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(54) **Title:** LIGNIN DERIVATIVES HAVING POLYCATIONS AND USES THEREOF

(57) **Abstract:** A lignin derivative including one or more polycations is provided and an article including such a lignin derivative is also provided. Methods of inhibiting microbial growth with an article including such a lignin derivative are further provided.



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LIGNIN DERIVATIVES HAVING POLYCATIONS AND USES THEREOF

FIELD

[0001] The present technology relates to a lignin derivative including one or more polycations and articles including such a lignin derivative. Also provided are methods of inhibiting microbial growth with an article including such a lignin derivative.

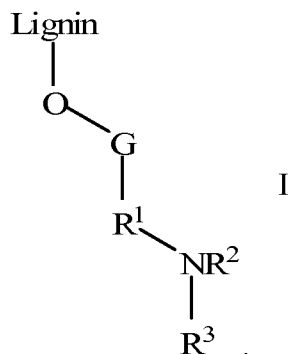
BACKGROUND

[0002] The following description is provided to assist the understanding of the reader. None of the information provided or references cited is admitted to be prior art to the present technology.

[0003] Native lignin is a naturally occurring, cross-linked, amorphous biopolymer that is an integral component of plant biomass. Lignin is the second most abundant biopolymer on earth after cellulose, and contributes to the strength and rigidity of plants and trees. Lignin hinders the process of converting wood into paper because most of the lignin must first be removed from wood to liberate wood fibers for the production of paper. Consequently, the pulp and paper industry annually generates over 45 million metric tons of lignin as a by-product of chemically-processed wood pulps and over 10 million metric tons of lignin as a by-product of mechanically-processed wood pulps. Some of the by-product lignin is used to make short-life paper products such as newsprint and telephone directories, but the majority is being used internally by pulp producers as a low-grade fuel for the chemical pulping operation. Accordingly, there is significant economic incentive to find new markets and more valuable uses for by-product lignin.

SUMMARY

[0004] In accordance with one aspect, a lignin derivative is provided, where the lignin derivative includes one or more polycations. In some embodiments, the lignin derivative is an antimicrobial agent. For example, in some embodiments, the lignin derivative is represented by Formula I:

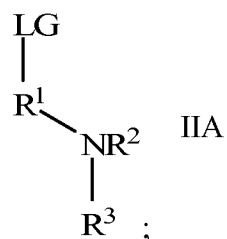
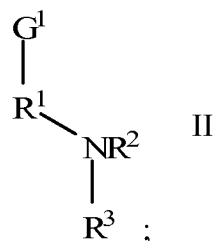


In Formula I, G is absent or a polymeric group; R^1 is a bond, alkylene, (alkyleneamino) $_q$, (alkyleneoxy) $_q$, (alkyleneoxyarylene) $_q$, or (alkyleneoxyarylene)alkylene (aryleneoxyalkylene) $_q$ wherein q is an integer of 1 to 10; R^2 is H or alkyl; and R^3 is a polycation. In some embodiments, R^3 is a polypeptide having at least one or more amino acid residues selected from lysine, histidine, arginine, tryptophan, ornithine, 2,4-diaminobutyric acid, 2,3-diamino, and combinations thereof, where at least one basic residue of the polypeptide is protonated. In other embodiments, R^3 is selected from poly(methylene-co-guanidine), poly-L-lysine, ϵ -poly-L-lysine, poly-L-ornithine, poly-L-arginine, poly-L-histidine, poly-L-tryptophan, poly-2,4-diaminobutyric acid, poly-2,3-diaminopropionic acid, and a protamine. In still other embodiments, R^3 is poly(methylene-co-guanidine) or ϵ -poly-L-lysine.

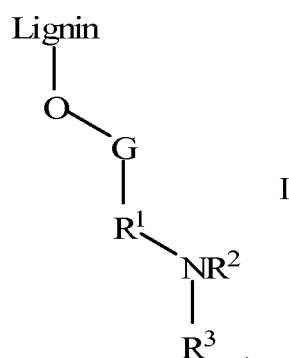
[0005] In accordance with another aspect, an article is provided, where the article includes any of the lignin derivatives described herein. In some embodiments, the article has antimicrobial activity.

[0006] In accordance with yet another aspect, a method is provided of inhibiting microbial growth, where the method includes contacting one or more microbes with any of the lignin derivatives or articles described herein.

[0007] In accordance with an additional aspect, a method is provided for preparing a lignin derivative, where the method includes contacting a lignin-containing material with one or more groups of Formula II or IIA:



to form the lignin derivative, where the lignin derivative is represented by Formula I:



In Formula I and Formula II, G^1 is absent or a polymerizable group; G is absent or a polymeric group; LG is a leaving group; R^1 is a bond, alkylene, (alkyleneamino)_q, (alkyleneoxy)_q, (alkyleneoxyarylene)_q, or (alkyleneoxyarylene)alkylene(aryleneoxyalkylene)_q where q is an integer of 1 to 10; R^2 is H or alkyl; and R^3 is a polycation.

[0008] The foregoing summary is illustrative only and is not intended to be in any way limiting. In addition to the illustrative aspects, embodiments and features described above, further aspects, embodiments and features will become apparent by reference to the detailed description.

DETAILED DESCRIPTION

[0009] The illustrative embodiments described in the detailed description and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here.

[0010] The present technology is described herein using several definitions, as set forth throughout the specification.

[0011] As used herein, unless otherwise stated, the singular forms “a,” “an,” and “the” include plural reference. Thus, for example, a reference to “an article” includes a plurality of articles, and a reference to “a compound” is a reference to one or more compounds.

[0012] As used herein, “about” will be understood by persons of ordinary skill in the art and will vary to some extent depending upon the context in which it is used. If there are uses of the term which are not clear to persons of ordinary skill in the art, given the context in which it is used, “about” will mean up to plus or minus 10% of the particular term.

[0013] Alkyl groups include straight chain, branched chain, or cyclic alkyl groups having 1 to 24 carbons or the number of carbons indicated herein. In some embodiments, an alkyl group has from 1 to 16 carbon atoms, from 1 to 12 carbons, from 1 to 8 carbons or, in some embodiments, from 1 to 6, or 1, 2, 3, 4 or 5 carbon atoms. Examples of straight chain alkyl groups include groups such as methyl, ethyl, n-propyl, n-butyl, n-pentyl, n-hexyl, n-heptyl, and n-octyl groups. Examples of branched alkyl groups include, but are not limited to, isopropyl, iso-butyl, sec-butyl, tert-butyl, neopentyl, isopentyl, and 2,2-dimethylpropyl groups. In some embodiments, the alkyl groups may be substituted alkyl groups. In some embodiments, the alkyl groups may be cycloalkyl groups.

