoretical maximum.

[00333] Hydrating the biomass composition can produce a hydrated biomass composition comprising about 1% to about 20% solids by dry biomass weight.

[00334] The aqueous medium can be at a temperature of about 30° C to about 70° C. For example, the aqueous medium can be at the temperature of about: 30-70 °C, 30-65 °C, 30-60 °C, 30-55 °C, 30-50 °C, 30-45 °C, 30-40 °C, 40-65 °C, 40-60 °C, 40-55 °C, 40-50 °C, 40-45 °C, 45-60 °C, 45-55 °C, 45-50 °C, 50-60 °C, 50-55 °C.

[00335] The aqueous medium can comprise an acid. The acid can be at about 0.1% to about 50% w/w or v/w by dry biomass weight in the aqueous medium. For example, the aqueous medium can comprise about 25-50%, 10-50%, 10-25%, 5-50%, 5-25%, 5-10%, 4-50%, 4-25%, 4-10%, 4-5%, 3-50%, 3-25%, 3-10%, 3-5%, 3-4%, 2-50%, 2-25%, 2-10%, 2-5%, 2-4%, 2-3%, 1-50%, 1-25%, 1-10%, 1-5%, 1-4%, 1-3%, 1-2%, 0.5-50%, 0.5-25%, 0.5-10%, 0.5-5%, 0.5-4%, 0.5-3%, 0.5-2%, 0.5-1%, 0.5-%, 0.1-50%, 0.1-25%, 0.1-10%, 0.1-5%, 0.1-4%, 0.1-3%, 0.1-2%, 0.1-1%, 0.1-0.5%, 50%, 45%, 40%, 35%, 30%, 25%, 24%, 23%, 22%, 21%, 20%, 19%, 18%, 17%, 16%, 15%, 14%, 13%, 12%, 11%, 10%, 9.5%, 9%, 8.5%, 8%, 7.5%, 7%, 6.5%, 6%, 5.5%, 5%, 4.9%,

4.8%, 4.7%, 4.6%, 4.5%, 4.4%, 4.3%, 4.2%, 4.1%, 4%, 3.9%, 3.8%, 3.7%, 3.6%, 3.5%, 3.4%, 3.3%, 3.2%, 3.1%, 3%, 2.9%, 2.8%, 2.7%, 2.6%, 2.5%, 2.4%, 2.3%, 2.2%, 2.1%, 2%, 1.9%, 1.8%, 1.7%, 1.6%, 1.5%, 1.4%, 1.3%, 1.2%, 1.1%, 1%, 0.9%, 0.8%, 0.7%, 0.6%, 0.5%, 0.4%, 0.3%, 0.2%, or 0.1% of the acid. In some embodiments, the acid is at from about 0.1% to about 5% v/w by dry biomass weight in the aqueous medium. In some embodiments, the acid comprises sulfuric acid, peroxyacetic acid, lactic acid, formic acid, acetic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, or a combination thereof.

[00336] Mechanical size reduction can comprise cutting, steam explosion, acid-catalyzed steam explosion, or a combination thereof.

[00337] Heating the biomass composition can be at a temperature of from about 100° C to about 250° C. For example, the temperature can be about 100-250 °C, 100-200 °C, 100-180 °C, 100-160 °C, 100-140 °C, 100-120 °C, 120-200 °C, 120-180 °C, 120-160 °C, 120-140 °C, 140-180 °C, 140-160 °C, 160-180 °C, 100 °C, 110 °C, 120 °C, 130 °C, 140 °C, 150 °C, 155 °C, 160 °C, 165 °C, 170 °C, 175 °C, 180 °C, 185 °C, 190 °C, 200 °C, 210 °C, 220 °C, 230 °C, 240 °C, or 250 °C.

[00338] Heating the biomass composition can be performed at a pressure of about 25 PSIG to about 250 PSIG. For example, the pressure can be about 25-250 PSIG, 25-225 PSIG, 25-200 PSIG, 25-175 PSIG, 25-150 PSIG, 25-125 PSIG, 25-100 PSIG, 25-75 PSIG, 25-50 PSIG, 50-225 PSIG, 50-200 PSIG, 50-175 PSIG, 50-150 PSIG, 50-125 PSIG, 50-100 PSIG, 50-75 PSIG, 75-200 PSIG, 75-175 PSIG, 75-150 PSIG, 75-125 PSIG, 75-100 PSIG, 100-175 PSIG, 100-150 PSIG, 100-125 PSIG, 125-150 PSIG, 25 PSIG, 30 PSIG, 35 PSIG, 40 PSIG, 45 PSIG, 50 PSIG, 55 PSIG, 60 PSIG, 65 PSIG, 70 PSIG, 75 PSIG, 80 PSIG, 85 PSIG, 90 PSIG, 95 PSIG, 100 PSIG, 105 PSIG, 110 PSIG, 115 PSIG, 120 PSIG, 125 PSIG, 130 PSIG, 135 PSIG, 140 PSIG, 145 PSIG, 150 PSIG, 155 PSIG, 160 PSIG, 165 PSIG, 170 PSIG, 175 PSIG, 180 PSIG, 185 PSIG, 190 PSIG, 195 PSIG, 200 PSIG, 205 PSIG, 210 PSIG, 215 PSIG, 220 PSIG, 225 PSIG, 230 PSIG, 235 PSIG, 240 PSIG, 245 PSIG, 250 PSIG. In some embodiments, heating the biomass composition can be performed at a pressure of from about 100 PSIG to about 150 PSIG.

[00339] Heating the biomass composition can be performed for about 1 minute to about 120 minutes. For example, the biomass composition can be heated for about: 1-120 min, 1-90 min, 1-60 min, 1-30 min, 1-15 min, 1-10 min, 1-5 min, 5-60 min, 5-30 min, 5-15 min, 5-10 min, 120 min, 110 min, 100 min, 90 min, 80 min, 70 min, 60 min, 50 min, 45 min, 40 min, 35 min, 30 min, 25 min, 20 min, 19 min, 18 min, 17 min, 16 min, 15 min, 14 min, 13 min, 12 min, 11 min,

10 min, 9 min, 8 min, 7 min, 6 min, 5 min, 4 min, 3 min, 2 min, 1 min.. In some embodiments, heating the biomass composition can be performed for about 1 minute to about 30 minutes.

[00340] Mechanical size reduction can follow hydrating the biomass composition. Heating can follow mechanical size reduction of the biomass composition.

[00341] Hydrolyzing the biomass composition with one or more polymeric catalysts can follow heating.

[00342] Hydrolyzing the biomass composition with one or more polymeric catalysts can occur during heating.

[00343] The methods can further comprise dewatering the biomass composition to from about 5% to about 40% solids by dry biomass weight prior to heating. For example, the water content can be adjusted to about 4-40%, 5-30%, 5-25%, 5-20%, 5-15%, 5-12%, 5-10%, 5-8%, 8-30%, 8-25%, 8-20%, 8-15%, 8-12%, 8-10%, 10-40%, 10-30%, 10-25%, 10-20%, 10-15%, 10-12%, 12-30%, 12-25%, 12-20%, 12-15%, 15-30%, 15-25%, 15-20%, 20-30%, 20-25%, 25-30%, 5%, 6%, 7%, 8%, 9%, 10%, 11%, 12%, 13%, 14%, 15%, 16%, 17%, 18%, 19%, 20%, 21%, 22%, 23%, 24%, 25%, 26%, 27%, 28%, 29%, 30%, 31%, 32%, 33%, 34%, 35%, 36%, 37%, 38%, 39%, or 40%. In some embodiments, the methods further comprise dewatering the biomass composition to from about 10% to about 40% solids by dry biomass weight prior to heating.

[00344] Heating can comprise steam injection, steam explosion, acid-catalyzed steam explosion, or a combination thereof.

[00345] The methods can be performed in a continuous mode of operation.

[00346] The methods can further comprise hydrolyzing the biomass composition with one or more enzymes. In some embodiments, the one or more enzymes comprise one or more hemicellulases, one or more cellulases, or a combination thereof.

[00347] The methods can further comprise adjusting the water content of the biomass composition to from about 5% to about 30% solids by dry biomass weight prior to hydrolyzing.

[00348] The saccharide stream can comprise C5 saccharides, C6 saccharides, or a combination thereof. In some embodiments, the saccharide stream comprises glucose, xylose, mannose, galactose, rhamnose, arabinose, or a combination thereof.

The biomass composition can comprise alfalfa, algae, bagasse, bamboo, corn stover, corn cobs, corn kernels, corn mash, corn steep liquor, corn steep solids, distiller's grains, distiller's dried solubles, distiller's dried grains, condensed distiller's solubles, distiller's wet grains, distiller's dried grains with solubles, eucalyptus, food waste, fruit peels, garden residue, grass, grain hulls, modified crop plants, municipal waste, oat hulls, paper, paper pulp, prairie bluestem, poplar, rice hulls, seed hulls, silage, sorghum, straw, sugarcane, switchgrass, wheat, wheat straw, wheat bran,

de-starched wheat bran, willows, wood, plant cells, plant tissue cultures, tissue cultures, or a combination thereof.

[00349] In some embodiments, mechanical size reduction does not comprise milling.

[00350] The saccharide stream can comprise one or more inhibitors In some embodiments, the method further comprises removing at least a portion of the one or more inhibitors using any of the humidification:dehumidification processes disclosed herein.

[00351] Also provided are saccharide streams produced by any of the methods disclosed herein.

[00352] **Separation and Purification**

[00353] Separation and purification are an integral part and major cost factor in the chemical industry, especially for their role in removing toxic inhibitors. Distillation is very commonly used as a solvent separation and purification process for volatiles like ethanol, butanol, and formic acid. However, it can be neither cost effective nor process efficient when dealing with close boiling and azeotropic solvent mixtures without modifying the relative volatility of the solvent components with an extraneous solvent or a non-volatile solute electrolyte or non-electrolyte.

[00354] Separation and recovery in the distillation column depends on the high, column pressure, vapor pressure differential, relative humidity, surface area. Thus it is possible to separate acetic acid and other volatiles only if the pressure has a considerable effect on azeotropic composition. Moreover an extra separation step may be needed to recover the solvent or to adjust the pressure which can add extra cost to the separation.

[00355] Instead of adding a solvent, a non volatile salt can be used as a separating agent to alter the Vapor-Liquid Equilibirum (VLE) of a given mixture. The ions of the added salt can form association complexes more with the molecules of one of the components to be separated than with the other components. This association complex phenomenon may result in altering the vapor and partial pressures, solubility, thermal conductivity, density, surface tension etc. These changes may result in altering the VLE of the system, thus altering the ease of separation and shifting or eliminating the azeotropic point of a given mixture.

[00356] Acetic acid and water do not form an azeotrope. Despite this, it can be very difficult to separate pure acetic acid (boiling point: 118.1 °C) from a dilute solution of acetic acid and water by distillation alone. As progressive distillations produce solutions with less and less water, each further distillation becomes less effective at removing the remaining water. Distilling the solution to dry acetic acid may therefore economically impractical. Towers having a large number of stages, which would have to be operated with a high reflux ratio, would be needed. This would

necessarily involve high costs for energy and high operating costs. Conventionally, for solutions of higher concentrations of acetic acid (i.e. 50-70 %) this problem is solved by adding ethyl acetate as an entrainer, which forms an azeotrope with water that boils at 70.4 °C. By adding ethyl acetate as an entrainer one can separate and refine acetic acid from water. Similarly, a salt such as LiBr can also be used to break an azeotropic mixture like ethanol-water. In this case, water is the less volatile component and hence a small amount of salt may be sufficient to break an azeotrope.

[00357] Evaporation can be used as a means to remove inhibitors from cellulosic sugar solutions. Evaporation is a process that only occurs at the surface of a liquid and is driven by available heat/temperature, air/gas movement, and overall atmospheric pressure. Elevated temperature increases the vapor pressure of the liquid and the rate of vaporization.

[00358] Any evaporation method known in the art can be used to reduce the levels of fermentation inhibitors in saccharide streams or compositions produced by any of the pretreatment and/or hydrolysis methods described herein. In one embodiment, a closed loop humidification-dehumidification (HDH) process can be used to reduce the levels of one or more fermentation inhibitors in saccharide streams or compositions produced by any of the pretreatment and/or hydrolysis methods described herein. In one embodiment, the closed loop humidification-dehumidification (HDH) process that can be used is the system found in US Patent Number 8252092 and U.S. Patent Application Nos. 2013/0074694A1, and 2013/0075940A1, each of which is hereby incorporated by reference in their entirety.

[00359] In one embodiment, a saccharide or sugar stream or composition produced by any of the methods described herein is subjected to a humidification-dehumidification process comprising a closed loop system with a carrier gas that is humidified with vaporized inhibitors and water in a low pressure chamber and dehumidified in a separate chamber at higher pressure. Overall, the humidification-dehumidification process can entail evaporating a liquid thereby humidifying a carrier gas followed by condensing a liquid from the carrier gas, thereby dehumidifying the carrier gas. The liquid condensed during dehumidification serves to remove inhibitors from the system. The inhibitors can comprise one or more organic acids. In one embodiment, the organic acid is formic acid. In one embodiment, the organic acid is acetic acid. In one embodiment, the carrier gas is air. In one embodiment, the carrier gas is nitrogen. In one embodiment, a salt is added to the saccharide stream or composition prior to being subjected to a humidification-dehumidification process. In one embodiment, the salt is NaCl, LiBr, or KCl. In a preferred embodiment, the salt is LiBr. In one embodiment, the addition of salts to the saccharide stream or composition increases the boiling point of said stream or composition, thereby separating one

or more fermentation inhibitors from said solution. In one embodiment, the salt lowers the vapor pressure of the aqueous medium (i.e. water), wherein the aqueous medium becomes more difficult to evaporate. In one embodiment, the one or more fermentation inhibitors are volatile. In one embodiment, the volatile fermentation inhibitors can comprise one or more organic acids. In one embodiment, the organic acid is acetic acid. In one embodiment, the organic acid is formic acid. In one embodiment, the salt/saccharide stream or composition remains in a humidification zone or chamber following the humidification-dehumidification process. In one embodiment, the salt/saccharide stream or composition remains as residue following the humidification-dehumidification process. In one embodiment, the salt/saccharide stream or composition remains as a liquid following the humidification-dehumidification process. In embodiment, the salt can be separated from the saccharide stream or composition by any method known in the art.

[00360] In one embodiment, salt is added to a saccharide stream or composition to a salinity of about: 0.1- 0.5%, 0.5- 1.0, 1.0-1.5%, 1.5-2.0%, 2.0-2.5%, 2.5- 3.0%, 3.0-3.5% , 3.5-4.0%, 4.0-4.5%, 4.5-5%, 5.0- 5.5%, 5.5- 6%, 6.0- 6.5%, 6.5- 7%, 7.0- 7.5%, 7.5- 8%, 8.0-8.5%, 8.5-9%, 9.0-9.5%, 9.5- 10%, 10- 12%, 12-14%, or 14-16% w/v. In one embodiment, salt is added to a saccharide stream or composition to a salinity of greater than about: 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%, 1%, 1.1%, 1.2%, 1.3%, 1.4%, 1.5%, 1.6%, 1.7%, 1.8%, 1.9%, 2.0%, 2.1%, 2.2%, 2.3%, 2.4%, 2.5%, 2.6%, 2.7%, 2.8%, 2.9%, 3.0%, 3.1%, 3.2%, 3.3%, 3.4%, 3.5% , 3.6%, 3.7%, 3.8%, 3.9%, 4.0%, 4.1%, 4.2%, 4.3%, 4.4%, 4.5%, 4.6%, 4.7%, 4.8%, 4.9%, 5%, 5.1%, 5.2%, 5.3%, 5.4%, 5.5%, 5.6%, 5.7%, 5.8%, 5.9%, 6%, 6.1%, 6.2%, 6.3%, 6.4%, 6.5%, 6.6%, 6.7%, 6.8%, 6.9%, 7%, 7.1%, 7.2%, 7.3%, 7.4%, 7.5%, 7.6%, 7.7%, 7.8%, 7.9%, 8%, 8.1%, 8.2%, 8.3%, 8.4%, 8.5%, 8.6%, 8.7%, 8.8%, 8.9%, 9%, 9.1%, 9.2%, 9.3%, 9.4%, 9.5%, 9.6%, 9.7%, 9.8%, 9.9%, 10%, 11%, 12%, 13%, 14%, or 15% w/v. In one embodiment, salt is added to a saccharide stream or composition to a salinity of less than about: 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%, 1%, 1.1%, 1.2%, 1.3%, 1.4%, 1.5%, 1.6%, 1.7%, 1.8%, 1.9%, 2.0%, 2.1%, 2.2%, 2.3%, 2.4%, 2.5%, 2.6%, 2.7%, 2.8%, 2.9%, 3.0%, 3.1%, 3.2%, 3.3%, 3.4%, 3.5% , 3.6%, 3.7%, 3.8%, 3.9%, 4.0%, 4.1%, 4.2%, 4.3%, 4.4%, 4.5%, 4.6%, 4.7%, 4.8%, 4.9%, 5%, 5.1%, 5.2%, 5.3%, 5.4%, 5.5%, 5.6%, 5.7%, 5.8%, 5.9%, 6%, 6.1%, 6.2%, 6.3%, 6.4%, 6.5%, 6.6%, 6.7%, 6.8%, 6.9%, 7%, 7.1%, 7.2%, 7.3%, 7.4%, 7.5%, 7.6%, 7.7%, 7.8%, 7.9%, 8%, 8.1%, 8.2%, 8.3%, 8.4%, 8.5%, 8.6%, 8.7%, 8.8%, 8.9%, 9%, 9.1%, 9.2%, 9.3%, 9.4%, 9.5%, 9.6%, 9.7%, 9.8%, 9.9%, 10%, 11%, 12%, 13%, 14%, or 15% w/v. In one embodiment, salt is added to a saccharide stream or composition to a salinity of about: 0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%, 0.7%, 0.8%, 0.9%, 1%, 1.1%, 1.2%, 1.3%, 1.4%, 1.5%, 1.6%,

1.7%, 1.8%, 1.9%, 2.0%, 2.1%, 2.2%, 2.3%, 2.4%, 2.5%, 2.6%, 2.7%, 2.8%, 2.9%, 3.0%, 3.1%, 3.2%, 3.3%, 3.4%, 3.5% , 3.6%, 3.7%, 3.8%, 3.9%, 4.0%, 4.1%, 4.2%, 4.3%, 4.4%, 4.5%, 4.6%, 4.7%, 4.8%, 4.9%, 5%, 5.1%, 5.2%, 5.3%, 5.4%, 5.5%, 5.6%, 5.7%, 5.8%, 5.9%, 6%, 6.1%, 6.2%, 6.3%, 6.4%, 6.5%, 6.6%, 6.7%, 6.8%, 6.9%, 7%, 7.1%, 7.2%, 7.3%, 7.4%, 7.5%, 7.6%, 7.7%, 7.8%, 7.9%, 8%, 8.1%, 8.2%, 8.3%, 8.4%, 8.5%, 8.6%, 8.7%, 8.8%, 8.9%, 9%, 9.1%, 9.2%, 9.3%, 9.4%, 9.5%, 9.6%, 9.7%, 9.8%, 9.9%, 10%, 11%, 12%, 13%, 14%, or 15% w/v. In one embodiment, salt is added to a saccharide stream or composition to a salinity of about 3.5% w/v. In one embodiment, salt is added to a saccharide stream or composition to a salinity of about 3.1% w/v. In one embodiment, salt is added to a saccharide stream or composition to achieve a salinity of about 3.8% w/v. In one embodiment, the salt is NaCl, KCl, or LiBr. In one embodiment, the salt is LiBr.