[0014] Cycloalkyl groups are cyclic alkyl groups having from 3 to 10 carbon atoms. In some embodiments, the cycloalkyl group has 3 to 7 ring members, whereas in other embodiments the number of ring carbon atoms range from 3 to 5, 3 to 6, or 5, 6 or 7. Cycloalkyl groups further include monocyclic, bicyclic and polycyclic ring systems. Monocyclic groups

include, *e.g.*, cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, and cycloheptyl groups. Bicyclic and polycyclic cycloalkyl groups include bridged or fused rings, such as, but not limited to, bicyclo[3.2.1]octane, decalinyl, and the like. Cycloalkyl groups include rings that are substituted with straight or branched chain alkyl groups as defined above. In some embodiments, the cycloalkyl groups are substituted cycloalkyl groups. Representative substituted alkenyl groups may be mono-substituted or substituted more than once, such as, but not limited to, mono-, di- or tri-substituted with substituents such as those listed above. Representative substituted alkyl groups may be mono-substituted or substituted more than once, such as, but not limited to, mono-, di- or tri-substituted with substituents such as those listed above.

[0015] Alkenyl groups include straight and branched chain alkyl groups as defined above, except that at least one double bond exists between two carbon atoms. Thus, alkenyl groups have from 2 to 24 carbon atoms, and typically from 2 to 10 carbons or, in some embodiments, from 2 to 8, 2 to 6, or 2 to 4 carbon atoms. Examples include, but are not limited to vinyl, allyl, $-\text{CH}=\text{CH}(\text{CH}_3)$, $-\text{CH}=\text{C}(\text{CH}_3)_2$, $-\text{C}(\text{CH}_3)=\text{CH}_2$, $-\text{C}(\text{CH}_3)=\text{CH}(\text{CH}_3)$, $-\text{C}(\text{CH}_2\text{CH}_3)=\text{CH}_2$, among others. Representative substituted alkenyl groups may be mono-substituted or substituted more than once, such as, but not limited to, mono-, di- or tri-substituted with substituents such as those listed above.

[0016] Aryl groups are cyclic aromatic hydrocarbons that do not contain heteroatoms. Thus aryl groups include, but are not limited to, phenyl, azulenyl, heptalenyl, biphenylenyl, indacenyl, fluorenyl, phenanthrenyl, triphenylenyl, pyrenyl, naphthacenyl, chrysenyl, biphenyl, anthracenyl, and naphthenyl groups. Although the phrase “aryl groups” includes groups containing fused rings, such as fused aromatic-aliphatic ring systems (*e.g.*, indanyl, tetrahydronaphthyl, and the like), it does not include aryl groups that have other groups, such as alkyl or halo groups, bonded to one of the ring members. Rather, groups such as tolyl are referred to as substituted aryl groups. Representative substituted aryl groups may be mono-substituted or substituted more than once, such as, but not limited to, 2-, 3-, 4-, 5-, or 6-substituted phenyl or naphthyl groups, which may be substituted with groups including, but not limited to, amino, alkoxy, alkyl, cyano, and/or halo. In some embodiments, aryl is phenyl or naphthyl. In certain embodiments, aryl is phenyl.

[0017] Heteroaryl groups include an aromatic ring containing, for example, 5 to 12, or 5 to 10 atoms including one or more heteroatoms (*e.g.*, 1, 2, 3 or 4 heteroatoms) selected from N, O and S and with the remaining ring atoms being carbon. Heteroaryl groups do not contain adjacent S and O atoms. Unless otherwise indicated, heteroaryl groups may be bound to the parent structure by a carbon or nitrogen atom, as valency permits. For example, “pyridyl” includes 2-pyridyl, 3-pyridyl and 4-pyridyl groups, and “pyrrolyl” includes 1-pyrrolyl, 2-pyrrolyl and 3-pyrrolyl groups. Heteroaryl groups may be monocyclic or polycyclic (*e.g.*, bicyclic, tricyclic). In some embodiments, a heteroaryl group is monocyclic. Examples include pyrrole, pyrazole, imidazole, triazole (*e.g.*, 1,2,3-triazole, 1,2,4-triazole, 1,3,4-triazole), tetrazole, furan, isoxazole, oxazole, oxadiazole (*e.g.*, 1,2,3-oxadiazole, 1,2,4-oxadiazole, 1,3,4-oxadiazole), thiophene, isothiazole, thiazole, thiadiazole (*e.g.*, 1,2,3-thiadiazole, 1,2,4-thiadiazole, 1,3,4-thiadiazole), pyridine, pyridazine, pyrimidine, pyrazine, triazine (*e.g.*, 1,2,4-triazine, 1,3,5-triazine) and tetrazine. In some embodiments, more than one ring of a polycyclic heteroaryl group are aromatic. Examples include indole, isoindole, indazole, benzoimidazole, benzotriazole, benzofuran, and benzoxazole.

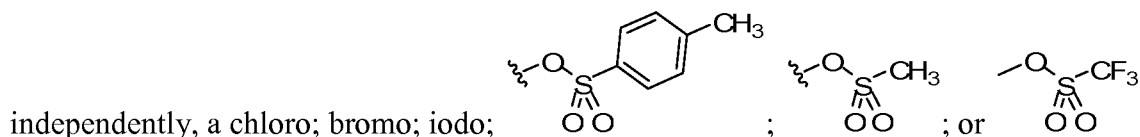
[0018] The terms “alkylene,” “alkenylene,” or “arylene,” alone or as part of another substituent, means a divalent radical derived from an alkyl, cycloalkyl, alkenyl, aryl, or heteroaryl group, respectively, as exemplified by $-\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2-$. For alkylene, alkenyl, or aryl linking groups, no orientation of the linking group is implied. Alkyleneamino is a divalent radical including alkylene and amino groups as defined herein. Alkyleneoxy is a divalent radical including alkylene and oxo groups as defined herein. Alkyleneoxyarylene and aryleneoxyalkylene are divalent radicals including alkylene, oxo, and aryl groups as defined herein.

[0019] The term “amine” (or “amino”) as used herein refers to $-\text{NHR}$ and $-\text{NRR}'$ groups, where R, and R' are independently hydrogen, or a substituted or unsubstituted alkyl, alkenyl, alkynyl, cycloalkyl, aryl or aralkyl group as defined herein. Examples of amino groups include $-\text{NH}_2$, methylamino, dimethylamino, ethylamino, diethylamino, propylamino, isopropylamino, phenylamino, benzylamino, and the like.