[00361] In one embodiment, a saccharide stream or composition produced by any of the methods described herein is subjected to a two stage refinement process. In one embodiment, the saccharide stream or composition produced by any of the methods described herein comprises one or more fermentation inhibitors. In one embodiment, the first stage comprises a humidification-dehumidification process comprising mixing a salt with the saccharide stream or composition to produce a salt/saccharide stream or composition. The salt can be NaCl, KCl or LiBr. In one embodiment, the salt is LiBr. In one embodiment, a carrier gas is brought into contact with the salt/saccharide solution. In one embodiment, the temperature and pressure is adjusted such that the one or more fermentation inhibitors are evaporated into the carrier gas by means of a humidification process. In one embodiment, the carrier gas is air or nitrogen. In one embodiment, the one or more fermentation inhibitors comprise one or more organics acids. The one or more organic acids can be formic acid. The one or more organic acids can be acetic acid. In one embodiment, the moisture laden carrier gas is subsequently compressed by an increase in pressure. Following compression, the moisture laden carrier gas is dehumidified wherein the one or more fermentation inhibitors condense out from the carrier gas. In one embodiment, the salt/saccharide stream or composition is subjected to the second stage of the refinement process. In this stage, the salt/saccharide stream or composition remaining after evaporation of the one or more fermentation inhibitors can be subjected to a separation process wherein the salt is separated from the saccharide stream or composition. Further to this embodiment, the salt/saccharide stream or composition remaining after evaporation of the fermentation inhibitors is brought into contact with a carrier gas. In one embodiment, the carrier gas is recycled from a previous humidification-dehumidification process. In one embodiment, the temperature and pressure is adjusted such that the aqueous medium of the saccharide stream or composition is

evaporated into the carrier gas by means of a humidification process, while the salt/saccharides remains as a residual. In one embodiment, the moisture laden carrier gas in the second stage humidification-dehumidification process is subsequently compressed by an increase in pressure. Following compression, the moisture laden carrier gas is dehumidified wherein the aqueous medium condenses out from the carrier gas. In one embodiment, the aqueous medium is water. In one embodiment, the salt/saccharides present in the residue remaining after evaporation of the aqueous medium are separated from each other by any method known in the art. In one embodiment, the salt/saccharides residue comprises salt and/or sugar crystals. In one embodiment, the separation of the salt from the saccharides comprises dissolving the salt/saccharide residue in a medium wherein the salt and saccharides experience differential solubility. In one embodiment, the salt/saccharide residue is dissolved in an alcohol, wherein the saccharides solubilize while the salt remains as an insoluble solid. In one embodiment, the alcohol is ethanol. In one embodiment, the saccharide/alcohol solution is separated from the insoluble salt. In one embodiment, the salt can be recycled.

[00362] In one embodiment, the carrier gas in a humidification-dehumidification process experiences a pressure ratio, wherein the carrier gas undergoes a humidification process at a lower pressure and a dehumidification process at a higher pressure. The pressure ratio is the ratio of the absolute pressure in the dehumidification process to the absolute pressure in the humidification process. In one embodiment, the pressure ratio is at least 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.8, 1.9, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, or 5.0. In one embodiment, the pressure ratio is above 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.8, 1.9, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, or 5.0. In one embodiment, the pressure ratio is about 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.8, 1.9, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, or 5.0. In one embodiment, the pressure ratio is from about 1.0 to 1.2, about 1.2 to 1.4, about 1.4 to 1.6, about 1.6 to 1.8, about 1.8 to 2.0, about 2.2 to 2.4, about 2.4 to 2.6, about 2.6 to 2.8, about 2.8 to 3.0, about 3.2 to 3.4, about 3.4 to 3.6, about 3.6 to 3.8, about 3.8 to 4, about 4 to 4.2, about 4.2 to 4.4, about 4.4 to 4.6, about 4.6 to 4.8, or about 4.8 to 5. In one embodiment, the pressure ratio is from about 1.0 to 1.5, about 1.0 to 2, about 1.0 to 2.5, about 1.0 to 3.0, about 1.0 to 3.5, about 1.0 to 4.0, about 1.0 to 4.5, or about 1.0 to 5. In one embodiment, the pressure ratio is from between 1.0 to 1.5, between 1.0 to 2, between 1.0 to 2.5, between 1.0 to 3.0, between 1.0 to 3.5, between 1.0 to 4.0, between 1.0 to 4.5, or between 1.0 to 5. In one embodiment, the humidification-dehumidification process as described herein is performed in an apparatus comprising a humidification chamber and a dehumidification chamber. In one embodiment, the humidification chamber and the dehumidification chamber are separate chambers that are fluidly coupled. In one embodiment, the absolute pressure inside the humidification chamber is at least

5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45%, 50%, 55%, 60%, 65%, 70%, 75%, 80%, 85%, 90%, 95%, or 99% lower than the absolute pressure inside the dehumidification chamber. In one embodiment, the absolute pressure inside the humidification chamber is at least 10%-20%, 20%-30%, 30%-40%, 40%-50%, 50%-60%, 60%-70%, 70%-80%, or 80%-90%, 90-95%, or 95%-99% lower than the absolute pressure inside the dehumidification chamber. In one embodiment, the absolute pressure inside the humidification chamber is at least 10% lower than the absolute pressure inside the dehumidification chamber. In one embodiment, the humidification chamber is at or near atmospheric pressure while the dehumidification chamber is at a pressure above atmospheric pressure.

[00363] In one embodiment, the average temperature for dehumidification is higher than the average temperature for humidification. In one embodiment, the humidification process and the dehumidification process are thermally separated from each other. In one embodiment, the humidification chamber and the dehumidification chamber are thermally separated from each other. In one embodiment, the average temperature difference between dehumidification and humidification and vice versa is at least 4° C, 5 °C, 6 °C, 7 °C, 8 °C, 9 °C, 10 °C, 15 °C, 20 °C, 25 °C, 30 °C, 35 °C, 40 °C, 45 °C, 50 °C, 55 °C, 60 °C, 65 °C, 70 °C, 75 °C, 80 °C, 85 °C, 90 °C, 95 °C, or 100 °C. In one embodiment, the average temperature difference between dehumidification and humidification and vice versa is from about 10 °C to 20 °C, 10 °C to 30 °C, 10 °C to 40 °C, 10 °C to 50 °C, 10 °C to 60 °C, 10 °C to 70 °C, 10 °C to 80 °C, 10 °C to 90 °C, or 10 °C to 100 °C. In one embodiment, the average temperature difference between dehumidification and humidification and vice versa is from about 10 °C to 20 °C, 20 °C to 30 °C, 30 °C to 40 °C, 40 °C to 50 °C, 50 °C to 60 °C, 60 °C to 70 °C, 70 °C to 80 °C, 80 °C to 90 °C, or 90 °C to 100 °C. In one embodiment, the average temperature difference between dehumidification and humidification and vice versa is at least 4 °C. In one embodiment, the average temperature difference between dehumidification and humidification and vice versa is from about 10 °C to 70 °C.

[00364] FIG. 3 depicts a humidification-dehumification system useful in the methods described herein. In FIG. 3, the saccharide stream or composition is introduced via spray nozzles **1** into the humidification chamber **2**, which is filled with a packing material **3** that increases both the liquid surface area and the turbulence and mixing of the carrier gas in order to increase evaporation rates. The liquid collected in the bottom of the chamber can either be removed from the system **4** or retained in the system via a recycling loop **5** via a pump. The humidified gas, with elevated inhibitor concentrations, is compressed **6** and conveyed to the dehumidification chamber **7**. Recycled or fresh saccharide stream or composition solution **8** is passed through the

dehumidification chamber to recapture heat as liquid is condensed from the carrier gas. The inhibitors are captured in the condensate **9** and are removed from the system. The carrier gas is then routed through an expander **10** to reduce the pressure prior to reintroduction to the humidification chamber. The saccharide stream or composition is passed through a heating system **11** prior to the introduction into the humidification chamber.

[00365] In one embodiment, the dehumidification chamber **7** in FIG. 3 can be a bubble column vapor mixture condenser as described in US2013/0074694A1 and US2013/0075940A1, each of which is incorporated by reference in its entirety. In one embodiment, the moisture laden carrier gas is bubbled through an aqueous solution in the bubble column vapor mixture condenser, wherein the moisture condenses into the aqueous solution. In one embodiment, the aqueous solution is water.

[00366] In one embodiment, the method of refining the saccharide compositions produced by any of the methods described herein comprises contacting the saccharide or sugar stream or composition with activated carbon. In one embodiment, the activated carbon is powdered activated carbon (PAC), granular activated carbon (GAC), graphene, or a combination thereof. In one embodiment, the activated carbon has a particle size ranging from about 5 microns to about 10 microns. In some embodiments, the method further comprises contacting the saccharide stream with diatomaceous earth. In some embodiments, the saccharide stream is agitated, mixed, stirred, blended, shaken, sonicated, subjected to bubbling with a gas, subjected to bubbling with an inert gas, or any combination thereof during some or all of the contacting. In some embodiments, the method further comprises, after the contacting, conducting a purification. In some embodiments, the purification is a flocculation, a filtration, a centrifugation, or any combination thereof. In some embodiments, the activated carbon, before the contacting, is activated by heating. In some embodiments, the heating is conducted under vacuum. In some embodiments, the method further comprises, after the contacting, or after the conducting a purification, or after the contacting and the conducting a purification, concentrating the saccharide stream. In some embodiments, the saccharide stream comprises water, an alcohol, an acid, or a combination thereof. In some embodiments, the saccharide stream, prior to the contacting, is subjected to an enzymatic hydrolysis. In some embodiments, wherein the saccharide stream, prior to the contacting, is subjected to a pretreatment. In some embodiments, the saccharide stream is derived from a biomass. In some embodiments, is provided an isolated, refined saccharide stream produced by the method of any one of the above embodiments. In some embodiments is provided an isolated saccharide stream comprising activated carbon and optionally at least one of diatomaceous earth, an acid, an alcohol, or any combination thereof. In

some embodiments, the isolated saccharide stream comprises C5 sugars, C6 sugars, or a combination thereof.

[00367] In some embodiments is provided a system for producing a refined saccharide stream, comprising: a purification unit configured to refine the saccharide stream by the method of any previous method embodiment. In some embodiments, the system further comprises, upstream of the purification unit a concentrator configured to concentrate the saccharide stream before it is fed to the purification unit. In some embodiments, the system further comprises, upstream of the concentrator, a hydrolysis unit configured to perform a hydrolysis on a biomass to create a saccharide stream. In some embodiments, the system further comprises, upstream of the hydrolysis unit, a pretreatment unit, configured to pretreat a biomass by at least one of mechanical processing, heat, acid hydrolysis, or any combination thereof. In some embodiments, the system further comprises, upstream of the pretreatment unit, a washing unit configured to wash a biomass before the biomass is fed to the pretreatment unit. In some embodiments, the system further comprises, upstream of the hydrolysis unit and downstream of the pretreatment unit, a washing unit configured to wash pretreated biomass before the pretreated biomass is fed to the hydrolysis unit.

[00368] Disclosed herein are humidification:dehumidification processes for removing one or more inhibitors from a saccharide stream, the processes comprising: (a) contacting in a counter-current manner the saccharide stream with a carrier gas at a first temperature and a first pressure to produce a humidified gas, wherein at least a portion of the one or more inhibitors is transferred from the saccharide stream to the humidified gas; (b) separating the humidified gas from the saccharide stream; (c) dehumidifying the humidified gas at a second temperature and a second pressure to condense the one or more fermentation inhibitors; and (d) recovering the saccharide stream, wherein the saccharide stream comprises a lower level of the one or more inhibitors.

[00369] The one or more inhibitors can comprise acetic acid, formic acid, furfural, hydrozymethylfurfural, sulfuric acid, peroxyacetic acid, lactic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, or a combination thereof. In some embodiments, the one or more inhibitors comprise acetic acid. In some embodiments, the one or more inhibitors comprise formic acid. In some embodiments, the one or more inhibitors comprise acetic acid and formic acid.

[00370] The carrier gas can comprise air, nitrogen, argon, carbon dioxide, or a combination thereof. In some embodiments, the carrier gas is air. In some embodiments, the carrier gas is nitrogen.

[00371] The first temperature can be at least about 4°C lower than the second temperature. In some embodiments, the first temperature is at least about 10°C lower than the second temperature.

[00372] The first temperature can be about 4°C to about 90°C lower than the second temperature. In some embodiments, the first temperature is about 10°C to about 70°C lower than the second temperature. In some embodiments, the first temperature is about 15°C to about 50°C lower than the second temperature.

[00373] The first temperature can be about 4°C to about 100°C. In some embodiments, the first temperature is about 10°C to about 70°C. In some embodiments, the first temperature is about 15°C to about 50°C.

[00374] The second pressure can be at least about 1.1 times higher than the first pressure. In some embodiments, the second pressure is at least about 1.5 times higher than the first pressure. In some embodiments, the second pressure is at least about 2.0 times higher than the first pressure.

[00375] The first pressure can be about 25 kPa to about 250 kPa. For example, the first pressure can be about 25-250 kPa, 25-225 kPa, 25-200 kPa, 25-175 kPa, 25-150 kPa, 25-125 kPa, 25-100 kPa, 25-75 kPa, 25-50 kPa, 50-225 kPa, 50-200 kPa, 50-175 kPa, 50-150 kPa, 50-125 kPa, 50-100 kPa, 50-75 kPa, 75-200 kPa, 75-175 kPa, 75-150 kPa, 75-125 kPa, 75-100 kPa, 100-175 kPa, 100-150 kPa, 100-125 kPa, 125-150 kPa, 25 kPa, 30 kPa, 35 kPa, 40 kPa, 45 kPa, 50 kPa, 55 kPa, 60 kPa, 65 kPa, 70 kPa, 75 kPa, 80 kPa, 85 kPa, 90 kPa, 95 kPa, 100 kPa, 105 kPa, 110 kPa, 115 kPa, 120 kPa, 125 kPa, 130 kPa, 135 kPa, 140 kPa, 145 kPa, 150 kPa, 155 kPa, 160 kPa, 165 kPa, 170 kPa, 175 kPa, 180 kPa, 185 kPa, 190 kPa, 195 kPa, 200 kPa, 205 kPa, 210 kPa, 215 kPa, 220 kPa, 225 kPa, 230 kPa, 235 kPa, 240 kPa, 245 kPa, 250 kPa. In some embodiments, the first pressure is about 10 kPa to about 100 kPa. In some embodiments, the first pressure is about 20 kPa to about 60 kPa.

[00376] After recovering the saccharide stream, the process can be repeated one or more additional times with the recovered saccharide stream.

[00377] The process can further comprise dissolving a salt in the saccharide stream prior to contacting. In some embodiments, the salt comprises LiBr, NaCl, KCl, or a combination thereof. In some embodiments, the salt comprises LiBr.

[00378] The process can further comprise, after recovering the saccharide stream, separating the salt from the saccharide stream. In some embodiments, separating the salt from the saccharide stream comprises filtration.

[00379] At least about 10% of the one or more inhibitors can removed from the saccharide stream during contacting. In some embodiments, at least about 25% of the one or more inhibitors is removed from the saccharide stream. In some embodiments, at least about 50% of the one or more inhibitors is removed from the saccharide stream. In some embodiments, at least about 75% of the one or more inhibitors is removed from the saccharide stream.

[00380] Contacting the saccharide stream and the carrier gas can be performed in a humidification chamber. In some embodiments, the humidification chamber comprises packing material. In some embodiments, the packing material comprises polyvinyl chloride packing.

[00381] The saccharide stream can be introduced into a top portion of the humidifying chamber.

[00382] The first temperature can be an average temperature in the humidifying chamber.

[00383] The carrier gas can be introduced into a bottom portion of the humidification chamber.

[00384] Contacting the saccharide stream and the carrier gas can comprise spraying the saccharide stream with a spray nozzle.

[00385] Dehumidifying the humidified gas can occur in a dehumidifying chamber. In some embodiments, the second temperature is an average temperature in the dehumidifying chamber.

[00386] A compressor can be used to transfer the humidified gas from the humidifying chamber to the dehumidifying chamber.

[00387] An expander can be used to transfer the carrier gas from the dehumidifying chamber to the humidifying chamber after the one or more fermentation inhibitors are condensed out of the humidified gas.

[00388] The saccharide stream can be piped through the dehumidifying chamber to effect a heat transfer from the humidified gas to the saccharide stream.

[00389] A heater can be used to increase the temperature of the saccharide stream before contacting with the carrier gas.

[00390] The saccharide stream can comprise C5 saccharides, C6 saccharides, or a combination thereof. In some embodiments, the C5 saccharides comprise xylose, arabinose, or a combination thereof. In some embodiments, the C6 sugars comprise glucose, mannose, galactose, rhamnose, or a combination thereof. In some embodiments, the saccharide stream comprises glucose, mannose, galactose, rhamnose, xylose, arabinose, or a combination thereof.