[0020] The term “oxo” refers to a divalent oxygen group. While the term includes doubly bonded oxygen, such as that found in a carbonyl group, as used herein, the term oxo explicitly includes singly bonded oxygen of the form $-O-$ which is part of a polymer backbone. Thus, an oxo group may be part of an ether linkage ($-O-$), an ester linkage ($-O-C(O)-$), a carbonate linkage ($-O-C(O)O-$), a carbamate linkage ($-O-C(O)NH-$ or $-O-C(O)NR-$), and the like.

[0021] “Substituted” refers to a chemical group as described herein that further includes one or more substituents, such as lower alkyl (including substituted lower alkyl such as haloalkyl, hydroxyalkyl, aminoalkyl), aryl (including substituted aryl), acyl, halogen, hydroxy, amino, alkoxy, alkylamino, acylamino, thioamido, acyloxy, aryloxy, aryloxyalkyl, carboxy, thiol, sulfide, sulfonyl, oxo, both saturated and unsaturated cyclic hydrocarbons (e.g., cycloalkyl, cycloalkenyl), cycloheteroalkyls and the like. These groups may be attached to any carbon or substituent of the alkyl, alkenyl, alkynyl, aryl, cycloheteroalkyl, alkylene, alkenylene, alkynylene, arylene, hetero moieties. Additionally, the substituents may be pendent from, or integral to, the carbon chain itself.

[0022] The term “leaving group” or “LG” as used herein, is well known among those of skill in the art as a labile substituent of a compound that is readily displaced from the compound. Leaving groups, as used herein, are described in *March's Advanced Organic Chemistry*, (John Wiley, and Sons, 5th Edition, 2001), and encompass the group consisting of a halo or $O(SO_2)R^A$; where each R^A is, independently, alkyl or aryl. In certain embodiments, each leaving group is,



[0023] The term “moldable thermoplastic material,” as used herein, refers to thermoplastic polymers known in the art, including polymers including at least one of a polyacrylate, a polymethacrylate, a polyolefin, a polyepoxy, a polyurethane, or a polyurea.

[0024] The term “polycation,” as used herein, refers to a polycationic polymer, wherein at least 50% of the monomers within the polycationic polymer have at least one substituent that

is configured to provide a positively charged amino substituent when protonated. The substituent may be an amino group. For example, the polycationic polymer may be a polycationic polypeptide. In some embodiments, at least 50% of the (natural or non-natural) amino acid residues within a polycationic polypeptide are basic amino acids, such as lysine, ornithine, 2,3-diaminopropionic acid, or a combination thereof. The term “polycation,” further encompasses the following compounds:

a) Protamines: Protamines are small (MW up to about 8000) strongly basic proteins, the positively charged amino acid groups of which (especially arginines) are usually arranged in groups. Protamines may be of natural origin or produced by recombinant methods.

b) Histones: Histones are small DNA-binding proteins present in the chromatin, having a high proportion of positively charged amino acids (lysine and arginine) which enable them to bind to DNA independently of the nucleotide sequence and fold it into nucleosomes.

c) Synthetic polypeptides: Synthetic polypeptides include homologous polypeptides (poly-lysine, poly-arginine) or heterologous polypeptides (consisting of two or more representatives of positively charged amino acids). Synthetic polypeptides further include non-natural amino acids, such as 2,4-diaminobutyric acid and 2,3-diaminopropionic acid, *etc.*

d) Non-peptide polycations: Non-peptide polycations include aminoalkyl polymers such as a polyethyleneimine or spermine. Non-peptide polycations generally include from about 5 to 500 positively charged cations.

[0025] In some embodiments, the polycation includes lysine, histidine, arginine, tryptophan, ornithine, 2,4-diaminobutyric acid, 2,3-diaminopropionic acid, or a combination thereof. In some embodiments, at least one basic residue of the polypeptide is protonated. In other embodiments, the polycation is poly(methylene-co-guanidine), poly-L-lysine, ϵ -poly-L-lysine, poly-L-ornithine, poly-L-arginine, poly-L-histidine, poly-L-tryptophan, poly-2,4-diaminobutyric acid, poly-2,3-diaminopropionic acid, a protamine, polymyxin B nonapeptide (PMBN). In some embodiments, the polycation includes one or more polyalkylamines (*e.g.*, polyethyleneimine (PEI) or spermine).

[0026] The term “antimicrobial polycation,” as used herein, refers to any polycation that kills or inhibits the growth of bacteria (*i.e.*, Gram-positive and/or Gram negative) and/or fungi. As noted, illustrative antimicrobial polycations include poly(methylene-co-guanidine), poly-L-lysine, ϵ -poly-L-lysine, poly-L-ornithine, poly-L-arginine, poly-L-histidine, poly-L-tryptophan, poly-2,4-diaminobutyric acid, poly-2,3-diaminopropionic acid, or combinations thereof. In some embodiments, at least one basic residue of the polypeptide is protonated. See, for example, Vaara, M. *Microbiol Rev* (1992) 56, 395-411; and Helander, I. M., Latva-Kala, K. & Lounatmaa, K. *Microbiology* (1998)144, 385-390.

[0027] As used herein, the term “lignin” refers to a phenolic biopolymer found in vascular plants that provides rigidity and strength to their cell walls. The lignin polymeric structure may include several phenylpropanoid building units interconnected by ether and carbon-to-carbon linkages. The phenylpropane units are not linked to each other in any systematic order. The phenylpropane units may be methoxylated to various degrees (*e.g.*, trans-coniferyl alcohol and trans-sinapyl alcohol) or non-methoxylated (*e.g.*, trans-p-coumaryl alcohol). Various combinations of these phenylpropane units are polymerized to form the lignin biopolymer.

[0028] Extracting lignin from lignocellulosic feedstocks (*e.g.*, plant material) during pulping generally results in irregular lignin fragments. As it is difficult to elucidate and characterize lignin, it may be described in terms of the lignocellulosic plant material from which it was obtained, *e.g.*, hardwood lignins, softwood lignins, and annual fibre lignins, and/or the methods by which it was recovered, *e.g.*, Kraft lignin or organosolv lignin.

[0029] Lignin derivatives, and articles made from such lignin derivatives, can be made from lignin recovered during or after pulping of lignocellulosic feedstocks. The pulp may be from any suitable lignocellulosic feedstock including hardwoods, softwoods, annual fibers, and combinations thereof. For example, hardwood feedstocks for the present technology may be selected from acacia, aspen, beech, eucalyptus, maple, birch, gum, oak, poplar, and combinations/hybrids thereof. Illustrative softwood feedstocks which may be used herein include cedar, fir, pine, spruce, and combinations thereof. Representative annual fiber

feedstocks include biomass derived from annual plants, plants which complete their growth in one growing season and therefore must be planted yearly. Examples of annual fibers include: flax, cereal straw (wheat, barley, oats), sugarcane bagasse, rice straw, corn stover, corn cobs, hemp, fruit pulp, alfa grass, switchgrass, and combinations/hybrids thereof. Lignin derivatives of the present technology can be derived from any feedstock, including those described above.

[0030] Lignin derivatives, and articles made from such lignin derivatives, can be made from lignin recovered by a variety of methods. For example, lignin may be obtained by solvent extraction of finely ground wood (milled-wood lignin) or by acidic dioxane extraction (acidolysis) of wood. Derivatives of lignin can be also isolated from biomass pre-treated using steam explosion, dilute acid hydrolysis, ammonia fiber expansion, or autohydrolysis methods. Derivatives of native lignin can be recovered after pulping of lignocellulosics including industrially operated Kraft pulping, soda pulping, and sulphite pulping. Alternatively, the “organosolv” pulping methods known to those of ordinary skill may be used to produce lignin. One organosolv method uses ethanol/solvent pulping (*i.e.*, the Alcell process); a second organosolv method uses alkaline sulphite anthraquinone methanol pulping (*i.e.*, the “ASAM” process); a third organosolv process uses methanol pulping followed by methanol, NaOH, and anthraquinone pulping (*i.e.*, the “organocell” process); a fourth organosolv process uses acetic acid/hydrochloric acid or formic acid pulping (*i.e.*, the “acetosolv” process). Lignin derivatives of the present technology can be recovered by any known method, including those described above. Lignin derivatives may be prepared by functionalizing lignin through one or more of its various chemically active substituents, such as hydroxyl groups.

[0031] In another aspect, an article containing depolymerized lignin is also provided. The lignin may be depolymerized either prior to being functionalized through one or more of its various chemically active substituents, or the lignin may be depolymerized after being functionalized.

[0032] Depolymerized lignin or lignin derivatives may be prepared, for example, by a process that includes either the hydrogenolysis of lignin or, alternatively, the acid-catalyzed or base-catalyzed treatment of lignin to produce smaller sized lignin particles having an average

particle size ranging from, for example, about 40 nanometers (nm) to about 4,000 nm. Alternatively, depolymerized lignin may have an average particle size ranging from, for example, about 40 nm to about 1,000 nm, or from about 40 nm to about 500 nm. Such treated lignin may be referred to herein as “depolymerized lignin.” As noted, depolymerizing lignin may include a hydrogenolysis reaction. The hydrogenolysis reaction may be catalyzed by a transition metal (*e.g.*, nickel, iron, copper, platinum, or palladium) catalyst. The transition metal catalyst will generally include one or more ligands, such as carbene ligands. Illustrative carbene ligands include *N,N'*-bis(2,6-diisopropylphenyl)-4,5-dihydroimidazol-2-ylidene (SIPr), bis(1,3-(2,4,6-trimethylphenyl)imidazol-2-ylidene) (IMes), (*N,N'*-bis(2,6-diisopropylphenyl)imidazol-2-ylidene) (IPr), *N,N'*-bis(adamantyl)imidazol-2-ylidene (IAd), 1,3-di-*tert*-butylimidazol-2-ylidene (ItBu), 1,3-dicyclohexyl-1,3-dihydro-2H-imidazol-2-ylidene (ICy), and 1,3-diisopropyl-4,5-dimethylimidazol-2-ylidene (iPrIM).

[0033] Depolymerized lignin or lignin derivatives may also be obtained upon treatment of lignin with acid, such as for example, hydrochloric acid, sulfuric acid, and mixtures thereof, although other acid catalysts, including Lewis acid catalysts, could be used. Alternatively, depolymerized lignin may also be obtained upon treatment of the lignin material with a base, such as NaOH, KOH, Ca(OH)₂, Mg(OH)₂ and mixtures thereof, although other base catalysts could be used.

[0034] The depolymerization of lignin or lignin derivatives by a process that includes either the hydrogenolysis of lignin or, alternatively, the acid-catalyzed or base-catalyzed treatment of lignin may be conducted in the presence of a solvent. The dissolved lignin material can then be subjected to reaction conditions sufficient to at least partially depolymerize the lignin material. The solvents are chosen to achieve solvolysis of lignin, facilitate depolymerization of lignin, and inhibit repolymerization of lignin. Illustrative solvents may include methanol, ethanol, water, and dimethoxyethane, and dimethyl ether.

[0035] The instant technology is generally directed to a lignin derivative, where the lignin derivative includes a moiety derived from a polycation. Also provided are methods of inhibiting microbial growth with an article including such a lignin derivative having a

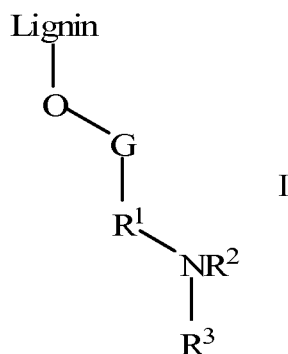
polycation. The lignin derivatives having a polycation are characterized by providing protection to an article or materials containing the lignin derivatives from degradation by microbes including bacteria and fungi.

[0036] In one aspect, lignin derivatives are provided having a polycation. The polycation may be an antimicrobial polycation. For example, an antimicrobial polycation, such as poly(methylene-co-guanidine), poly-L-lysine, ϵ -poly-L-lysine, poly-L-ornithine, poly-L-arginine, poly-L-histidine, poly-L-tryptophan, poly-2,4-diaminobutyric acid, poly-2,3-diaminopropionic acid, or combinations thereof, where at least one basic residue of the polypeptide is protonated, can be covalently attached to lignin to impart antimicrobial activity to the lignin derivative. As noted, native lignin is a cross-linked amorphous organic biopolymer. The lignin derivatives of the present technology may optionally be depolymerized to various degrees. For example, the lignin derivatives of the present technology may be depolymerized before one or more antimicrobial polycations are attached to the depolymerized lignin. Alternatively, one or more antimicrobial polycations can be attached to lignin prior to depolymerization, because the antimicrobial activity of the lignin derivatives of the present technology persists even after depolymerization. In some embodiments, the lignin is covalently attached to the polycations. In some embodiments, the lignin is covalently attached to the polycations via a linker.