[00391] The saccharide stream can have been produced by pretreating or hydrolyzing a biomass composition comprising cellulose, hemicellulose, or lignocellulose. In some embodiments, the

biomass composition comprises alfalfa, algae, bagasse, bamboo, corn stover, corn cobs, corn kernels, corn mash, corn steep liquor, corn steep solids, distiller's grains, distiller's dried solubles, distiller's dried grains, condensed distiller's solubles, distiller's wet grains, distiller's dried grains with solubles, eucalyptus, food waste, fruit peels, garden residue, grass, grain hulls, modified crop plants, municipal waste, oat hulls, paper, paper pulp, prairie bluestem, poplar, rice hulls, seed hulls, silage, sorghum, straw, sugarcane, switchgrass, wheat, wheat straw, wheat bran, de-starched wheat bran, willows, wood, plant cells, plant tissue cultures, or a combination thereof.

[00392] Pretreating or hydrolyzing can comprise mechanical size reduction, hot water treatment, acid treatment, base treatment, steam explosion, acid-catalyzed steam explosion, ammonia fiber/freeze explosion, enzymatic hydrolysis, catalytic peptide hydrolysis, ionic liquid dissolution, or a combination thereof.

[00393] Pretreating or hydrolyzing can comprise mechanical size reduction, acid treatment, and hydrolysis with one or more enzymes or one or more polymeric catalysts.

[00394] Pretreating or hydrolyzing can comprise treating the biomass composition with hot water or dilute acid to solubilize hemicellulose, substantially separating the solubilized hemicellulose from remaining lignocellulose solids, and hydrolysis of the remaining lignocellulose solids with one or more enzymes or polymeric catalysts.

[00395] Pretreating or hydrolyzing can comprise ionic liquid dissolution with [bmim] 1-butyl-3-methylimidazolium, [emim] 1-ethyl-3-methylimidazolium, [amim] 1-allyl-3-methylimidazolium, [Ch] cholinium, [bzmim] 1-benzyl-3-methylimidazolium, [HEA] 2- hydroxyethylammonium, [bmpy] 1-butyl-3-methylpyridinium, [Me(OEt)3Et3N] triethyl-(2-(2-methoxyethoxy)ethoxy) ethylammonium, [DMEA] N,N-dimethylethanolammonium, [mmim] 1,3-dimethylimidazolium, [hmim] 1-hexyl-3-methylimidazolium, [pmim] 1-propyl-3-methylimidazolium, [abim] 1-allyl-3-butylimidazolium, [eMeOHpy] 1-ethyl-3-(hydroxymethyl)pyridine, [bHim] 1-butylimidazolium, [Cl] chloride, [CH3COO] acetate, [Et2PO4] diethylphosphate, [Me2PO4] dimethylphosphate, [MeOSO3] methylsulphate, [OTf] trifluoromethanesulphonate, [PrOO] propionate, [CF3COO] trifluoroacetate, [MeSO3] methanesulphonate, [HSO4] hydrogen sulphate, [PO(O)H2] phosphinate, [HCOO] formate, [BF4] tetrafluoroborate, [PF6] hexafluorophosphate, [Lys] lysinate, [Gly] glycinate, [Ala] alaninate, [Ser] serinate, [Thr] threoninate, [Met] methioninate, [Pro] prolinate, [Phe] phenylalaninate, [OHCH2COO] glycolate, [(CH2COO)2] succinate, [ABS] alkylbenzenesulphonate, [XS] xylenesulphonate, [MePO3] methylphosphonate, [EtPO3] ethylphosphonate, [i-PrPO3] i-propylphosphonate, [BuPO3] butylphosphonate, [NTf2] bis(trifluoromethylsulfonyl)amide, [EtOSO3] ethylsulphate , or a combination thereof.

[00396] Also provided herein are saccharide streams produced by any of the humidification:dehumidification processes disclosed herein.

[00397] Also disclosed herein are humidification:dehumidification systems for removing one or more inhibitors from a saccharide stream, the systems comprising: (a) a saccharide stream comprising one or more inhibitors; (b) a carrier gas; (c) a humidification chamber containing packing material for contacting in a counter-current manner the saccharide stream with the carrier gas to produce a humidified gas, wherein at least a portion of the one or more inhibitors is transferred from the saccharide stream to the humidified gas; and (d) a dehumidification chamber at a second temperature and pressure for condensing the one or more fermentation inhibitors from the humidified gas.

[00398] The system can further comprise a compressor to transfer the humidified gas from the humidifying chamber to the dehumidifying chamber.

[00399] The system can further comprise an expander to transfer the carrier gas from the dehumidifying chamber to the humidifying chamber after the one or more fermentation inhibitors are condensed out of the humidified gas.

[00400] The saccharide stream can be piped through the dehumidifying chamber to effect a heat transfer from the humidified gas to the saccharide stream.

[00401] The system can further comprise a heater to increase the temperature of the saccharide stream before contacting with the carrier gas.

[00402] **Fermentation**

[00403] The present disclosure also provides a fermentative mixture comprising: a cellulosic feedstock pre-treated with an alkaline or acid substance and at a temperature of from about 80°C to about 120°C; subsequently hydrolyzed with an enzyme mixture, and a microorganism capable of fermenting a five-carbon saccharide and/or a six-carbon saccharide. In one embodiment, the five-carbon saccharide is xylose, arabinose, or a combination thereof. In one embodiment, the six-carbon saccharide is glucose, galactose, mannose, or a combination thereof. In one embodiment, the six-carbon saccharide is a saccharide polymer comprising glucose polymers, galactose polymers, mannose polymers, rhamnose polymers or a combination thereof. In one embodiment, the five-carbon saccharide is a saccharide polymer comprising xylose polymers, arabinose polymers, or a combination thereof. In one embodiment, the alkaline substance is NaOH. In some embodiments, NaOH is added at a concentration of about 0.5% to about 2% by weight of the feedstock. In one embodiment, the acid is equal to or less than 2% HCl or H_2SO_4. In one embodiment, the microorganism is a *Rhodococcus* strain, a *Clostridium* strain, a

Trichoderma strain, a *Saccharomyces* strain, a *Zymomonas* strain, or another microorganism suitable for fermentation of biomass. In one embodiment, the microorganism is a *Lactobacillus* strain. In another embodiment, the fermentation process comprises fermentation of the biomass using a microorganism that is *Clostridium phytofermentans, Clostridium algidixylanolyticum, Clostridium xylanolyticum, Clostridium cellulovorans, Clostridium cellulolyticum, Clostridium thermocellum, Clostridium josui, Clostridium papyrosolvens, Clostridium cellobioparum, Clostridium hungatei, Clostridium cellulosi, Clostridium stercorarium, Clostridium termitidis, Clostridium thermocopriae, Clostridium celerecrescens, Clostridium polysaccharolyticum, Clostridium populeti, Clostridium lentocellum, Clostridium chartatabidum, Clostridium aldrichii, Clostridium herbivorans, Acetivibrio cellulolyticus, Bacteroides cellulosolvens, Caldicellulosiruptor saccharolyticum, Rhodococcus opacus, Ruminococcus albus, Ruminococcus flavefaciens, Fibrobacter succinogenes, Eubacterium cellulosolvens, Butyrivibrio fibrisolvens, Anaerocellum thermophilum, Halocella cellulolytica, Thermoanaerobacterium thermosaccharolyticum, Sacharophagus degradans, or Thermoanaerobacterium saccharolyticum*. In still another embodiment, the microorganism is genetically modified to enhance activity of one or more hydrolytic enzymes, such as a genetically-modified *Saccharomyces cerevisiae*.

[00404] In one embodiment, a wild type or a genetically-improved microorganism can be used for chemical production by fermentation. Methods to produce a genetically-improved strain can include genetic modification, mutagenesis, and adaptive processes, such as directed evolution. For example, yeasts can be genetically-modified to ferment C5 saccharides. Other useful yeasts are species of *Candida, Cryptococcus, Debaryomyces, Deddera, Hanseniaspora, Kluyveromyces, Pichia,* Schizosaccharomyces, and *Zygosaccharomyces*. *Rhodococus* strains, such as *Rhodococcus opacus* variants are a source of triacylglycerols and other storage lipids. (See, *e.g.*, Waltermann, *et al.*, Microbiology 146:1143-1149 (2000)). Other useful organisms for fermentation include, but are not limited to, yeasts, especially *Saccaromyces* strains and bacteria such as *Clostridium phytofermentans, Thermoanaerobacter ethanolicus, Clostridium thermocellum, Clostridium beijerinickii, Clostridium acetobutylicum, Clostridium tyrobutyricum, Clostridium thermobutyricum, Thermoanaerobacterium saccharolyticum, Thermoanaerobacter thermohydrosulfuricus, Clostridium acetobutylicum, Moorella ssp., Carboxydocella ssp., Zymomonas mobilis,* recombinant *E. Coli, Klebsiella oxytoca, Rhodococcus opacus* and *Clostridium beijerickii.*

[00405] An advantage of yeasts are their ability to grow under conditions that include elevated ethanol concentration, high saccharide concentration, low saccharide concentration, and/or

operate under anaerobic conditions. These characteristics, in various combinations, can be used to achieve operation with long or short fermentation cycles and can be used in combination with batch fermentations, fed batch fermentations, self-seeding/partial harvest fermentations, and recycle of cells from the final fermentation as inoculum.

[00406] In one embodiment, fed-batch fermentation is performed on the treated biomass to produce a fermentation end-product, such as alcohol, ethanol, organic acid, succinic acid, TAG, or hydrogen. In one embodiment, the fermentation process comprises simultaneous hydrolysis and fermentation (SSF) of the biomass using one or more microorganisms such as a *Rhodococcus* strain, a *Clostridium* strain, a *Trichoderma* strain, a *Saccharomyces* strain, a *Zymomonas* strain, or another microorganism suitable for fermentation of biomass. In another embodiment, the fermentation process comprises simultaneous hydrolysis and fermentation of the biomass using a microorganism that is *Clostridium algidixylanolyticum, Clostridium xylanolyticum, Clostridium cellulovorans, Clostridium cellulolyticum, Clostridium thermocellum, Clostridium josui, Clostridium papyrosolvens, Clostridium cellobioparum, Clostridium hungatei, Clostridium cellulosi, Clostridium stercorarium, Clostridium termitidis, Clostridium thermocopriae, Clostridium celerecrescens, Clostridium polysaccharolyticum, Clostridium populeti, Clostridium lentocellum, Clostridium chartatabidum, Clostridium aldrichii, Clostridium herbivorans, Clostridium phytofermentans, Acetivibrio cellulolyticus, Bacteroides cellulosolvens, Caldicellulosiruptor saccharolyticum, Ruminococcus albus, Ruminococcus flavefaciens, Fibrobacter succinogenes, Eubacterium cellulosolvens, Butyrivibrio fibrisolvens, Anaerocellum thermophilum, Halocella cellulolytica, Thermoanaerobacterium thermosaccharolyticum, Sacharophagus degradans,* or *Thermoanaerobacterium saccharolyticum.*

[00407] In one embodiment, the fermentation process can include separate hydrolysis and fermentation (SHF) of a biomass with one or more enzymes, such as a xylanases, endo-1,4-beta-xylanases, xylosidases, beta-D-xylosidases, cellulases, hemicellulases, carbohydrases, glucanases, endoglucanases, endo-1,4-beta-glucanases, exoglucanases, glucosidases, beta-D-glucosidases, amylases, cellobiohydrolases, exocellobiohydrolases, phytases, proteases, peroxidase, pectate lyases, galacturonases, or laccases. In one embodiment, one or more enzymes used to treat a biomass are thermostable. In another embodiment a biomass is treated with one or more enzymes, such as those provided herein, prior to fermentation. In another embodiment a biomass is treated with one or more enzymes, such as those provided herein, during fermentation. In another embodiment a biomass is treated with one or more enzymes, such as those provided herein, prior to fermentation and during fermentation. In another embodiment an

enzyme used for hydrolysis of a biomass is the same as those added during fermentation. In another embodiment an enzyme used for hydrolysis of biomass is different from those added during fermentation.

[00408] In some embodiments, fermentation can be performed in an apparatus such as bioreactor, a fermentation vessel, a stirred tank reactor, or a fluidized bed reactor. In one embodiment, the treated biomass can be supplemented with suitable chemicals to facilitate robust growth of the one or more fermenting organisms. In one embodiment, a useful supplement includes but is not limited to, a source of nitrogen and/or amino acids such as yeast extract, cysteine, or ammonium salts (*e.g.* nitrate, sulfate, phosphate, *etc.*); a source of simple carbohydrates such as corn steep liquor, and malt syrup; a source of vitamins such as yeast extract; buffering agents such as salts (including but not limited to citrate salts, phosphate salts, or carbonate salts); or mineral nutrients such as salts of magnesium, calcium, or iron. In some embodiments redox modifiers are added to the fermentation mixture including but not limited to cysteine or mercaptoethanol.

[00409] In one embodiment, the titer and/or productivity of fermentation end-product production by a microorganism is improved by culturing the microorganism in a medium comprising one or more compounds comprising hexose and/or pentose saccharides. In one embodiment, a process comprises conversion of a starting material (such as a biomass) to a biofuel, such as one or more alcohols. In one embodiment, methods of the invention comprise contacting substrate comprising both hexose (*e.g.* glucose, cellobiose) and pentose (*e.g.* xylose, arabinose) saccharides with a microorganism that can hydrolyze C5 and C6 saccharides to produce ethanol. In another embodiment, methods of the invention comprise contacting substrate comprising both hexose (*e.g.* glucose, cellobiose) and pentose (*e.g.* xylose, arabinose) saccharides with *R. opacus* to produce TAG.

[00410] In some embodiments of the present invention, batch fermentation with a microorganism of a mixture of hexose and pentose saccharides using the methods of the present invention provides uptake rates of about 0.1-8 g/L/h or more of hexose and about 0.1-8 g/L/h or more of pentose (xylose, arabinose, *etc.*). In some embodiments of the present invention, batch fermentation with a microorganism of a mixture of hexose and pentose saccharides using the methods of the present invention provides uptake rates of about 0.1, 0.2, 0.4, 0.5, 0.6 0.7, 0.8, 1, 2, 3, 4, 5, or 6 g/L/h or more of hexose and about 0.1, 0.2, 0.4, 0.5, 0.6 0.7, 0.8, 1, 2, 3, 4, 5, or 6 g/L/h or more of pentose.

[00411] In one embodiment, a method for production of ethanol or another alcohol produces about 10 g/l to 120 gain 40 hours or less. In another embodiment a method for production of

ethanol produces about 10 g/l, 11 g/L, 12 g/L, 13 g/L, 14 g/L, 15 g/L, 16 g/L, 17 g/L, 18 g/L, 19 g/L, 20 g/L, 21 g/L, 22 g/L, 23 g/L, 24 g/L, 25 g/L, 26 g/L, 27 g/L, 28 g/L, 29 g/L, 30 g/L, 31 g/L, 32 g/L, 33 g/L, 34 g/L, 35 g/L, 36 g/L, 37 g/L, 38 g/L, 39 g/L, 40 g/L, 41 g/L, 42 g/L, 43 g/L, 44 g/L, 45 g/L, 46 g/L, 47 g/L, 48 g/L, 49 g/L, 50 g/L, 51 g/L, 52 g/L, 53 g/L, 54 g/L, 55 g/L, 56 g/L, 57 g/L, 58 g/L, 59 g/L, 60 g/L, 61 g/L, 62 g/L, 63 g/L, 64 g/L, 65 g/L, 66 g/L, 67 g/L, 68 g/L, 69 g/L, 70 g/L, 71 g/L, 72 g/L, 73 g/L, 74 g/L, 75 g/L, 76 g/L, 77 g/L, 78 g/L, 79 g/L, 80 g/L, 81 g/L, 82 g/L, 83 g/L, 84 g/L, 85 g/L, 86 g/L, 87 g/L, 88 g/L, 89 g/L, 90 g/L, 91 g/L, 92 g/L, 93 g/L, 94 g/L, 95 g/L, 96 g/L, 97 g/L, 98 g/L, 99 g/L, 100 g/L, 110 g/l, 120 g/l, or more alcohol in 40 hours by the fermentation of biomass. In another embodiment, alcohol is produced by a method comprising simultaneous fermentation of hexose and pentose saccharides. In another embodiment, alcohol is produced by a microorganism comprising simultaneous fermentation of hexose and pentose saccharides.

[00412] In another embodiment, the level of a medium component is maintained at a desired level by adding additional medium component as the component is consumed or taken up by the organism. Examples of medium components included, but are not limited to, carbon substrate, nitrogen substrate, vitamins, minerals, growth factors, cofactors, and biocatalysts. The medium component can be added continuously or at regular or irregular intervals. In one embodiment, additional medium component is added prior to the complete depletion of the medium component in the medium. In one embodiment, complete depletion can effectively be used, for example to initiate different metabolic pathways, to simplify downstream operations, or for other reasons as well. In one embodiment, the medium component level is allowed to vary by about 10% around a midpoint, in one embodiment, it is allowed to vary by about 30% around a midpoint, and in one embodiment, it is allowed to vary by 60% or more around a midpoint. In one embodiment, the medium component level is maintained by allowing the medium component to be depleted to an appropriate level, followed by increasing the medium component level to another appropriate level. In one embodiment, a medium component, such as vitamin, is added at two different time points during fermentation process. For example, one-half of a total amount of vitamin is added at the beginning of fermentation and the other half is added at midpoint of fermentation.

[00413] In another embodiment, the nitrogen level is maintained at a desired level by adding additional nitrogen-containing material as nitrogen is consumed or taken up by the organism. The nitrogen-containing material can be added continuously or at regular or irregular intervals. Useful nitrogen levels include levels of about 5 to about 10 g/L. In one embodiment, levels of about 1 to about 12 g/L can also be usefully employed. In another embodiment levels, such as

about 0.5, 0.1 g/L or even lower, and higher levels, such as about 20, 30 g/L or even higher are used. In another embodiment a useful nitrogen level is about 0.01, 0.05, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22 23, 24, 25, 26, 27, 28, 29 or 30 g/L. Nitrogen can be supplied as a simple nitrogen-containing material, such as an ammonium compounds (*e.g.* ammonium sulfate, ammonium hydroxide, ammonia, ammonium nitrate, or any other compound or mixture containing an ammonium moiety), nitrate or nitrite compounds (*e.g.* potassium, sodium, ammonium, calcium, or other compound or mixture containing a nitrate or nitrite moiety), or as a more complex nitrogen-containing material, such as amino acids, proteins, hydrolyzed protein, hydrolyzed yeast, yeast extract, dried brewer's yeast, yeast hydrolysates, distillers' grains, soy protein, hydrolyzed soy protein, fermentation products, and processed or corn steep powder or unprocessed protein-rich vegetable or animal matter, including those derived from bean, seeds, soy, legumes, nuts, milk, pig, cattle, mammal, fish, as well as other parts of plants and other types of animals. Nitrogen-containing materials useful in various embodiments also include materials that contain a nitrogen-containing material, including, but not limited to mixtures of a simple or more complex nitrogen-containing material mixed with a carbon source, another nitrogen-containing material, or other nutrients or non-nutrients, and AFEX treated plant matter.

[00414] In another embodiment, the carbon level is maintained at a desired level by adding saccharide compounds or material containing saccharide compounds ("saccharide-containing material") as saccharide is consumed or taken up by the organism. The saccharide-containing material can be added continuously or at regular or irregular intervals. In one embodiment, additional saccharide-containing material is added prior to the complete depletion of the saccharide compounds available in the medium. In one embodiment, complete depletion can effectively be used, for example to initiate different metabolic pathways, to simplify downstream operations, or for other reasons as well. In one embodiment, the carbon level (as measured by the grams of saccharide present in the saccharide-containing material per liter of broth) is allowed to vary by about 10% around a midpoint, in one embodiment, it is allowed to vary by about 30% around a midpoint, and in one embodiment, it is allowed to vary by 60% or more around a midpoint. In one embodiment, the carbon level is maintained by allowing the carbon to be depleted to an appropriate level, followed by increasing the carbon level to another appropriate level. In some embodiments, the carbon level can be maintained at a level of about 5 to about 120 g/L. However, levels of about 30 to about 100 g/L can also be usefully employed as well as levels of about 60 to about 80 g/L. In one embodiment, the carbon level is maintained at greater than 25 g/L for a portion of the culturing. In another embodiment, the carbon level is

maintained at about 5 g/L, 6 g/L, 7 g/L, 8 g/L, 9 g/L, 10 g/L, 11 g/L, 12 g/L, 13 g/L, 14 g/L, 15 g/L, 16 g/L, 17 g/L, 18 g/L, 19 g/L, 20 g/L, 21 g/L, 22 g/L, 23 g/L, 24 g/L, 25 g/L, 26 g/L, 27 g/L, 28 g/L, 29 g/L, 30 g/L, 31 g/L, 32 g/L, 33 g/L, 34 g/L, 35 g/L, 36 g/L, 37 g/L, 38 g/L, 39 g/L, 40 g/L, 41 g/L, 42 g/L, 43 g/L, 44 g/L, 45 g/L, 46 g/L, 47 g/L, 48 g/L, 49 g/L, 50 g/L, 51 g/L, 52 g/L, 53 g/L, 54 g/L, 55 g/L, 56 g/L, 57 g/L, 58 g/L, 59 g/L, 60 g/L, 61 g/L, 62 g/L, 63 g/L, 64 g/L, 65 g/L, 66 g/L, 67 g/L, 68 g/L, 69 g/L, 70 g/L, 71 g/L, 72 g/L, 73 g/L, 74 g/L, 75 g/L, 76 g/L, 77 g/L, 78 g/L, 79 g/L, 80 g/L, 81 g/L, 82 g/L, 83 g/L, 84 g/L, 85 g/L, 86 g/L, 87 g/L, 88 g/L, 89 g/L, 90 g/L, 91 g/L, 92 g/L, 93 g/L, 94 g/L, 95 g/L, 96 g/L, 97 g/L, 98 g/L, 99 g/L, 100 g/L, 101 g/L, 102 g/L, 103 g/L, 104 g/L, 105 g/L, 106 g/L, 107 g/L, 108 g/L, 109 g/L, 110 g/L, 111 g/L, 112 g/L, 113 g/L, 114 g/L, 115 g/L, 116 g/L, 117 g/L, 118 g/L, 119 g/L, 120 g/L, 121 g/L, 122 g/L, 123 g/L, 124 g/L, 125 g/L, 126 g/L, 127 g/L, 128 g/L, 129 g/L, 130 g/L, 131 g/L, 132 g/L, 133 g/L, 134 g/L, 135 g/L, 136 g/L, 137 g/L, 138 g/L, 139 g/L, 140 g/L, 141 g/L, 142 g/L, 143 g/L, 144 g/L, 145 g/L, 146 g/L, 147 g/L, 148 g/L, 149 g/L, or 150 g/L.

[00415] The carbon substrate, like the nitrogen substrate, is necessary for cell production and enzyme production, but unlike the nitrogen substrate, it serves as the raw material for production of end products. Frequently, more carbon substrate can lead to greater production of end products. In another embodiment, it can be advantageous to operate with the carbon level and nitrogen level related to each other for at least a portion of the fermentation time. In one embodiment, the ratio of carbon to nitrogen is maintained within a range of about 30:1 to about 10:1. In another embodiment, the ratio of carbon nitrogen is maintained from about 20:1 to about 10:1 or more preferably from about 15:1 to about 10:1. In another embodiment the ratio of carbon nitrogen is about 30:1, 29:1, 28:1, 27:1, 26:1, 25:1, 24:1, 23:1, 22:1, 21:1, 20:1, 19:1, 18:1, 17:1, 16:1, 15:1, 14:1, 13:1, 12:1, 11:1, 10:1, 9:1, 8:1, 7:1, 6:1, 5:1, 4:1, 3:1, 2:1, or 1:1.

[00416] Maintaining the ratio of carbon and nitrogen ratio within particular ranges can result in benefits to the operation such as the rate of metabolism of carbon substrate, which depends on the amount of carbon substrate and the amount and activity of enzymes present, being balanced to the rate of end product production. Balancing the carbon to nitrogen ratio can, for example, facilitate the sustained production of these enzymes such as to replace those which have lost activity.

[00417] In another embodiment, the amount and/or timing of carbon, nitrogen, or other medium component addition can be related to measurements taken during the fermentation. For example, the amount of monosaccharides present, the amount of insoluble polysaccharide present, the polysaccharase activity, the amount of product present, the amount of cellular material (for example, packed cell volume, dry cell weight, *etc.*) and/or the amount of nitrogen (for example,

nitrate, nitrite, ammonia, urea, proteins, amino acids, *etc.*) present can be measured. The concentration of the particular species, the total amount of the species present in the fermentor, the number of hours the fermentation has been running, and the volume of the fermentor can be considered. In various embodiments, these measurements can be compared to each other and/or they can be compared to previous measurements of the same parameter previously taken from the same fermentation or another fermentation. Adjustments to the amount of a medium component can be accomplished such as by changing the flow rate of a stream containing that component or by changing the frequency of the additions for that component. For example, the amount of saccharide can be increased when the cell production increases faster than the end product production. In another embodiment the amount of nitrogen can be increased when the enzyme activity level decreases.

[00418] In another embodiment, a fed batch operation can be employed, wherein medium components and/or fresh cells are added during the fermentation without removal of a portion of the broth for harvest prior to the end of the fermentation. In one embodiment, a fed-batch process is based on feeding a growth limiting nutrient medium to a culture of microorganisms. In one embodiment, the feed medium is highly concentrated to avoid dilution of the bioreactor. In another embodiment the controlled addition of the nutrient directly affects the growth rate of the culture and avoids overflow metabolism such as the formation of side metabolites. In one embodiment, the growth limiting nutrient is a nitrogen source or a saccharide source.

[00419] In various embodiments, particular medium components can have beneficial effects on the performance of the fermentation, such as increasing the titer of desired products, or increasing the rate that the desired products are produced. Specific compounds can be supplied as a specific, pure ingredient, such as a particular amino acid, or it can be supplied as a component of a more complex ingredient, such as using a microbial, plant or animal product as a medium ingredient to provide a particular amino acid, promoter, cofactor, or other beneficial compound. In some cases, the particular compound supplied in the medium ingredient can be combined with other compounds by the organism resulting in a fermentation-beneficial compound. One example of this situation would be where a medium ingredient provides a specific amino acid which the organism uses to make an enzyme beneficial to the fermentation. Other examples can include medium components that are used to generate growth or product promoters, *etc.* In such cases, it can be possible to obtain a fermentation-beneficial result by supplementing the enzyme, promoter, growth factor, *etc.* or by adding the precursor. In some situations, the specific mechanism whereby the medium component benefits the fermentation is not known, only that a beneficial result is achieved.

[00420] In one embodiment, a fermentation to produce a fuel is performed by culturing a strain of *R. opacus* in a medium having a supplement of lignin component and a concentration of one or more carbon sources. The resulting production of end product such as TAG can be up to 1-fold, 2-fold, 3-fold, 4-fold, 5-fold, 6-fold, 7-fold, 8-fold, 9-fold, and in some cases up to 10-fold and higher in volumetric productivity than a process using only the addition of a relatively pure saccharide source, and can achieve a carbon conversion efficiency approaching the theoretical maximum. The theoretical maximum can vary with the substrate and product. For example, the generally accepted maximum efficiency for conversion of glucose to ethanol is 0.51 g ethanol/g glucose. In one embodiment, a biocatalyst can produce about 40-100% of a theoretical maximum yield of ethanol. In another embodiment, a biocatalyst can produce up to about 40%, 50%, 60%, 70%, 80%, 90%, 95% and even 100% of the theoretical maximum yield of ethanol. In one embodiment, a biocatalyst can produce up to about 1 %, 2 %, 3 %, 4 %, 5 %, 6 %, 7 %, 8 %, 9 %, 10 %, 11 %, 12 %, 13 %, 14 %, 15 %, 16 %, 17 %, 18 %, 19 %, 20 %, 21 %, 22 %, 23 %, 24 %, 25 %, 26 %, 27 %, 28 %, 29 %, 30 %, 31 %, 32 %, 33 %, 34 %, 35 %, 36 %, 37 %, 38 %, 39 %, 40 %, 41 %, 42 %, 43 %, 44 %, 45 %, 46 %, 47 %, 48 %, 49 %, 50 %, 51 %, 52 %, 53 %, 54 %, 55 %, 56 %, 57 %, 58 %, 59 %, 60 %, 61 %, 62 %, 63 %, 64 %, 65 %, 66 %, 67 %, 68 %, 69 %, 70 %, 71 %, 72 %, 73 %, 74 %, 75 %, 76 %, 77 %, 78 %, 79 %, 80 %, 81 %, 82 %, 83 %, 84 %, 85 %, 86 %, 87 %, 88 %, 89 %, 90 %, 91 %, 92 %, 93 %, 94 %, 95 %, 96 %, 97 %, 98 %, 99 %, 99.99 %, or100 % of a theoretical maximum yield of a fuel. It can be possible to obtain a fermentation-beneficial result by supplementing the medium with a pretreatment or hydrolysis component. In some situations, the specific mechanism whereby the medium component benefits the fermentation is not known, only that a beneficial result is achieved.

[00421] Various embodiments offer benefits relating to improving the titer and/or productivity of fermentation end-product production by a biocatalyst by culturing the organism in a medium comprising one or more compounds comprising particular fatty acid moieties and/or culturing the organism under conditions of controlled pH.

[00422] In one embodiment, the pH of the medium is controlled at less than about pH 7.2 for at least a portion of the fermentation. In one embodiment, the pH is controlled within a range of about pH 3.0 to about 7.1 or about pH 4.5 to about 7.1, or about pH 5.0 to about 6.3, or about pH 5.5 to about 6.3, or about pH 6.0 to about 6.5, or about pH 5.5 to about 6.9 or about pH 6.2 to about 6.7. The pH can be controlled by the addition of a pH modifier. In one embodiment, a pH modifier is an acid, a base, a buffer, or a material that reacts with other materials present to serve to raise of lower the pH. In one embodiment, more than one pH modifier can be used, such as more than one acid, more than one base, one or more acid with one or more bases, one or more

acids with one or more buffers, one or more bases with one or more buffers, or one or more acids with one or more bases with one or more buffers. When more than one pH modifiers are utilized, they can be added at the same time or at different times. In one embodiment, one or more acids and one or more bases can be combined, resulting in a buffer. In one embodiment, media components, such as a carbon source or a nitrogen source can also serve as a pH modifier; suitable media components include those with high or low pH or those with buffering capacity. Exemplary media components include acid- or base-hydrolyzed plant polysaccharides having with residual acid or base, AFEX treated plant material with residual ammonia, lactic acid, corn steep solids or liquor.

[00423] In one embodiment, a constant pH can be utilized throughout the fermentation. In one embodiment, the timing and/or amount of pH reduction can be related to the growth conditions of the cells, such as in relation to the cell count, the end product produced, the end product present, or the rate of end product production. In one embodiment, the pH reduction can be made in relation to physical or chemical properties of the fermentation, such as viscosity, medium composition, gas production, off gas composition, *etc.*

[00424] Recovery of Fermentive End Products

[00425] In another aspect, methods are provided for the recovery of the fermentive end products, such as an alcohol (*e.g.* ethanol, propanol, methanol, butanol, *etc.*) another biofuel or chemical product. In one embodiment, broth will be harvested at some point during of the fermentation, and fermentive end product or products will be recovered. The broth with end product to be recovered will include both end product and impurities. The impurities include materials such as water, cell bodies, cellular debris, excess carbon substrate, excess nitrogen substrate, other remaining nutrients, other metabolites, and other medium components or digested medium components. During the course of processing the broth, the broth can be heated and/or reacted with various reagents, resulting in additional impurities in the broth.

[00426] In one embodiment, the processing steps to recover end product frequently includes several separation steps, including, for example, distillation of a high concentration alcohol material from a less pure alcohol-containing material. In one embodiment, the high concentration ethanol material can be further concentrated to achieve very high concentration alcohol, such as 98% or 99% or 99.5% (wt.) or even higher. Other separation steps, such as filtration, centrifugation, extraction, adsorption, *etc.* can also be a part of some recovery processes for alcohol as a product or biofuel, or other biofuels or chemical products.

[00427] In one embodiment, a process can be scaled to produce commercially useful biofuels. In another embodiment biocatalyst is used to produce an alcohol, *e.g.*, ethanol, butanol, propanol, methanol, or a fuel such as hydrocarbons hydrogen, TAG, and hydroxy compounds. In another embodiment biocatalyst is used to produce a carbonyl compound such as an aldehyde or ketone (*e.g.* acetone, formaldehyde, 1-propanal, *etc.*), an organic acid, a derivative of an organic acid such as an ester (*e.g.* wax ester, glyceride, *etc.*), 1, 2-propanediol, 1, 3-propanediol, lactic acid, formic acid, acetic acid, succinic acid, pyruvic acid, or an enzyme such as a cellulase, polysaccharase, lipases, protease, ligninase, and hemicellulase.

[00428] TAG biosynthesis is widely distributed in nature and the occurrence of TAG as reserve compounds is widespread among plants, animals, yeast and fungi. In contrast, however, TAGs have not been regarded as common storage compounds in bacteria. Biosynthesis and accumulation of TAGs have been described only for a few bacteria belonging to the actinomycetes group, such as genera of *Streptomyces, Nocardia, Rhodococcus, Mycobacterium, Dietzia* and *Gordonia*, and, to a minor extent, also in a few other bacteria, such as *Acinetobacter baylyi* and *Alcanivorax borkumensis*. Since the mid-1990's, TAG production in hydrocarbon-degrading strains of those genera has been frequently reported. TAGs are stored in spherical lipid bodies as intracellular inclusions, with the amounts depending on the respective species, cultural conditions and growth phase. Commonly, the important factor for the production of TAGs is the amount of nitrogen that is supplied to the culture medium. The excess carbon, which is available to the culture after nitrogen exhaustion, continues to be assimilated by the cells and, by virtue of oleaginous bacteria possessing the requisite enzymes, is converted directly into lipid. The compositions and structures of bacterial TAG molecules vary considerably depending on the bacterium and on the cultural conditions, especially the carbon sources. See, Brigham CJ, *et al.* (2011) J Microbial Biochem Technol S3:002.

[00429] In one embodiment, useful biochemicals can be produced from non-food plant biomass, with a steam or hot-water extraction technique that is carried out by contacting a charge of non-food plant pretreated biomass material such as corn stover or sorghum with water and/or acid (with or without additional process enhancing compounds or materials), in a pressurized vessel at an elevated temperature up to about 160 -220° C. and at a pH below about 7.0, to yield an aqueous (extract solution) mixture of useful saccharides including long-chain saccharides (saccharides), acetic acid, and lignin, while leaving the structural (cellulose and lignin) portion of the lignocellulosic material largely intact. In combination, these potential inhibitory chemicals especially saccharide degradation products are low, and the plant derived nutrients that are naturally occurring lignocellulosic-based components are also recovered that are beneficial to a

C5and C6 fermenting organism. Toward this objective, the aqueous extract is concentrated (by centrifugation, filtration, solvent extraction, flocculation, evaporation), by producing a concentrated saccharide stream, apart from the other hemicellulose (C5 rich) and cellulosic derived saccharides (C6 rich) which are channeled into a fermentable stream.

[00430] In another embodiment, following enzyme/acid hydrolysis or polymeric acid catalyst hydrolysis, additional chemical compounds that are released are recovered with the saccharide stream resulting in a short-chain saccharide solution containing xylose, mannose, arabinose, rhamnose, galactose, and glucose (5 and 6-carbon saccharides). The saccharide stream, now significantly rich in C5 and C6 substances can be converted by microbial fermentation or chemical catalysis into such products as triacylglycerol or TAG and further refined to produce stream rich in JP8 or jet fuels. If C5 saccharide percentage correction has not been performed, it can be performed before fermentation to satisfy desired combination of C5 and C6 saccharides for the fermentation organism and corresponding end product.

[00431] Biofuel plant and process of producing biofuel:

[00432] Generally, there are several basic approaches to producing fuels and chemical end-products from biomass on a large scale utilizing of microbial cells. In the one method, one first pretreats and hydrolyzes a biomass material that includes high molecular weight carbohydrates to lower molecular weight carbohydrates, and then ferments the lower molecular weight carbohydrates utilizing of microbial cells to produce fuel or other products. In the second method, one treats the biomass material itself using mechanical, chemical and/or enzymatic methods. In all methods, depending on the type of biomass and its physical manifestation, one of the processes can comprise a milling of the carbonaceous material, via wet or dry milling, to reduce the material in size and increase the surface to volume ratio (physical modification).