[0037] In some embodiments, the modified lignin derivative exhibits antimicrobial activity and thus can be incorporated into numerous articles. The articles may be for use in antimicrobial applications. In some embodiments, the article may be antimicrobial packaging, a food packaging, pharmaceutical, cosmetic, or perfume. In some embodiments, the lignin derivative and/or the article is a moldable thermoplastic material. In other embodiments, the article is a cloth, a garment, a coating, packaging, paper product (*e.g.*, cardboard), drywall (*i.e.*, plasterboard, wallboard, or gypsum board for construction), medical equipment or a toy.

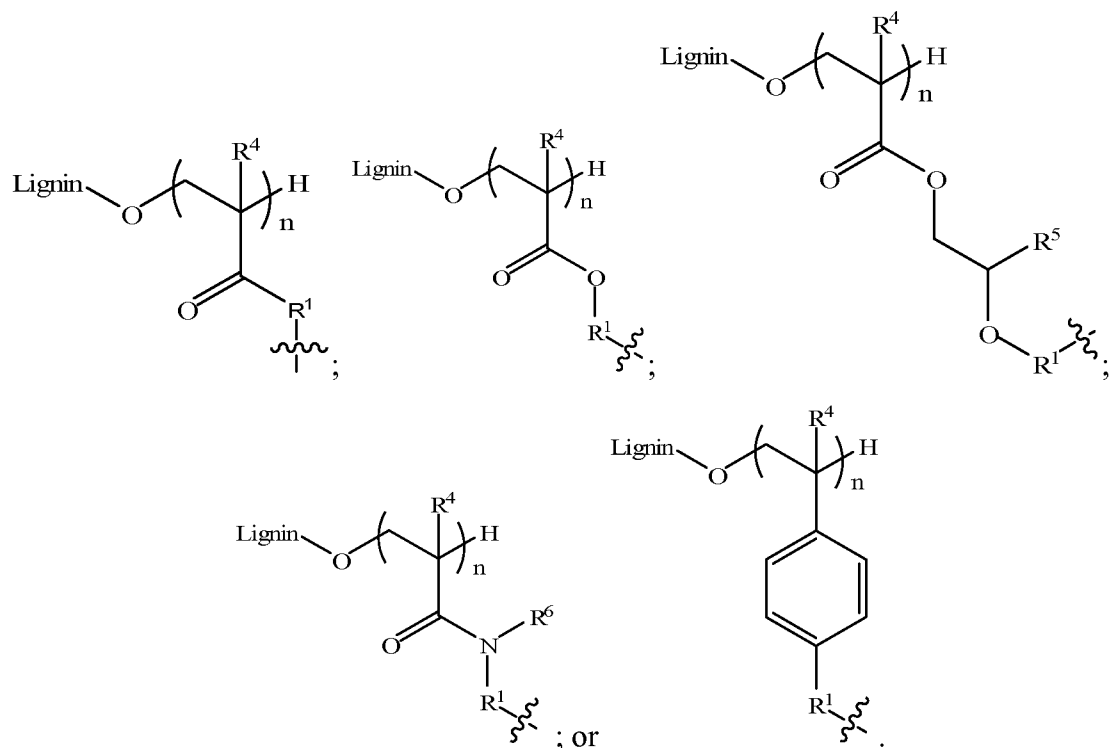
[0038] In accordance with one aspect, a lignin derivative is provided, where the lignin derivative includes one or more polycations. In some embodiments, the lignin derivative is an

antimicrobial agent. For example, in some embodiments, the lignin derivative is represented by Formula I:

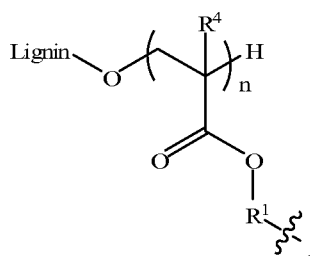


In Formula I, G is absent or a polymeric group; R^1 is a bond, alkylene, (alkyleneamino)_q, (alkyleneoxy)_q, (alkyleneoxyarylene)_q or (alkyleneoxyarylene)alkylene(aryleneoxyalkylene)_q, wherein q is an integer of 1 to 10; R^2 is H or alkyl; and R^3 is a polycation.

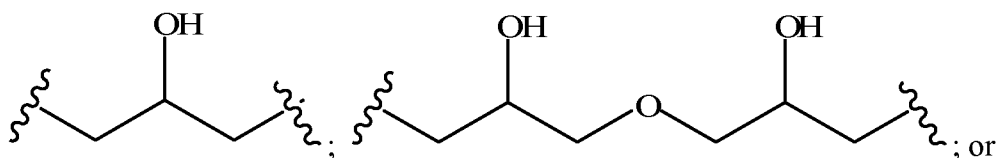
[0039] In some embodiments, G includes a group selected from a polyacrylate, polyalkylacrylate, polymethacrylate, polyacrylamide, polyolefin, polyepoxide, polyurethane, and polyurea. In other embodiments, G is absent. In some embodiments, Lignin-OGR¹- is a group of formula:

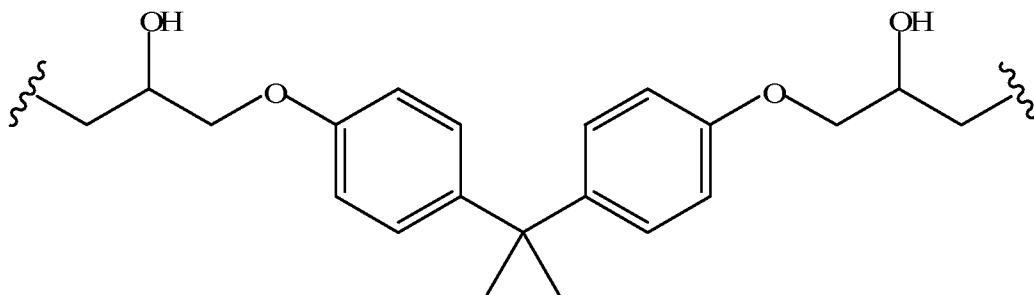


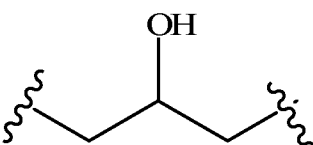
In the above formulae, R^4 is H, alkyl, alkenyl, alkynyl, alkoxy, ester, or CN; R^5 is H or alkyl; R^6 is H or alkyl; and n is an integer of 1 to 1000. In some embodiments, Lignin-OGR¹- is a group of formula:

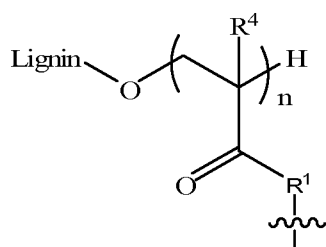


[0040] In other embodiments, R^2 , R^4 , R^5 , and R^6 is each independently H or C₁-C₄ alkyl. In some embodiments, R^1 is an alkylene, (alkyleneoxy)_q, (alkyleneoxyarylene)_q or (alkyleneoxyarylene)alkylene(aryleneoxyalkylene)_q moiety. In other embodiments, R^1 is





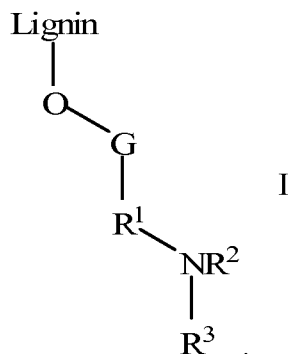
[0041] In other embodiments, R^1 is . In some embodiments, R^1 is a



bond and Lignin-OGR¹- is

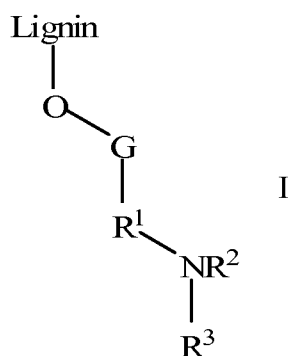
[0042] In other embodiments, R^3 is a polypeptide having at least one or more amino acid residues selected from lysine, histidine, arginine, tryptophan, ornithine, 2,4-diaminobutyric acid, 2,3-diaminopropionic acid, and combinations thereof, where at least one basic residue of the polypeptide is protonated. In some embodiments, R^3 is selected from poly(methylene-co-guanidine), poly-L-lysine, ϵ -poly-L-lysine, poly-L-ornithine, poly-L-arginine, poly-L-histidine, poly-L-tryptophan, poly-2,4-diaminobutyric acid, poly-2,3-diaminopropionic acid, and a protamine. In other embodiments, R^3 is poly(methylene-co-guanidine) or ϵ -poly-L-lysine.

[0043] According to another aspect, an article including a lignin derivative is provided, where the lignin derivative includes one or more polycations. In some embodiments, the article is an antimicrobial agent. For example, in some embodiments, the lignin derivative is represented by Formula I:



In Formula I, G is absent or a polymeric group; R^1 is a bond, alkylene, (alkyleneamino)_q, (alkyleneoxy)_q, (alkyleneoxyarylene)_q or (alkyleneoxyarylene)alkylene(aryleneoxyalkylene)_q moiety, wherein q is an integer of 1 to 10; R^2 is H or alkyl; and R^3 is a polycation. In some embodiments, the article is an antimicrobial agent. In some embodiments, the lignin derivative is as described anywhere herein.

[0044] According to another aspect, a method is provided of inhibiting microbial growth, where the method includes contacting one or more microbes with any of the lignin derivatives or articles described herein. The one or more microbes may include, but are not limited to, bacteria or fungi. For example, the bacteria may include Gram-positive and/or Gram negative bacteria. In some embodiments, the method includes contacting one or more microbes with an article including a lignin derivative, where the lignin derivative is represented by Formula I:



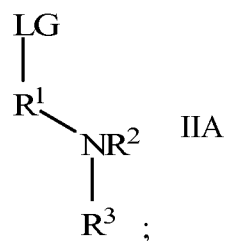
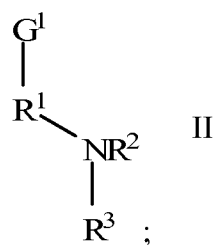
In Formula I, G^1 is absent or a polymerizable group; G is absent or a polymeric group; R^1 is a bond, alkylene, (alkyleneoxy)_q, (alkyleneamino)_q, (alkyleneoxyarylene)_q or (alkyleneoxyarylene)alkylene(aryleneoxyalkylene)_q moiety; R^2 is H or alkyl; and R^3 is a

polycation. The one or more microbes may include, but are not limited to, bacteria or fungi. For example, the bacteria may include Gram-positive or Gram-negative bacteria.

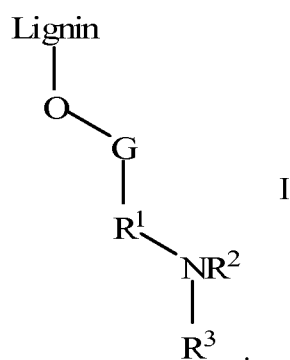
[0045] The antimicrobial activity of the lignin derivatives, or articles thereof, can be evaluated according to various methods, such as those described in the American Association of Textile and Color Chemists (AATCC) Test Method 100-1993, as published in the AATCC Technical Manual, 1997, pages 143-144, and as described in published U.S. patent application No. 2011/0117176. Samples of the articles including any of the lignin derivatives having antimicrobial moieties may be evaluated according to Test Method 100-1993 for percent reductions in, for example, *Staphylococcus aureus* colony forming units (CFU) after, for example, a 24-hour exposure time at temperatures of about 25°C.

[0046] Alternatively, the antimicrobial activity of lignin derivatives, or articles including the lignin derivatives, can be evaluated according to high throughput methods, such as those described by the National Committee for Clinical Laboratory Standards (NCCLS), Villanova, Pa., *Approved standard M7-A3: Methods for dilution antimicrobial susceptibility tests for bacteria that grow aerobically*, (1993) 3rd ed, and as described in published U.S. patent application No. 2010/0240592. For example, the antimicrobial activities of lignin derivatives of the present technology, or articles thereof, may be determined in 96-well plates (e.g., Nunclon® polystyrene) by the standard NCCLS broth microdilution method. Illustrative microorganisms that may be used to determine antibiotic activity include *Escherichia coli* (ATCC 25922) or *Pseudomonas aeruginosa* (*P. aeruginosa* ATCC 27853). Antimicrobial activities may be expressed as the minimal inhibitory concentration (MIC) in µg/ml at which no visible growth is observed after, for example, 18-20 hours of incubation at, for example, 37°C.