[00433] In one embodiment, hydrolysis can be accomplished using acids, *e.g.*, Bronsted acids (*e.g.*, sulfuric or hydrochloric acid), bases, *e.g.*, sodium hydroxide, hydrothermal processes, ammonia fiber explosion processes ("AFEX"), lime processes, enzymes, or combination of these. Hydrogen, and other end products of the fermentation can be captured and purified if desired, or disposed of, *e.g.*, by burning. For example, the hydrogen gas can be flared, or used as an energy source in the process, *e.g.*, to drive a steam boiler, *e.g.*, by burning. Hydrolysis and/or steam treatment of the biomass can, *e.g.*, increase porosity and/or surface area of the biomass, often leaving the cellulosic materials more exposed to the biocatalyst cells, which can increase fermentation rate and yield. Removal of lignin can, *e.g.*, provide a combustible fuel for driving a boiler, and can also, *e.g.*, increase porosity and/or surface area of the biomass, often increasing fermentation rate and yield. Generally, in any of the these embodiments, the initial concentration

of the carbohydrates in the medium is greater than 20 mM, *e.g.*, greater than 30 mM, 50 mM, 75 mM, 100 mM, 150 mM, 200 mM, or even greater than 500 mM.

[00434] Biomass processing plant and process of producing products from biomass

[00435] In one aspect, a fuel or chemical plant that includes a pretreatment unit to prepare biomass for improved exposure and biopolymer separation, a hydrolysis unit configured to hydrolyze a biomass material that includes a high molecular weight carbohydrate, and one or more product recovery system(s) to isolate a product or products and associated by-products and co-products is provided. In another aspect, methods of purifying lower molecular weight carbohydrate from solid byproducts and/or toxic impurities is provided.

[00436] In another aspect, methods of making a product or products that include combining biocatalyst cells of a microorganism and a biomass feed in a medium wherein the biomass feed contains lower molecular weight carbohydrates and unseparated solids and/or other liquids from pretreatment and hydrolysis, and fermenting the biomass material under conditions and for a time sufficient to produce a biofuel, chemical product or fermentive end-products, *e.g.* ethanol, propanol, hydrogen, succinic acid, lignin, terpenoids, and the like as described above, is provided.

[00437] In another aspect, products made by any of the processes described herein is also provided herein.

[00438] Figure 1 is an example of a method for producing chemical products from biomass by a first mechanical treatment that consists of one or more steps, depending on the condition of the biomass feedstock. In a first step, debris is removed by sifting, sorting, or other means to remove non-carbohydrate containing material. In another step, the feedstock is chopped, shredded, ground or otherwise reduced in size. This process can include dry processing or wet processing. If wet processing occurs, the feedstock can be swollen with steam or hot water and pressure applied to soften or swell the fibers in the material. The material can then be ground to very small size particles. If the feedstock is woody, it is expected that the majority of the processing will be chopping. If a more malleable feedstock is present, grinding, vortexing, or even just hot water and pressure can be all that is necessary. It is expected that the biomass is reduced in size to a fine powder or sludge (if wet) for further processing, if necessary, prior to further pretreatment to produce more accessible cellulose and hemicellulose prior to enzymatic hydrolysis of these polymers.

[00439] Biomass is then treated with an acid at elevated temperature and pressure in a hydrolysis unit. The biomass may first be heated by addition of hot water or steam. The biomass may be

acidified by bubbling gaseous sulfur dioxide through the biomass that is suspended in water, or by adding a strong acid, *e.g.*, sulfuric, hydrochloric, or nitric acid with or without preheating/presteaming/water addition. During the acidification, the pH is maintained at a low level, *e.g.*, below about 5. The temperature and pressure may be elevated after acid addition. In addition to the acid already in the acidification unit, optionally, a metal salt such as ferrous sulfate, ferric sulfate, ferric chloride, aluminum sulfate, aluminum chloride, magnesium sulfate, or mixtures of these can be added to aid in the acid hydrolysis of the biomass. The acid-impregnated biomass is fed into the hydrolysis section of the pretreatment unit. Steam is injected into the hydrolysis portion of the pretreatment unit to directly contact and heat the biomass to the desired temperature. The temperature of the biomass after steam addition is, *e.g.*, between about 130° C and 220° C. The acid hydrolysate is then discharged into the flash tank portion of the pretreatment unit, and is held in the tank for a period of time to further hydrolyze the biomass, *e.g.*, into oligosaccharides and monomeric saccharides. Other methods can also be used to further break down biomass. Alternatively, the biomass can be subject to discharge through a pressure lock for any high-pressure pretreatment process. Hydrolysate is then discharged from the pretreatment reactor, with or without the addition of water, *e.g.*, at solids concentrations between about 10% and 60%.

[00440] After pretreatment, the biomass may be dewatered and/or washed with a quantity of water, *e.g.* by squeezing or by centrifugation, or by filtration using, *e.g.* a countercurrent extractor, wash press, filter press, pressure filter, a screw conveyor extractor, or a vacuum belt extractor to remove acidified fluid. Wash fluids can be collected to concentrate the C5 saccharides in the wash stream. The acidified fluid, with or without further treatment, *e.g.* addition of alkali (*e.g.* lime) and or ammonia (*e.g.* ammonium phosphate), can be re-used, *e.g.*, in the acidification portion of the pretreatment unit, or added to the fermentation, or collected for other use/treatment. Products may be derived from treatment of the acidified fluid, *e.g.*, gypsum or ammonium phosphate. Enzymes or a mixture of enzymes can be added during pretreatment to hydrolyze, *e.g.* endoglucanases, exoglucanases, cellobiohydrolases (CBH), beta-glucosidases, glycoside hydrolases, glycosyltransferases, alphyamylases, chitinases, pectinases, lyases, and esterases active against components of cellulose, hemicelluloses, pectin, and starch, in the hydrolysis of high molecular weight components.

[00441] Figure 2 is an example of a method for producing chemical products from biomass by a first mechanical treatment that consists of one or more steps, depending on the condition of the biomass feedstock. In a first step, debris is removed by sifting, sorting, or other means to remove non-carbohydrate containing material. In another step, the feedstock is chopped,

shredded, ground or otherwise reduced in size. This process can include dry processing or wet processing. If wet processing occurs, the feedstock can be swollen with steam or hot water and pressure applied to soften or swell the fibers in the material. The material can then be ground to very small (less than 1.5 mm diameter or length) uniform size particles. If the feedstock is woody, it is expected that the majority of the processing will be chopping. If a more malleable feedstock is present, grinding, vortexing, or even just hot water and pressure can be all that is necessary. It is expected that the biomass is reduced in size to fine uniform particles (if wet) for further processing, if necessary, prior to further pretreatment to produce more accessible cellulose and hemicellulose prior to polymeric acid hydrolysis of these polymers. It is important that the particles be as uniform as possible, generally 1-1.5 mm in size to ensure uniform contact and temperature and pressure treatment. In this manner, polysaccharides are fully released within a period of time without further disintegration into inhibitors. Further, if polysaccharides are converted to monomers (and/or oligomers), the treatment of these saccharides must be uniform, so that partial hydrolysis does not occur within the hydrolysis timespan.

[00442] Biomass is then combined and mixed by agitation with a polymeric acid catalyst at elevated temperature and pressure in a polymeric hydrolysis unit. The amount of biomass and catalyst is tightly controlled in order to achieve a specific biomass:polymeric acid catalyst ratio, which is dependent on the type of biomass and/or catalyst. The biomass may first be heated by addition of hot water or steam prior to addition of the polymeric acid catalyst. The temperature and pressure may be elevated after catalyst addition. The catalyst-impregnated biomass is fed into the polymeric hydrolysis unit. Steam is injected into the hydrolysis unit to directly contact and heat the biomass to the desired temperature. The temperature of the biomass after steam addition is, *e.g.*, between about 130° C and 220° C. The hydrolysate is then discharged into the flash tank portion of the hydrolysis unit, and is held in the tank for a period of time to further hydrolyze the biomass, *e.g.*, into oligosaccharides and monomeric saccharides. Other methods can also be used to further break down biomass (i.e. enzymatic hydrolysis). Alternatively, the biomass can be subject to discharge through a pressure lock for any high-pressure treatment process. Hydrolysate is then discharged from the polymeric hydrolysis unit, with or without the addition of water, *e.g.*, at solids concentrations between about 10% and 60%.

[00443] After hydrolysis, the biomass can be subjected to differential sedimentation wherein the biomass-polymeric acid catalyst mixture separates into multiple layers, wherein the soluble saccharides can be decanted from the insoluble solids. The insoluble solids can also be layered wherein the polymer acid catalyst forms a layer and the residual biomass forms a separate layer. The polymeric acid catalyst can be re-used in further polymeric hydrolysis reactions. The

residual solid biomass can also be recycled into the polymeric hydrolysis unit, where it can be combined with polymeric acid catalyst and subjected to polymeric hydrolysis as described above. The soluble saccharide streams recovered from polymeric hydrolysis can be further subjected to water recovery and fermentation inhibitors removal (e.g. acetic/formic acid removal) using the humidification-dehumidification apparatus shown in FIG. 3 and described herein. Following inhibitor recovery, the soluble saccharides can be subjected to concentration.

[00444] In an alternative embodiment, the pretreatment process from FIG. 1 and described herein can be combined with the process depicted in FIG. 3, whereby the pretreatment process can be performed upstream of the polymeric hydrolysis unit in FIG. 3. In one embodiment, the pretreatment process can comprise mechanical size reduction and acid hydrolysis. In one embodiment, the pretreatment process from FIG. 1 can produce a soluble saccharide or sugar stream that is rich in C5 monosaccharides and/or disaccharides and residual solid biomass that can be mixed with a polymeric acid catalyst and subjected to polymeric hydrolysis in a polymeric hydrolysis unit as depicted in FIG.3 as described herein.In one embodiment, the polymeric hydrolysis can produce a composition comprising C6 and/or C5 saccharides. In one embodiment, the composition comprising C6 and/or C5 saccharide is soluble. In one embodiment, the soluble composition comprising C6 and/or C5 saccharides can be decanted off of residual biomass and polymer acid catalyst following polymeric hydrolysis. In one embodiment, the composition comprising C6 and/or C5 saccharides can be subjected to water recovery and fermentation inhibitor removal. In one embodiment, the fermentation inhibitor removal can be performed using a humidification-dehumidification process described herein.

[00445] One aspect of this invention is the reduction in size and uniformity of biomass particles, whether a single feedstock or mixed feedstocks are used. Without being limited by theory, it is believed that an unexpected increase in the conversion of the feedstock to fermentable saccharides is achieved if the size of any feedstock fed to the enzyme hydrolysis reactor is small and uniform, as long as sufficient enzyme is present for hydrolysis of the feedstock. If the cellulosic feedstock that is fed to a hot water, acid, or steam explosion reactor is not uniform and cannot be uniformly treated, then a smaller percentage of the available sites of the feedstock are activated and/or hydrolyzed than would be expected. Further, it is difficult to mix larger-sized particles and process a batch of heterogeneous material so that heat and moisture is evenly distributed; thus resulting in an uneven autohydrolysis reaction. Even transfer of heat, chemicals, and moisture results in reduced processing time, less release of inhibitors, and improved release of hemicellulose and cellulose, especially microcrystalline cellulose. If the temperature in parts of the processing feedstock are too high, then some percentage of the

hemicellulose saccharides are degraded to inhibitory compounds. Further, even heat prevents charring of the material that can lead to significant losses in saccharides. This also prevents undercooking which can lead to unhydrolyzed cellulose during enzyme hydrolysis.

[00446] Feedstocks pretreated under any of the conditions described above, which are reduced to a uniform size of less than 50 mm, less than 40 mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, or 1 mm in size (*e.g.*, length, width, height , or diameter), are then hydrolyzed with enzymes to reduce the carbohydrate polymers to disaccharides or monomeric saccharides. In one embodiment, the particle size is reduced wherein approximately all of the particles are 50, 45, 40, 35, 30, 25, 20, 17.5, 15, 12.5, 10, 7.5, 5, 2.5, 2.0, 1.5, 1.4, 1.3, 1.2, 1.1, 1.0, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2 or 0.1 mm in diameter (or length, width, or height). In one embodiment, wherein isolated enzymes are used, the standard addition or "normal load" is 5% (5kg)/per 100 kg of the feedstock solids wherein the solids are at 1-25% w/v. The enzymes can be any combination of cellulases, hemicellulases, amylases, lipases, chitinases, pectinases, pulluninases *etc.*, peroxidase depending on the combination and kind of polymers in the solids mix. In another embodiment of this invention, wherein the particle size of the feedstock is uniformly reduced to a size of less than 50 mm, less than 40 mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, or 1 mm in size (*e.g.*, length, width, height , or diameter), the enzyme addition can be reduced to 20% (1.0 kg per 100 kg solids), 25%(1.25 kg per 100 kg solids), 30%(1.5 kg per 100 kg solids), 35%(1.75 kg per 100 kg solids), 40%(2.0 kg per 100 kg solids), 45%(2.25 kg per 100 kg solids), 50%(2.50 kg per 100 kg solids), 55%(2.75 kg per 100 kg solids), 60%(3.0 kg per 100 kg solids), 65%(3.25 kg per 100 kg solids), 70%(3.5 kg per 100 kg solids), 75%(3.75 kg per 100 kg solids), 80(4.0 kg per 100 kg solids), 85%(4.25 kg per 100 kg solids), or 90% (4.5 kg per 100 kg solids) of a normal load. Preferably, the total enzyme addition is 1% (1 kg) per 100 kg solids for particles less than 1 mm and are consistent in diameter or length. In another embodiment of this invention, wherein the particle size of the feedstock is uniformly reduced to a size of less than 50 mm, less than 40 mm, less than 30 mm, less than 25 mm, less than 20 mm, less than 17.5 mm, less than 15 mm, less than 12.5 mm, less than 10 mm, 7.5 mm, 5 mm, 2.5 mm, 2 mm, 1.5 mm, or 1 mm in size (*e.g.*, length, width, height , or diameter),), the enzyme addition can be reduced to 15% (0.75 kg per 100 kg solids), 10%(0.5 kg per 100 kg solids), 5%(0.25 kg per 100 kg solids), 2%(0.1 kg per 100 kg solids), 1%(0.05 kg per 100 kg solids) of a normal load, 0.5%(0.025 kg per 100 kg solids) of a normal load,

0.25%(0.0125 kg per 100 kg solids), or 0.1%(0.005 kg per 100 kg solids) of a normal load of a normal load.

[00447] The commercial viability of a hydrolysis process is dependent on the character of the feedstock provided to the hydrolysis unit. If such an activated feedstock is provided to an enzymatic hydrolysis unit, then at least 60%, preferably more than 75% and more preferably over 90% of the cellulose and hemicelluloses may be converted to monomeric saccharides. This saccharide rich process stream may subsequently be subjected to fermentation to produce an alcohol stream. The alcohol stream from the fermentation stage (*e.g.*, the raw alcohol stream) may have an alcohol content of about 3-22% v/v, preferably about 5-15% and more preferably more about 8-12%.

[00448] In another embodiment, a combination of isolated enzymes and a microorganism that produces carbohydrate polymerases can be used to hydrolyze the polymers or saccharide polymers in an SSF reaction whereby the microorganism's enzymatic metabolism is supplemented by the addition of enzymes. In one embodiment, the additional enzymes are primarily hemicellulases and the microorganism is able to produce C6 monomeric saccharides or oligomers from polymers by its own endogenous cellulases. An example would be yeasts, *C. thermocellum, or C. beijerinckii*, and the product produced from the saccharides is an alcohol, such as ethanol or butanol. In another embodiment, the microorganism is a C5/C6 hydrolyzing microorganism, such as *C. phytofermentans,* and the microorganism is able to produce C5/C6 monomeric saccharides or oligomers from polymers and oligomers by its own endogenouse hemicellulases and cellulases which can more easily and quickly access the polymers and oligomers of the evenly-treated smaller biomass particles. In a further embodiment, the microorganism is a C5/C6 hydrolyzing microorganism, such as *C. phytofermentans* and the addition of other enzymes speeds up the fermentation process. In any of the above-described processes the additional enzymes can be added prior to microorganism in an SHF process or simultaneously with the microorganism (SSF), or in a "fed-batch" type process wherein the exogenous enzyme is added partially before or through the fermentation process with a microorganism. The reduced particle size can assist such microorganisms in accessibility to the carbohydrate polymers because of the availability of increased surface area and because the crystalline cellulose is less tightly latticed and, available for enzymatic hydrolysis. For these reasons, the exogenous enzyme amount can be reduced as well.

[00449] Examples of such organisms, in addition to those described *supra*, *Clostridium thermohydrosulfuricum, Thermoanaerobacter ethanolicus, Theroanaerobium brockii, T. reesei, Aspergilus sp., Rhizopus sp., Zygmitis sp., Trichosporon cutaneum, R. albus, B. succinogenes, B.*

fibrisolvens, R. flavefaciens, E. cellulosolvens, C. cellobioparum, Chlorella sp., and the like. Also, recombinant cellulolytic or xylanolytic microorganisms have been developed by expressing heterologous cellulases or hemicellulases, such as *S. cerevisiae, Z. mobilis, E. coli, K. marxianus, A. aculeatus, Thermoanaerobacterium saccharolyticum, Pichia stipitis, H. polymorpha, Klebsiella oxytoca, R. opacus,* and the like. Further, there are examples of amylolytic microorganisms that can benefit from the addition of exogenous enzymes to make starch more accessible. In one embodiment, examples of amylolytic yeasts and bacteria are *Saccharomyces castelli, S. diastaticus, Edomycopsis filbuligera, C. thermohydrosulfuricum.*

[00450] In another embodiment, it would be understood by those of skill in the art that the microorganism enzymes are more efficient in such processes as those described *supra* since the small particle size benefits the microorganism's enzyme. The same advantages of uniform small particle size and access to hemicellulose and cellulose fractions would apply to any enzyme, whether enmeshed in a cellulosome or extracellular docking type molecules. The reduced inhibitor fraction and additional available microcrystalline cellulose can reduce lag periods of initial growth.

[00451] A fermenter, attached or at a separate site, can be fed with hydrolyzed biomass, any liquid fraction from biomass pretreatment, an active seed culture of a biocatalyst, such as a yeast, if desired a co-fermenting microbe, *e.g.*, another yeast or *E. coli*, and, if required, nutrients to promote growth of the biocatalyst or other microbes. Alternatively, the pretreated biomass or liquid fraction can be split into multiple fermenters, each containing a different strain of a biocatalyst and/or other microbes, and each operating under specific physical conditions. Fermentation is allowed to proceed for a period of time, *e.g.*, between about 1 and 150 hours, while maintaining a temperature of, *e.g.,* between about 25° C and 50° C. Gas produced during the fermentation is swept from fermentor and is discharged, collected, or flared with or without additional processing, *e.g.* hydrogen gas may be collected and used as a power source or purified as a co-product.

[00452] In another aspect, methods of making a fuel or fuels that include combining one or more biocatalyst and a lignocellulosic material (and/or other biomass material) in a medium, adding a lignin fraction from pretreatment, and fermenting the lignocellulosic material under conditions and for a time sufficient to produce a fuel or fuels, *e.g.*, ethanol, propanol and/or hydrogen or another chemical compound is provided herein.

[00453] In another aspect, the products made by any of the processes described herein is provided.

[00454] **Systems:**

[00455] Any of the methods and/or compositions described herein may be comprised in a system. In a non-limiting example, the system comprises: a pretreatment unit or vessel, a hydration unit, a first and/or second size reduction unit, a hydrolyzation unit, a separation and purification unit, and, optionally, a fermentation unit. One or more of the units can be separate units or different components within a single system. Various combinations of units can be considered for inclusion in a shared housing. In some embodiments, the system comprises a pretreatment vessel wherein the pretreatment vessel comprises a hydration unit, a size reduction unit, a heating unit. The hydration unit can be used for hydration of the biomass composition in a non-neutral pH aqueous medium to produce a hydrated biomass composition as described herein. The size reduction unit can be used for mechanical size reduction of the hydrated biomass composition to produce the solid particles that are homogenous as described herein. The heating unit can be used for heating the hydrated biomass composition for a time sufficient to produce the pretreated biomass composition as described herein. In one embodiment, the system comprises a hydrolysis unit for hydrolyzing the pretreated biomass composition with one or more enzymes for a time sufficient to produce the compositions comprising C6 and C5 saccharides or saccharide polymers as described herein. In one embodiment, the system comprises a hydrolysis unit for hydrolyzing the pretreated biomass composition with one or more polymeric acid catalysts for a time sufficient to produce the compositions comprising C6 and C5 saccharides or saccharide polymers as described herein. In some embodiments, the system can comprise a first and a second hydration unit. In some embodiments, the first and second hydration unit can be the same unit but used at different steps in the pretreatment procedure. In some embodiments, the system comprises a first and second size reduction unit. In some embodiments, the first and second size reduction units are distinct units. In some embodiments, the first and second size reduction units are the same unit. In some embodiments, the system can comprise a humidification-dehumidification unit. The dehumidification unit can be a vapor mixture condenser. In some embodiments, the vapor mixture condenser can be a bubble-column vapor mixture condenser. The humidification-dehumidification unit can be used for removing one or more fermentation inhibitors from the compositions comprising C6 and C5 saccharides or saccharide polymers through evaporation as described herein. In some embodiments, the compositions comprising C6 and C5 saccharides or saccharide polymers produced by the methods described herein can be mixed with a salt such as LiBr before entering or upon entry into the humidification-dehumidification unit.

EXAMPLES

[00456] The following examples serve to illustrate certain embodiments and aspects and are not to be construed as limiting the scope thereof.

[00457] Example 1. Pretreatment of Biomass and Digestion using Polymeric Acid Catalyst

[00458] Biomass comprising cellulose, hemicellulose, and/or lignocellulose is pretreated and hydrolyzed to release soluble C5 and C6 saccharides. The biomass is hydrated in water at 50 °C, for 1-30 min. The hydrated material is cut by rotating blades and dewatered to a solids content of about 25-30% by dry biomass weight. The dewatered solids are simultaneously injected with steam and cut by a second set of rotating blades to produce solid particles less than 1.5 mm in size. The small, homogenous particles are maintained at a temperature of about 160°C to 180°C and a pressure of about 135 PSIG for about 10-30 minutes before explosive pressure release. A C5 monosaccharides and/or disaccharides stream is then separated from the homogenous particles.

[00459] The homogenous particles are then further hydrolyzed by solid:solid hydrolysis using a polymeric acid catalyst to release a second stream of saccharides comprising C6 and C5 saccharides. For polymeric acid catalyst based hydrolysis, the solids from the pretreatment are placed through a filter press wash to remove soluble monomeric glucose and xylose produced from the pretreatment. Following the filter press wash, the solids are adjusted to a solids content of 30% (w/w) in water and mixed by agitation with a polymeric acid catalyst as described herein. The polymeric acid catalyst is added and mixed with the solids in a 1:1 ratio and the ratio of liquids to solids is adjusted to be in the region of 2:1. Adjustment of the liquid to solids ratio is achieved using a worm press, which also serves to remove almost 100% of the air. The polymeric acid catalyst:solids mixture is heated at a temperature of about 160°C to 170°C and a pressure of about 135 -260 PSIG for about 0.5 to 5 minutes to produce the second stream of saccharides comprising C6 and C5 saccharides. The second stream is separated from the residual biomass and polymeric acid catalyst using differential sedimentation followed by decanting the saccharide stream comprising C6 and C5 saccharides.

[00460] Example 2. Separation of Acetic Acid from Saccharide Streams

[00461] A saccharide stream comprising C6 and C5 saccharides is produced as shown in example 1. As shown in FIG. 3, the saccharide stream is introduced via spray nozzles **1** into the humidification chamber **2**, which is filled with a packing material **3** that increases both the liquid surface area and the turbulence and mixing of the carrier gas in order to increase evaporation rates. The liquid collected in the bottom of the chamber can either be removed from the system

4 or retained in the system via a recycling loop **5** via a pump. The humidified gas, with elevated acetic acid concentrations, is compressed **6** and conveyed to the dehumidification chamber **7**. Recycled or fresh sugar solution **8** is passed through the dehumidification chamber to recapture heat as liquid is condensed from the carrier gas. The acetic acid is captured in the condensate **9** and are removed from the system. The carrier gas is then routed through an expander **10** to reduce the pressure prior to reintroduction to the humidification chamber. The sugar solution is passed through a heating system **11** prior to the introduction into the humidification chamber. Following the removal of acetic acid, the saccharide stream is collected.

[00462] While preferred embodiments of the present invention have been shown and described herein, it will be obvious to those skilled in the art that such embodiments are provided by way of example only. Numerous variations, changes, and substitutions will now occur to those skilled in the art without departing from the invention. It should be understood that various alternatives to the embodiments of the invention described herein may be employed in practicing the invention. It is intended that the following claims define the scope of the invention and that methods and structures within the scope of these claims and their equivalents be covered thereby.

CLAIMS

WHAT IS CLAIMED IS:

1. A humidification:dehumidification process for removing one or more inhibitors from a saccharide stream, the process comprising:
    (a) contacting in a counter-current manner the saccharide stream with a carrier gas at a first temperature and a first pressure to produce a humidified gas, wherein at least a portion of the one or more inhibitors is transferred from the saccharide stream to the humidified gas;
    (b) separating the humidified gas from the saccharide stream;
    (c) dehumidifying the humidified gas at a second temperature and a second pressure to condense the one or more fermentation inhibitors; and
    (d) recovering the saccharide stream, wherein the saccharide stream comprises a lower level of the one or more inhibitors.
2. The process of claim 1, wherein the one or more inhibitors comprise acetic acid, formic acid, furfural, hydrozymethylfurfural, sulfuric acid, peroxyacetic acid, lactic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, or a combination thereof.
3. The process of any one of claims 1-2, wherein the one or more inhibitors comprise acetic acid.
4. The process of any one of claims 1-3, wherein the one or more inhibitors comprise formic acid.
5. The process of any one of claims 1-4, wherein the one or more inhibitors comprise acetic acid and formic acid.
6. The process of any one of claims 1-5, wherein the carrier gas comprises air, nitrogen, argon, carbon dioxide, or a combination thereof.
7. The process of any one of claims 1-6, wherein the carrier gas is air.
8. The process of any one of claims 1-6, wherein the carrier gas is nitrogen.
9. The process of any one of claims 1-8, wherein the first temperature is at least about 4°C lower than the second temperature.
10. The process of any one of claims 1-9, wherein the first temperature is at least about 10°C lower than the second temperature.
11. The process of any one of claims 1-10, wherein the first temperature is about 4°C to about 90°C lower than the second temperature.

12. The process of any one of claims 1-11, wherein the first temperature is about 10°C to about 70°C lower than the second temperature.
13. The process of any one of claims 1-12, wherein the first temperature is about 15°C to about 50°C lower than the second temperature.
14. The process of any one of claims 1-13, wherein the first temperature is about 4°C to about 100°C.
15. The process of any one of claims 1-14, wherein the first temperature is about 10°C to about 70°C.
16. The process of any one of claims 1-15, wherein the first temperature is about 15°C to about 50°C.
17. The process of any one of claims 1-16, wherein the second pressure is at least about 1.1 times higher than the first pressure.
18. The process of any one of claims 1-17, wherein the second pressure is at least about 1.5 times higher than the first pressure.
19. The process of any one of claims 1-18, wherein the second pressure is at least about 2.0 times higher than the first pressure.
20. The process of any one of claims 1-19, wherein the first pressure is about 10 kPa to about 100 kPa.
21. The process of any one of claims 1-20, wherein the first pressure is about 20 kPa to about 60 kPa.
22. The process of any one of claims 1-21, wherein, after recovering the saccharide stream, the process is repeated one or more additional times with the recovered saccharide stream.
23. The process of any one of claims 1-22, wherein the process further comprises dissolving a salt in the saccharide stream prior to contacting.
24. The process of claim 23, wherein the salt comprises LiBr, NaCl, KCl, or a combination thereof.
25. The process of claim 23, wherein the salt comprises LiBr.
26. The process of any one of claims 23-25, wherein the process further comprises, after recovering the saccharide stream, separating the salt from the saccharide stream.
27. The process of claim 26, wherein separating the salt from the saccharide stream comprises filtration.
28. The process of any one of claims 1-27, wherein at least about 10% of the one or more inhibitors is removed from the saccharide stream.

29. The process of any one of claims 1-28, wherein at least about 25% of the one or more inhibitors is removed from the saccharide stream.
30. The process of any one of claims 1-29, wherein at least about 50% of the one or more inhibitors is removed from the saccharide stream.
31. The process of any one of claims 1-30, wherein at least about 75% of the one or more inhibitors is removed from the saccharide stream.
32. The process of any one of claims 1-31, wherein contacting is performed in a humidification chamber.
33. The process of claim 32, wherein the humidification chamber comprises packing material.
34. The process of claim 33, wherein the packing material comprises polyvinyl chloride packing.
35. The process of any one of claims 32-34, wherein the saccharide stream is introduced into a top portion of the humidifying chamber.
36. The process of any one of claims 32-35, wherein the first temperature is an average temperature in the humidifying chamber.
37. The process of any one of claims 32-36, wherein the carrier gas is introduced into a bottom portion of the humidification chamber.
38. The process of any one of claims 1-37, wherein contacting comprises spraying the saccharide stream with a spray nozzle.
39. The process of any one of claims 1-38, wherein dehumidifying occurs in a dehumidifying chamber.
40. The process of claim 39, wherein the second temperature is an average temperature in the dehumidifying chamber.
41. The process of any one of claims 32-**Error! Reference source not found.**, wherein a compressor is used to transfer the humidified gas from the humidifying chamber to the dehumidifying chamber.
42. The process of any one of claims 32-41, wherein an expander is used to transfer the carrier gas from the dehumidifying chamber to the humidifying chamber after the one or more fermentation inhibitors are condensed out of the humidified gas.
43. The process of any one of claims 32-42, wherein the saccharide stream is piped through the dehumidifying chamber to effect a heat transfer from the humidified gas to the saccharide stream.

44. The process of any one of claims 32-43, wherein a heater is used to increase the temperature of the saccharide stream before contacting with the carrier gas.
45. The process of any one of claims 1-45, wherein the saccharide stream comprises C5 saccharides, C6 saccharides, or a combination thereof.
46. The process of claim 45, wherein the C5 saccharides comprise xylose, arabinose, or a combination thereof.
47. The process of claim 45 or 46, wherein the C6 sugars comprise glucose, mannose, galactose, rhamnose, or a combination thereof.
48. The process of any one of claims 1-47, wherein the saccharide stream comprises glucose, mannose, galactose, rhamnose, xylose, arabinose, or a combination thereof.
49. The process of any one of claims 1-48, wherein the saccharide stream was produced by pretreating or hydrolyzing a biomass composition comprising cellulose, hemicellulose, or lignocellulose.
50. The process of claim 49, wherein the biomass composition comprises alfalfa, algae, bagasse, bamboo, corn stover, corn cobs, corn kernels, corn mash, corn steep liquor, corn steep solids, distiller's grains, distiller's dried solubles, distiller's dried grains, condensed distiller's solubles, distiller's wet grains, distiller's dried grains with solubles, eucalyptus, food waste, fruit peels, garden residue, grass, grain hulls, modified crop plants, municipal waste, oat hulls, paper, paper pulp, prairie bluestem, poplar, rice hulls, seed hulls, silage, sorghum, straw, sugarcane, switchgrass, wheat, wheat straw, wheat bran, de-starched wheat bran, willows, wood, plant cells, plant tissue cultures, or a combination thereof.
51. The process of any one of claims 49-50, wherein pretreating or hydrolyzing comprises mechanical size reduction, hot water treatment, acid treatment, base treatment, steam explosion, acid-catalyzed steam explosion, ammonia fiber/freeze explosion, enzymatic hydrolysis, catalytic peptide hydrolysis, ionic liquid dissolution, or a combination thereof.
52. The process of any one of claims 49-50, wherein pretreating or hydrolyzing comprises mechanical size reduction, acid treatment, and hydrolysis with one or more enzymes or one or more polymeric catalysts.
53. The process of any one of claims 49-50, wherein pretreating or hydrolyzing comprises treating the biomass composition with hot water or dilute acid to solubilize hemicellulose, substantially separating the solubilized hemicellulose from remaining lignocellulose solids, and hydrolysis of the remaining lignocellulose solids with one or more enzymes or polymeric catalysts.

54. The process of any one of claims 49-50, wherein pretreating or hydrolyzing comprises ionic liquid dissolution with [bmim] 1-butyl-3-methylimidazolium, [emim] 1-ethyl-3-methylimidazolium, [amim] 1-allyl-3-methylimidazolium, [Ch] cholinium, [bzmim] 1-benzyl-3-methylimidazolium, [HEA] 2- hydroxyethylammonium, [bmpy] 1-butyl-3-methylpyridinium, [Me(OEt)3Et3N] triethyl-(2-(2-methoxyethoxy)ethoxy) ethylammonium, [DMEA] N,N-dimethylethanolammonium, [mmim] 1,3-dimethylimidazolium, [hmim] 1-hexyl-3-methylimidazolium, [pmim] 1-propyl-3-methylimidazolium, [abim] 1-allyl-3-butylimidazolium, [eMeOHpy] 1-ethyl-3-(hydroxymethyl)pyridine, [bHim] 1-butylimidazolium, [Cl] chloride, [CH3COO] acetate, [Et2PO4] diethylphosphate, [Me2PO4] dimethylphosphate, [MeOSO3] methylsulphate, [OTf] trifluoromethanesulphonate, [PrOO] propionate, [CF3COO] trifluoroacetate, [MeSO3] methanesulphonate, [HSO4] hydrogen sulphate, [PO(O)H2] phosphinate, [HCOO] formate, [BF4] tetrafluoroborate, [PF6] hexafluorophosphate, [Lys] lysinate, [Gly] glycinate, [Ala] alaninate, [Ser] serinate, [Thr] threoninate, [Met] methioninate, [Pro] prolinate, [Phe] phenylalaninate, [OHCH2COO] glycolate, [(CH2COO)2] succinate, [ABS] alkylbenzenesulphonate, [XS] xylenesulphonate, [MePO3] methylphosphonate, [EtPO3] ethylphosphonate, [i-PrPO3] i-propylphosphonate, [BuPO3] butylphosphonate, [NTf2] bis(trifluoromethylsulfonyl)amide, [EtOSO3] ethylsulphate , or a combination thereof.

55. A saccharide stream produced by the process of any one of claims 1-54.

56. A humidification:dehumidification system for removing one or more inhibitors from a saccharide stream, the system comprising:

    (a) a saccharide stream comprising one or more inhibitors;

    (b) a carrier gas;

    (c) a humidification chamber containing packing material for contacting in a counter-current manner the saccharide stream with the carrier gas to produce a humidified gas, wherein at least a portion of the one or more inhibitors is transferred from the saccharide stream to the humidified gas; and

    (d) a dehumidification chamber at a second temperature and pressure for condensing the one or more fermentation inhibitors from the humidified gas.

57. The system of claim 56, wherein the one or more inhibitors comprise acetic acid, formic acid, furfural, hydrozymethylfurfural, sulfuric acid, peroxyacetic acid, lactic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic

acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, or a combination thereof.

58. The system of any one of claims 56-57, wherein the one or more inhibitors comprise acetic acid.
59. The system of any one of claims 56-58, wherein the one or more inhibitors comprise formic acid.
60. The system of any one of claims 56-59, wherein the one or more inhibitors comprise acetic acid and formic acid.
61. The system of any one of claims 56-60, wherein the carrier gas comprises air, nitrogen, argon, carbon dioxide, or a combination thereof.
62. The system of any one of claims 56-61, wherein the carrier gas is air.
63. The system of any one of claims 56-61, wherein the carrier gas is nitrogen.
64. The system of any one of claims 56-63, wherein the first temperature is at least about 4°C lower than the second temperature.
65. The system of any one of claims 56-64, wherein the first temperature is at least about 10°C lower than the second temperature.
66. The system of any one of claims 56-65, wherein the first temperature is about 4°C to about 90°C lower than the second temperature.
67. The system of any one of claims 56-66, wherein the first temperature is about 10°C to about 70°C lower than the second temperature.
68. The system of any one of claims 56-67, wherein the first temperature is about 15°C to about 50°C lower than the second temperature.
69. The system of any one of claims 56-68, wherein the first temperature is about 4°C to about 100°C.
70. The system of any one of claims 56-69, wherein the first temperature is about 10°C to about 70°C.
71. The system of any one of claims 56-70, wherein the first temperature is about 15°C to about 50°C.
72. The system of any one of claims 56-71, wherein the second pressure is at least about 1.1 times higher than the first pressure.
73. The system of any one of claims 56-72, wherein the second pressure is at least about 1.5 times higher than the first pressure.
74. The system of any one of claims 56-73, wherein the second pressure is at least about 2.0 times higher than the first pressure.

75. The system of any one of claims 56-74, wherein the first pressure is about 10 kPa to about 100 kPa.
76. The system of any one of claims 56-75, wherein the first pressure is about 20 kPa to about 60 kPa.
77. The system of any one of claims 56-76, wherein the system further comprises a salt dissolved in the saccharide stream prior to contacting.
78. The system of claim 77, wherein the salt comprises LiBr, NaCl, KCl, or a combination thereof.
79. The system of claim 77, wherein the salt comprises LiBr.
80. The system of any one of claims 56-79, wherein at least about 10% of the one or more inhibitors is removed from the saccharide stream.
81. The system of any one of claims 56-80, wherein at least about 25% of the one or more inhibitors is removed from the saccharide stream.
82. The system of any one of claims 56-81, wherein at least about 50% of the one or more inhibitors is removed from the saccharide stream.
83. The system of any one of claims 56-82, wherein at least about 75% of the one or more inhibitors is removed from the saccharide stream.
84. The system of any one of claims 56-83, wherein the packing material comprises polyvinyl chloride packing.
85. The system of any one of claims 56-84, wherein the saccharide stream is introduced into a top portion of the humidifying chamber.
86. The system of any one of claims 56-85, wherein the first temperature is an average temperature in the humidifying chamber.
87. The system of any one of claims 56-86, wherein the carrier gas is introduced into a bottom portion of the humidification chamber.
88. The system of any one of claims 56-87, wherein contacting comprises spraying the saccharide stream with a spray nozzle.
89. The system of any one of claims 56-88, wherein the second temperature is an average temperature in the dehumidifying chamber.
90. The system of any one of claims 56-89, wherein the system further comprises a compressor to transfer the humidified gas from the humidifying chamber to the dehumidifying chamber.
91. The system of any one of claims 56-90, wherein the system further comprises an expander to transfer the carrier gas from the dehumidifying chamber to the humidifying

chamber after the one or more fermentation inhibitors are condensed out of the humidified gas.

92. The system of any one of claims 56-91, wherein the saccharide stream is piped through the dehumidifying chamber to effect a heat transfer from the humidified gas to the saccharide stream.
93. The system of any one of claims 56-92, wherein the system further comprises a heater to increase the temperature of the saccharide stream before contacting with the carrier gas.
94. The system of any one of claims 56-93, wherein the saccharide stream comprises C5 saccharides, C6 saccharides, or a combination thereof.
95. The system of claim 94, wherein the C5 saccharides comprise xylose, arabinose, or a combination thereof.
96. The system of claim 94 or 95, wherein the C6 sugars comprise glucose, mannose, galactose, rhamnose, or a combination thereof.
97. The system of any one of claims 94-96, wherein the saccharide stream comprises glucose, mannose, galactose, rhamnose, xylose, arabinose, or a combination thereof.
98. The system of any one of claims 94-97, wherein the saccharide stream was produced by pretreating or hydrolyzing a biomass composition comprising cellulose, hemicellulose, or lignocellulose.
99. The system of claim 98, wherein the biomass composition comprises alfalfa, algae, bagasse, bamboo, corn stover, corn cobs, corn kernels, corn mash, corn steep liquor, corn steep solids, distiller's grains, distiller's dried solubles, distiller's dried grains, condensed distiller's solubles, distiller's wet grains, distiller's dried grains with solubles, eucalyptus, food waste, fruit peels, garden residue, grass, grain hulls, modified crop plants, municipal waste, oat hulls, paper, paper pulp, prairie bluestem, poplar, rice hulls, seed hulls, silage, sorghum, straw, sugarcane, switchgrass, wheat, wheat straw, wheat bran, de-starched wheat bran, willows, wood, plant cells, plant tissue cultures, or a combination thereof.
100. The system of any one of claims 98-99, wherein pretreating or hydrolyzing comprises mechanical size reduction, hot water treatment, acid treatment, base treatment, steam explosion, acid-catalyzed steam explosion, ammonia fiber/freeze explosion, enzymatic hydrolysis, catalytic peptide hydrolysis, ionic liquid dissolution, or a combination thereof.
101. The system of any one of claims 98-99, wherein pretreating or hydrolyzing comprises mechanical size reduction, acid treatment, and hydrolysis with one or more enzymes or one or more polymeric catalysts.

102. The system of any one of claims 98-99, wherein pretreating or hydrolyzing comprises treating the biomass composition with hot water or dilute acid to solubilize hemicellulose, substantially separating the solubilized hemicellulose from remaining lignocellulose solids, and hydrolysis of the remaining lignocellulose solids with one or more enzymes or polymeric catalysts.

103. The system of any one of claims 98-99, wherein pretreating or hydrolyzing comprises ionic liquid dissolution with [bmim] 1-butyl-3-methylimidazolium, [emim] 1-ethyl-3-methylimidazolium, [amim] 1-allyl-3-methylimidazolium, [Ch] cholinium, [bzmim] 1-benzyl-3-methylimidazolium, [HEA] 2- hydroxyethylammonium, [bmpy] 1-butyl-3-methylpyridinium, [Me(OEt)3Et3N] triethyl-(2-(2-methoxyethoxy)ethoxy) ethylammonium, [DMEA] N,N-dimethylethanolammonium, [mmim] 1,3-dimethylimidazolium, [hmim] 1-hexyl-3-methylimidazolium, [pmim] 1-propyl-3-methylimidazolium, [abim] 1-allyl-3-butylimidazolium, [eMeOHpy] 1-ethyl-3-(hydroxymethyl)pyridine, [bHim] 1-butylimidazolium, [Cl] chloride, [CH3COO] acetate, [Et2PO4] diethylphosphate, [Me2PO4] dimethylphosphate, [MeOSO3] methylsulphate, [OTf] trifluoromethanesulphonate, [PrOO] propionate, [CF3COO] trifluoroacetate, [MeSO3] methanesulphonate, [HSO4] hydrogen sulphate, [PO(O)H2] phosphinate, [HCOO] formate, [BF4] tetrafluoroborate, [PF6] hexafluorophosphate, [Lys] lysinate, [Gly] glycinate, [Ala] alaninate, [Ser] serinate, [Thr] threoninate, [Met] methioninate, [Pro] prolinate, [Phe] phenylalaninate, [OHCH2COO] glycolate, [(CH2COO)2] succinate, [ABS] alkylbenzenesulphonate, [XS] xylenesulphonate, [MePO3] methylphosphonate, [EtPO3] ethylphosphonate, [i-PrPO3] i-propylphosphonate, [BuPO3] butylphosphonate, [NTf2] bis(trifluoromethylsulfonyl)amide, [EtOSO3] ethylsulphate , or a combination thereof.

104. A method of producing a saccharide stream from a biomass composition comprising cellulose, hemicellulose, or lignocellulose, the method comprising:

(a) hydrating the biomass composition in an aqueous medium;

(b) mechanical size reduction of the biomass composition to produce a mixture of solid particles, wherein at least 50% of the solid particles are less than 1.5 mm in a dimension;

(c) heating the biomass composition; and

(d) hydrolyzing the biomass composition with one or more polymeric catalysts to produce a saccharide stream.

105. The method of claim 104, wherein the one or more polymeric catalysts are, individually, a polymer comprising acidic monomers and ionic monomers connected to form a polymeric backbone.

106. The method of claim 105, wherein each acidic monomer comprises, individually, at least one Bronsted-Lowry acid.

107. The method of claim 106, wherein the Bronsted-Lowry acid at each occurrence is independently selected from the group consisting of sulfonic acid, phosphonic acid, acetic acid, isophthalic acid, boronic acid, and perfluorinated acid.

108. The method of any one of claims 106-107, wherein one or more of the Bronsted-Lowry acids are directly connected to the polymeric backbone.

109. The method of any one of claims 106-108, wherein one or more of the acidic monomers further comprise a linker connecting the Bronsted-Lowry acid to the polymeric backbone.

110. The method of claim 109, wherein the linker at each occurrence is independently selected from the group consisting of unsubstituted or substituted alkylene, unsubstituted or substituted cycloalkylene, unsubstituted or substituted alkenylene, unsubstituted or substituted arylene, unsubstituted or substituted heteroarylene, unsubstituted or substituted alkylene ether, unsubstituted or substituted alkylene ester, and unsubstituted or substituted alkylene carbamate.

111. The method of any one of claims 105-110, wherein each ionic monomer comprises, individually, at least one nitrogen containing cationic group or phosphorous-containing cationic group.

112. The method of claim 111, wherein the nitrogen-containing cationic group at each occurrence is independently selected from the group consisting of pyrrolium, imidazolium, pyrazolium, oxazolium, thiazolium, pyridinium, pyrimidinium, pyrazinium, pyradizimium, thiazinium, morpholinium, piperidinium, piperizinium, and pyrollizinium.

113. The method of claim 111 or 112, wherein the phosphorous-containing cationic group at each occurrence is independently selected from the group consisting of triphenyl phosphonium, trimethyl phosphonium, triethyl phosphonium, tripropyl phosphonium, tributyl phosphonium, trichloro phosphonium, and trifluoro phosphonium.

114. The method of any one of claims 111-113, wherein one or more of the ionic monomers are directly connected to form the polymeric backbone.

115. The method of any one of claims 111-114, wherein one or more of the ionic monomers each further comprise a linker connecting the nitrogen-containing cationic group or the phosphorous-containing cationic group to the polymeric backbone.

116. The method of claim 115, wherein the linker at each occurrence is independently selected from the group consisting of unsubstituted or substituted alkylene, unsubstituted or substituted cycloalkylene, unsubstituted or substituted alkenylene, unsubstituted or substituted arylene, unsubstituted or substituted heteroarylene, unsubstituted or substituted alkylene ether, unsubstituted or substituted alkylene ester, and unsubstituted or substituted alkylene carbamate.

117. The method of any one of claims 105-116, wherein the polymeric backbone is selected from the group consisting of polyethylene, polypropylene, polyvinyl alcohol, polystyrene, polyurethane, polyvinyl chloride, polyphenol-aldehyde, polytetrafluoroethylene, polybutylene terephthalate, polycaprolactam, poly(acrylonitrile butadiene styrene), polyalkyleneammonium, polyalkylenediammonium, polyalkylenepyrrolium, polyalkyleneimidazolium, polyalkylenepyrazolium, polyalkyleneoxazolium, polyalkylenethiazolium, polyalkylenepyridinium, polyalkylenepyrimidinium, polyalkylenepyrazinium, polyalkylenepyradizimium, polyalkylenethiazinium, polyalkylenemorpholinium, polyalkylenepiperidinium, polyalkylenepiperizinium, polyalkylenepyrollizinium, polyalkylenetriphenylphosphonium, polyalkylenetrimethylphosphonium, polyalkylenetriethylphosphonium, polyalkylenetripropylphosphonium, polyalkylenetributylphosphonium, polyalkylenetrichlorophosphonium, polyalkylenetrifluorophosphonium, and polyalkylenediazolium.

118. The method of any one of claims 105-117, wherein the polymer is cross-linked.

119. The method of any one of claims 105-118, wherein the polymer further comprises hydrophobic monomers connected to form the polymeric backbone.

120. The method of claim 119, wherein each hydrophobic monomer comprises a hydrophobic group, wherein the hydrophobic group at each occurrence is independently selected from an unsubstituted or substituted alkyl, an unsubstituted or substituted cycloalkyl, an unsubstituted or substituted aryl, or an unsubstituted or substituted heteroaryl.

121. The method of any one of claims 105-120, wherein the one or more polymeric catalysts further comprise acidic-ionic monomers connected to form the polymeric

backbone, wherein each acidic-ionic monomer comprises a Bronsted-Lowry acid and a cationic group.

122. The method of any one of claims 105-121, wherein the polymeric catalyst has a total amount of Bronsted-Lowry acid of between 0.1 and 20 mmol per gram of polymer.

123. The method of any one of claims 105-122, wherein the polymeric catalyst is coated on a solid core.

124. The method of claim 123, wherein the solid core comprises an inert material or a magnetic material.

125. The method of any one of claims 123-124, wherein the solid core is iron.

126. The method of any one of claims 123-125, wherein the solid core is non-porous.

127. The method of any one of claims 104-126, wherein the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 3 : 1 to 1 : 3 polymer catalyst : biomass composition by dry weight.

128. The method of any one of claims 104-127, wherein the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 2 : 1 to 1 : 2 polymer catalyst : biomass composition by dry weight.

129. The method of any one of claims 104-128, wherein the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 1.5 : 1 to 1 : 1.5 polymer catalyst : biomass composition by dry weight.

130. The method of any one of claims 104-129, wherein the one or more polymer catalysts and the biomass composition are admixed in a ratio of about 1:1 polymer catalyst : biomass composition by dry weight.

131. The method of any one of claims 104-130, wherein hydrolyzing is performed at a temperature of about 75°C-200°C.

132. The method of any one of claims 104-131, wherein hydrolyzing is performed at a temperature of about 100°C-175°C.

133. The method of any one of claims 104-132, wherein hydrolyzing is performed at a temperature of about 120°C-150°C.

134. The method of any one of claims 104-133, wherein hydrolyzing is performed at a pressure of about 100 PSIG to about 150 PSIG.

135. The method of any one of claims 104-134, wherein hydrolyzing is performed for a time of about 0.5 minutes to about 24 hours.

136. The method of any one of claims 104-135, wherein hydrolyzing is performed for a time of about 0.5 minutes to about 12 hours.

137. The method of any one of claims 104-136, wherein hydrolyzing is performed for a time of about 0.5 minutes to about 4 hours.

138. The method of any one of claims 104-137, wherein hydrolyzing is performed for a time of about 0.5 minutes to about 1 hour.

139. The method of any one of claims 104-138, wherein hydrolyzing is performed for a time of about 0.5 minutes to about 30 minutes.

140. The method of any one of claims 104-139, wherein hydrolyzing is performed for a time of about 0.5 minutes to about 5 minutes.

141. The method of any one of claims 104-140, wherein the method further comprises (e) recovering the one or more polymeric catalysts from the saccharide stream and residual biomass.

142. The method of claim 141, wherein recovering the one or more polymeric catalysts comprises the use of a cyclone press, worm press, filter press, mechanical press, a centrifuge press, or a gravity press.

143. The method of any one of claims 141-142, wherein recovering the one or more polymeric catalysts comprises differential sedimentation, wherein the residual biomass and the polymeric catalyst sediment into one or more separate phases from the saccharide stream.

144. The method of any one of claims 104-143, wherein at least 50% of the mixture of solid particles in the pretreated biomass composition are from about 0.1 mm to about 1 mm in a dimension.

145. The method of any one of claims 104-144, wherein all of the solid particles in the pretreated biomass are less than 7.5 mm in a dimension.

146. The method of any one of claims 104-145, wherein all of the solid particles in the pretreated biomass are less than 1 mm in a dimension.

147. The method of any one of claims 104-146, wherein the dimension is diameter, length, or width.

148. The method of any one of claims 104-147, wherein heating the biomass composition solubilizes at least 50% of the hemicellulose in the biomass composition.

149. The method of any one of claims 104-148, wherein heating the biomass composition solubilizes at least 75% of the hemicellulose in the biomass composition.

150. The method of any one of claims 104-149, wherein heating the biomass composition solubilizes at least 95% of the hemicellulose in the biomass composition.

151. The method of any one of claims 148-150, wherein the hemicellulose is solubilized as polysaccharides.

152. The method of any one of claims 148-150, wherein the hemicellulose is solubilized as monosaccharides, disaccharides, or a combination thereof.

153. The method of any one of claims 104-152, wherein heating the biomass composition produces a yield of glucose that is less than about 20% of a theoretical maximum.

154. The method of any one of claims 104-153, wherein hydrating the biomass composition produces a hydrated biomass composition comprising about 1% to about 20% solids by dry biomass weight.

155. The method of any one of claims 104-154, wherein the aqueous medium is at a temperature of about 30° C to about 70° C.

156. The method of any one of claims 104-155, wherein the aqueous medium comprises an acid.

157. The method of claim 156, wherein the acid is at from about 0.1% to about 5% v/w by dry biomass weight in the aqueous medium.

158. The method of any one of claims 156-157, wherein the acid comprises sulfuric acid, peroxyacetic acid, lactic acid, formic acid, acetic acid, citric acid, phosphoric acid, hydrochloric acid, sulfurous acid, chloroacetic acid, dichloroacetic acid, trichloroacetic acid, trifluoroacetic acid, oxalic acid, benzoic acid, or a combination thereof.

159. The method of any one of claims 104-158, wherein mechanical size reduction comprises cutting, steam explosion, acid-catalyzed steam explosion, or a combination thereof.

160. The method of any one of claims 104-159, wherein heating the biomass composition is at a temperature of from about 100° C to about 250° C.

161. The method of any one of claims 104-160, wherein heating the biomass composition is performed at a pressure of from about 100 PSIG to about 150 PSIG.

162. The method of any one of claims 104-161, wherein heating the biomass composition is performed for about 1 minute to about 30 minutes.

163. The method of any one of claims 104-162, wherein mechanical size reduction follows hydrating the biomass composition.

164. The method of any one of claims 104-163, wherein heating follows mechanical size reduction of the biomass composition.

165. The method of any one of claims 104-164, wherein hydrolyzing the biomass composition with one or more polymeric catalysts follows heating.

166. The method of any one of claims 104-164, wherein hydrolyzing the biomass composition with one or more polymeric catalysts occurs during heating.

167. The method of any one of claims 104-166, wherein the method further comprises dewatering the biomass composition to from about 10% to about 40% solids by dry biomass weight prior to heating.

168. The method of any one of claims 104-167, wherein heating comprises steam injection, steam explosion, acid-catalyzed steam explosion, or a combination thereof.

169. The method of any one of claims 104-168, wherein the method is performed in a continuous mode of operation.

170. The method of any one of claims 104-169, wherein the method further comprises hydrolyzing the biomass composition with one or more enzymes.

171. The method of claim 170, wherein the one or more enzymes comprise one or more hemicellulases, one or more cellulases, or a combination thereof.

172. The method of any one of claims 104-171, wherein the method further comprises adjusting the water content of the biomass composition to from about 5% to about 30% solids by dry biomass weight prior to hydrolyzing.

173. The method of any one of claims 104-172, wherein the saccharide stream comprises C5 saccharides, C6 saccharides, or a combination thereof.

174. The method of any one of claims 104-173, wherein the saccharide stream comprises glucose, xylose, mannose, galactose, rhamnose, arabinose, or a combination thereof.

175. The method of any one of claims 104-174, wherein the biomass composition comprises alfalfa, algae, bagasse, bamboo, corn stover, corn cobs, corn kernels, corn mash, corn steep liquor, corn steep solids, distiller's grains, distiller's dried solubles, distiller's dried grains, condensed distiller's solubles, distiller's wet grains, distiller's dried grains with solubles, eucalyptus, food waste, fruit peels, garden residue, grass, grain hulls, modified crop plants, municipal waste, oat hulls, paper, paper pulp, prairie bluestem, poplar, rice hulls, seed hulls, silage, sorghum, straw, sugarcane, switchgrass, wheat, wheat straw, wheat bran, de-starched wheat bran, willows, wood, plant cells, plant tissue cultures, tissue cultures, or a combination thereof.

176. The method of any one of claims 104-175, wherein mechanical size reduction does not comprise milling.

177. The method of any one of claims 104-176, wherein the saccharide stream comprises one or more inhibitors.

178. The method of claim 177, wherein the method further comprises removing at least a portion of the one or more inhibitors using the humidification:dehumidification process of any one of claims 1-54.

179. A saccharide stream produced by the method of any one of claims 104-178.

FIG. 1

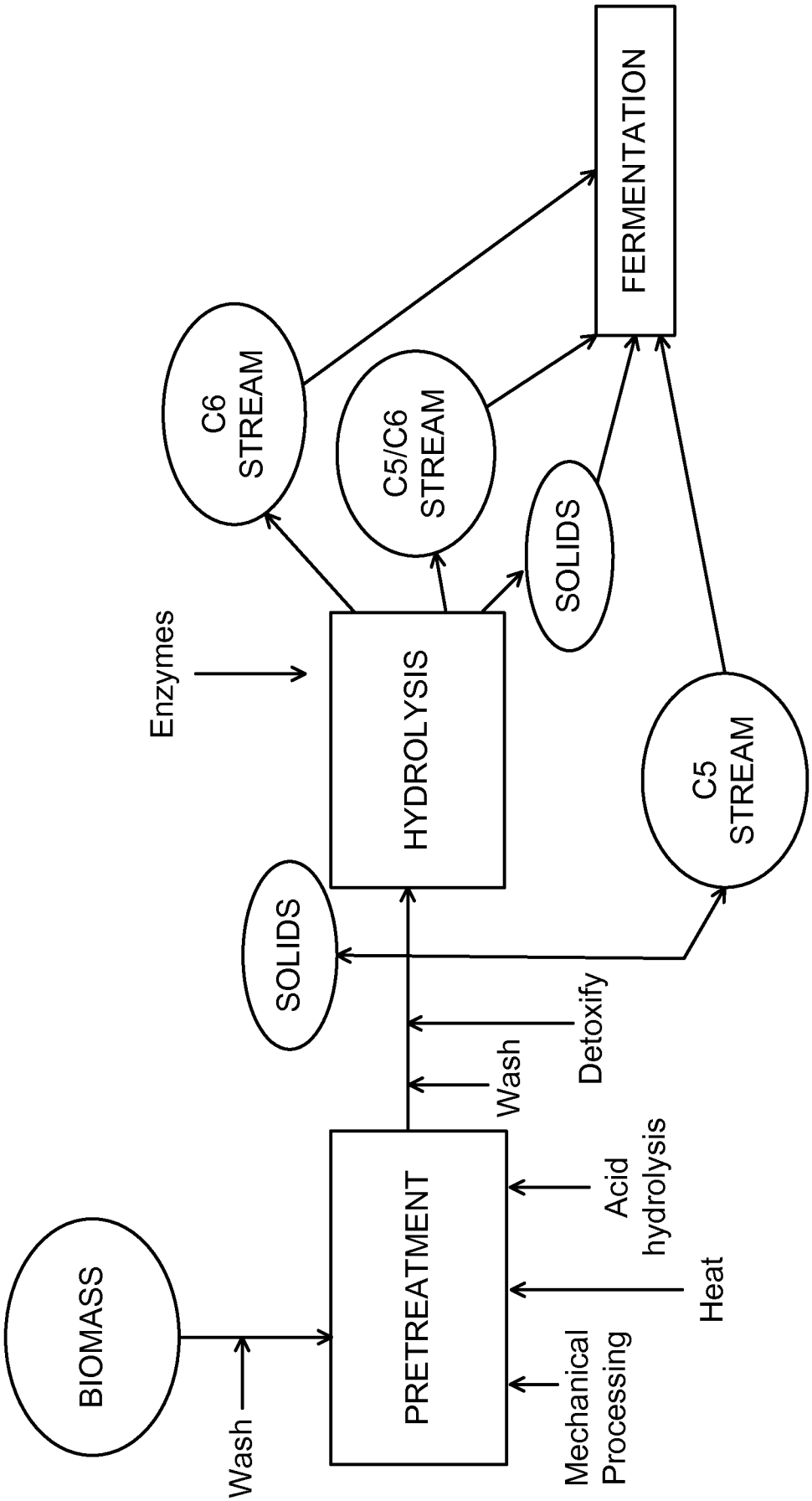

BIOMASS
Wash
PRETREATMENT
Mechanical Processing
Acid hydrolysis
Heat
Wash
Detoxify
SOLIDS
HYDROLYSIS
Enzymes
C6 STREAM
C5/C6 STREAM
SOLIDS
C5 STREAM
FERMENTATION

FIG. 2

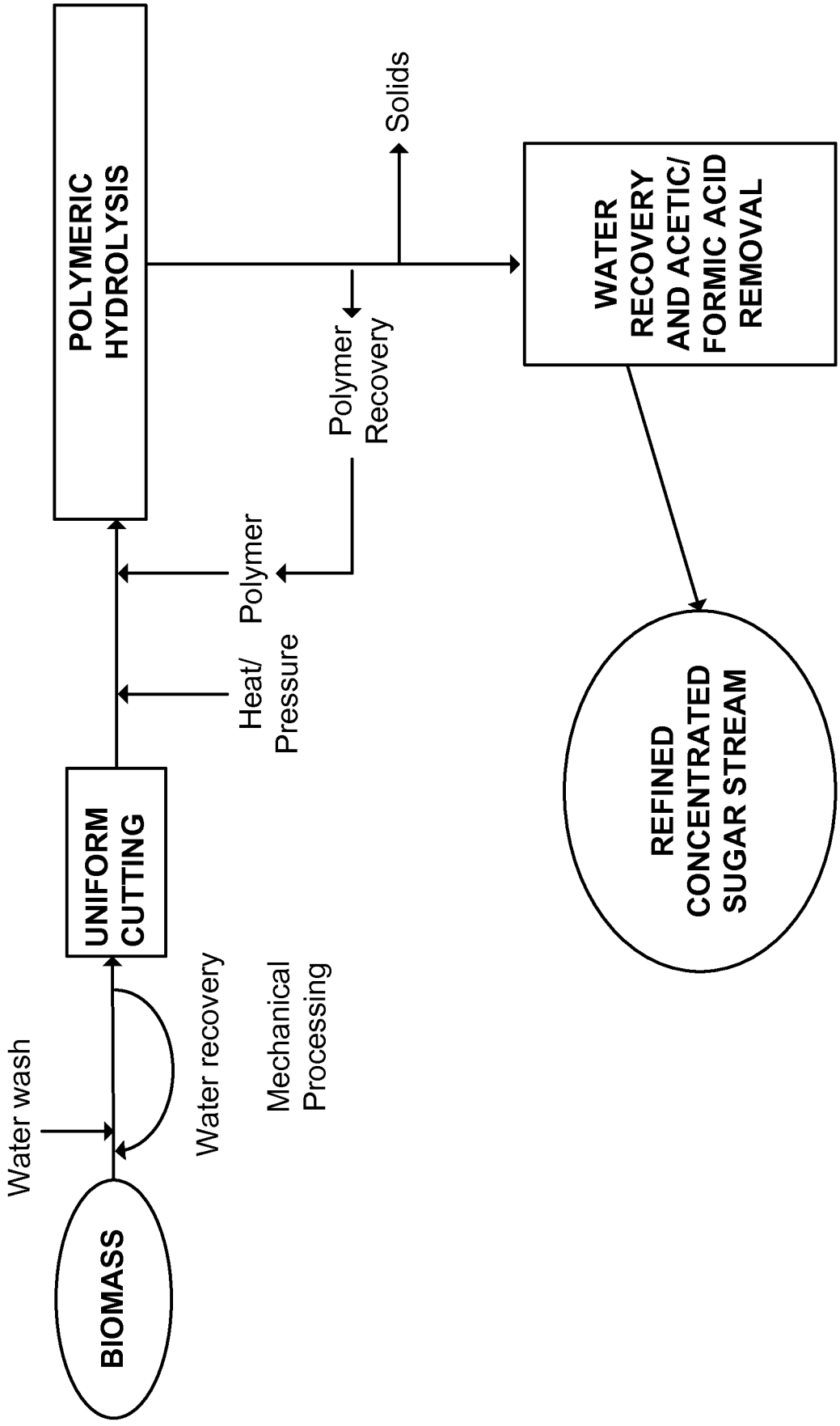
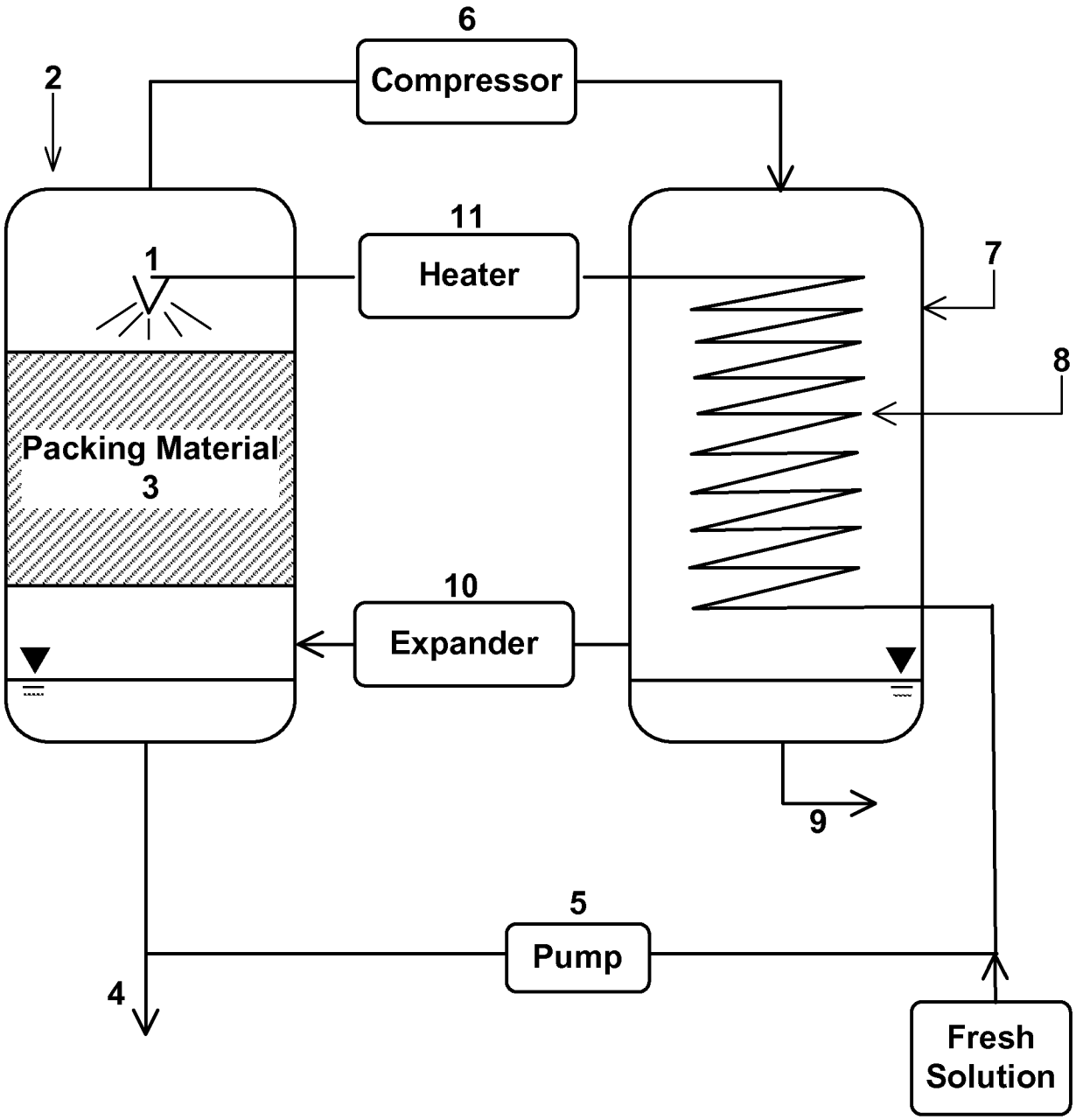

BIOMASS
Water wash
Water recovery
UNIFORM CUTTING
Mechanical Processing
Heat/ Pressure
Polymer
POLYMERIC HYDROLYSIS
Polymer Recovery
Solids
WATER RECOVERY AND ACETIC/ FORMIC ACID REMOVAL
REFINED CONCENTRATED SUGAR STREAM

FIG. 3


6
Compressor
2
11
Heater
1
7
8
Packing Material
3
10
Expander
9
5
Pump
4
Fresh Solution

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/039399

A. CLASSIFICATION OF SUBJECT MATTER

B01D 3/14 (2006.01) B01D 3/34 (2006.01) C13K 1/02 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC, NPL, XPMISC, TXTUS5, TXTUS4, TXTUS3, TXTUS2, TXTUS1, TXTUS0, TXTEP1, TXTGB1, TXTWO1, TXTAU1, TXTCA1, TXTSG1, EBSCO, AUSPAT; IPC Marks - B01D3/14/LOW, C13K1/00, C13K1/02, C13K1/08, "C12P19/00":"C12P19/10", B01D3/34/LOW; Key words - SACCHARIDE, GLUCOSE, DEXTROSE, XYLOSE, ARABINOSE, GALACTOSE, MANNOSE, RHAMNOSE, CELLOBIOSE, LACTOSE, SUCROSE, MALTOSE, FRUCTOSE, CARBOHYDRATE?, REDUC+, PURIF+, IMPROV+, TRANSFER+, INHIBIT+, ACETIC_ACID, FORMIC_ACID, FURFURAL, HYDRO_ZYMETHYL_FURFURAL, SULFURIC_ACID, AIR, GAS+, NITROGEN, ARGON, CARBON_DIOXIDE, APPLICANT NAME, INVENTORS NAME;

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 September 2014	08 September 2014
Name and mailing address of the ISA/AU	**Authorised officer**
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA Email address: pct@ipaustralia.gov.au	Praveen Jain AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No. 0262223653

INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation).	DOCUMENTS CONSIDERED TO BE RELEVANT	**PCT/US2014/039399**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	WO 2011/028853 A1 (MASSACHUSETTS INSTITUTE OF TECHNOLOGY) 10 March 2011 See whole document	56 - 103 1 - 55
A	WO 2011/022811 A1 (LOGEN ENERGY CORPORATION) 03 March 2011	
A	WO 2011/003962 A2 (METABOLIC EXPLORER) 13 January 2011	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/039399

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:

because they relate to subject matter not required to be searched by this Authority, namely:

the subject matter listed in Rule 39 on which, under Article 17(2)(a)(i), an international search is not required to be carried out, including

2. ☐ Claims Nos.:

because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos:

because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See Supplemental Box for Details

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1 - 103

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Supplemental Box

Continuation of: **Box III**

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

This Authority has found that there are different inventions based on the following features that separate the claims into distinct groups:

- Claims 1 - 103 are related to a humidification:dehumidification process for removing one or more inhibitors from a saccharide stream. The feature of the humidification:dehumidification process for removing one or more inhibitors from a saccharide stream, the process comprising: (a) contacting in a counter −current manner the saccharide stream with a carrier gas at a first temperature and a first pressure to produce a humidified gas, wherein at least a portion of the one or more inhibitors is transferred from the saccharide stream to the humidified gas; (b) separating the humidified gas from the saccharide stream; (c) dehumidifying the humidified gas at a second temperature and a second pressure to condense the one or more fermentation inhibitors; and (d) recovering the saccharide stream, wherein the saccharide stream comprises a lower level of the one or more inhibitors, is specific to this group of claims.

- Claims 104 - 179 are related to a method of producing a saccharide stream from a biomass composition comprising cellulose, hemicellulose, or lignocellulose. The feature of the method of producing a saccharide stream from a biomass composition comprising cellulose, hemicellulose, or lignocellulose, the method comprising: (a) hydrating the biomass composition in an aqueous medium; (b) mechanical size reduction of the biomass composition to produce a mixture of solid particles, wherein at least 50% of the solid particles are less than 1.5 mm in a dimension; (c) heating the biomass composition; and (d) hydrolyzing the biomass composition with one or more polymeric catalysts to produce a saccharide stream, is specific to this group of claims.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

When there is no special technical feature common to all the claimed inventions there is no unity of invention.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. Therefore there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied *a priori*.
It is considered that search and examination for the second invention will require more than negligible additional search and examination effort over that for the first invention, and therefore an additional search fee is warranted.

Where appended claims, for example claim 178, introduce features of one of the claimed inventions and yet are additionally appended to claims directed to any other of the claimed inventions, such claims will only be searched and reported on to the extent that additional search fees have been paid for all such claimed inventions.

INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/US2014/039399**

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document/s Cited in Search Report		Patent Family Member/s	
Publication Number	**Publication Date**	**Publication Number**	**Publication Date**
WO 2011/028853 A1	10 March 2011	US 2011056822 A1	10 Mar 2011
		US 8292272 B2	23 Oct 2012
		US 2013015051 A1	17 Jan 2013
		US 8465006 B2	18 Jun 2013
WO 2011/022811 A1	03 March 2011	CA 2772112 A1	03 Mar 2011
		CN 102574766 A	11 Jul 2012
		CN 102574766 B	13 Aug 2014
		EP 2470490 A1	04 Jul 2012
		US 2012209028 A1	16 Aug 2012
WO 2011/003962 A2	13 January 2011	None	

End of Annex

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.