[0047] According to another aspect, a method is provided for preparing a lignin derivative, where the method includes contacting a lignin-containing material with one or more groups of Formula II or IIA:

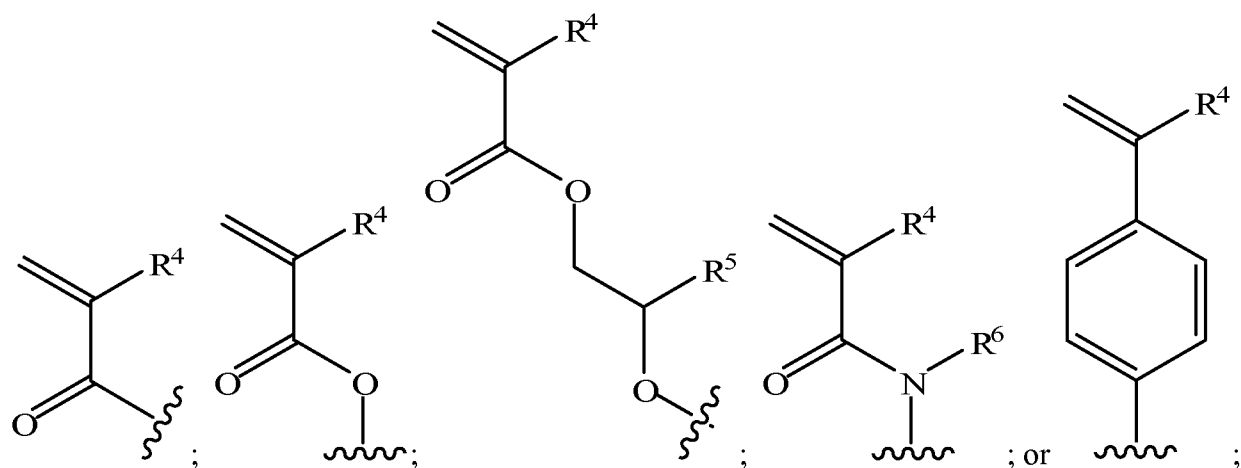


to form the lignin derivative, where the lignin derivative is represented by Formula I:

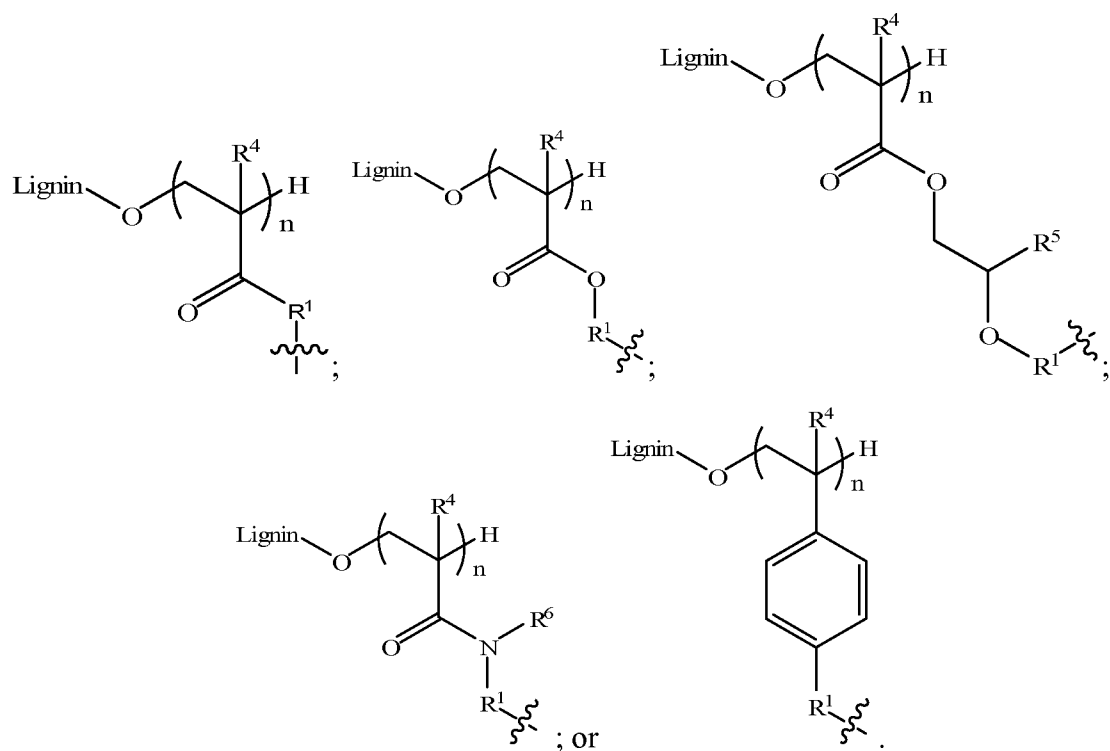


In Formula I, II, and IIA G^1 is absent or a polymerizable group; G is absent or a polymeric group; R^1 is a bond, alkylene, (alkyleneamino)_q, (alkyleneoxy)_q, (alkyleneoxyarylene)_q or (alkyleneoxyarylene)alkylene(aryleneoxyalkylene)_q moiety, where q is an integer of 1 to 10; R^2 is H or alkyl; R^3 is a polycation, and LG is a leaving group.

[0048] In some embodiments, G^1 and G are absent. In other embodiments, G^1 is a group of formula:

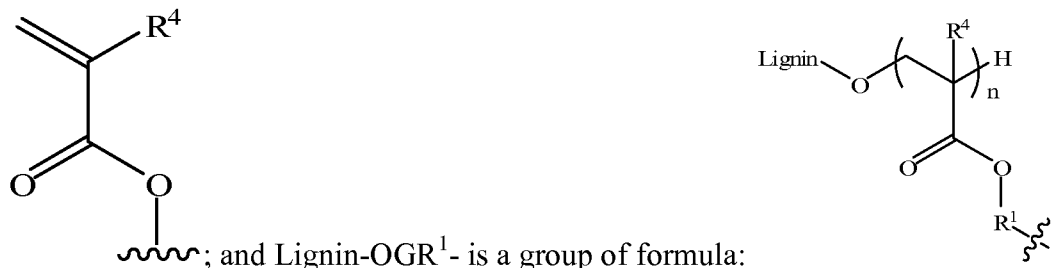


and Lignin-OGR¹ - is a group of formula:



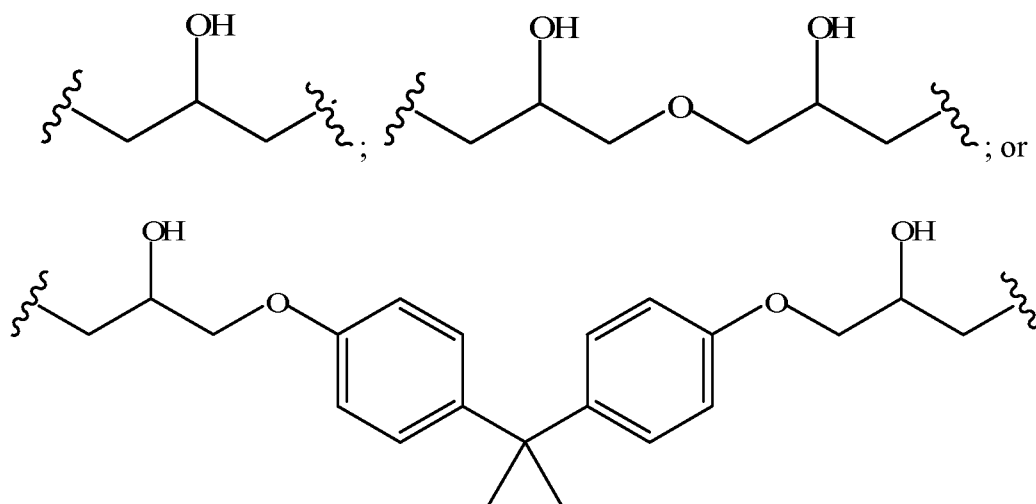
In the above formulae, R^4 is H, alkyl, alkenyl, alkynyl, alkoxy, ester, or CN; R^5 is H or alkyl; R^6 is H or alkyl; and n is an integer of 1 to 1000.

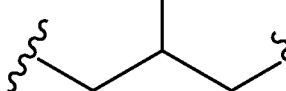
[0049] In other embodiments, G^1 is a group of formula:

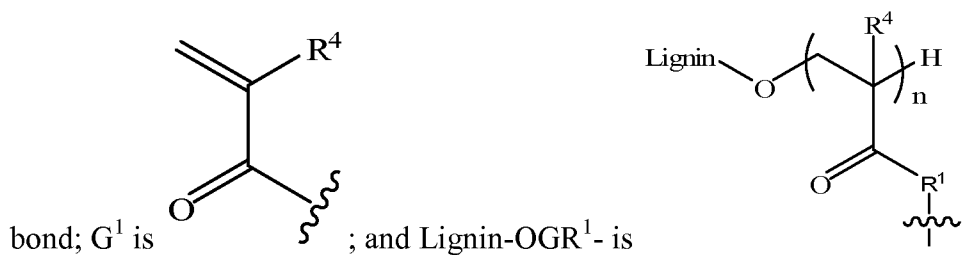


[0050] In some embodiments, R^2 , R^4 , R^5 , and R^6 is each independently H or C_1 - C_4 alkyl.

[0051] In other embodiments, R^1 is an alkylene, (alkyleneoxy) $_q$, (alkyleneoxyarylene) $_q$ or (alkyleneoxyarylene)alkylene(aryleneoxyalkylene) $_q$ moiety. In some embodiments, R^1 is

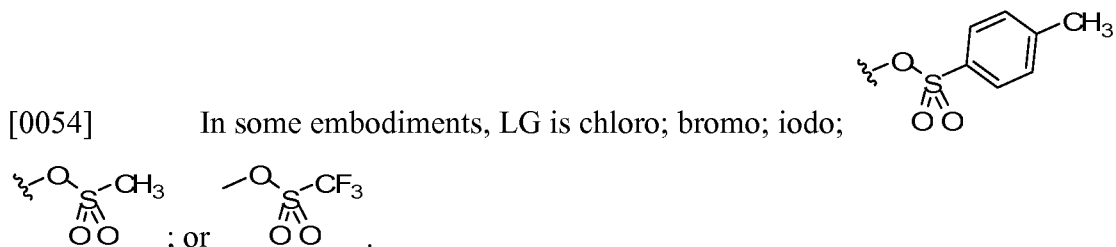


[0052] In other embodiments, R^1 is . In some embodiments, R^1 is a



[0053] In other embodiments, R^3 is a polypeptide having at least one or more amino acid residue selected from lysine, histidine, arginine, tryptophan, ornithine, 2,4-diaminobutyric acid, 2,3-diaminopropionic acid, and combinations thereof, where at least one basic residue of the polypeptide is protonated. In some embodiments, R^3 is selected from poly(methylene-co-guanidine), poly-L-lysine, ϵ -poly-L-lysine, poly-L-ornithine, poly-L-arginine, poly-L-histidine, poly-L-tryptophan, poly-2,4-diaminobutyric acid, poly-2,3-diaminopropionic acid, and a protamine. In other embodiments, R^3 is poly(methylene-co-guanidine) or ϵ -poly-L-lysine.

[0054] In some embodiments, LG is chloro; bromo; iodo;

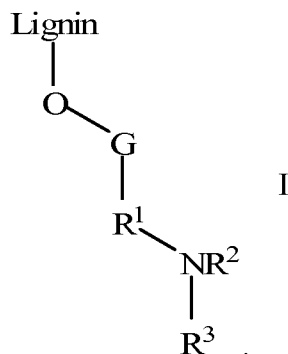


[0055] In some embodiments, the contacting step may also include a polymerizing step. The polymerizing step may also include activating the polymerizable group. For example, activation of the polymerizable group may include heating the polymerizable group, applying ultraviolet irradiation to the polymerizable group, adding a thermal initiator to the polymerizable group, adding a photochemical initiator to the polymerizable group, adding an oxidant to the polymerizable group, or adding a combination thereof. Where the activating the polymerizable group includes adding a thermal initiator to the polymerizable group, the thermal initiator may include, but is not limited to, an azonitrile, acyl peroxide, azobisisobutyronitrile, ammonium persulfate, 4,4'-azobis(4-cyanovaleric acid), 1,1'-azobis(cyclohexanecarbonitrile), 2,2'-azobisisobutyronitrile, benzoyl peroxide, *tert*-butyl peracetate, lauroyl peroxide, or dicumyl peroxide. Where the activating the polymerizable group includes adding a photochemical initiator to the polymerizable group, the initiator may include, but is not limited to, 3-butyl-2-[5-(1-butyl-3,3-dimethyl-1,3-dihydro-indol-2-ylidene)-penta-1,3-dienyl]-1,1-dimethyl-1H-benzo[e]indolium triphenylbutylborate, 3-butyl-2-[5-(3-butyl-1,1-dimethyl-1,3-dihydro-benzo[e]indol-2-ylidene)-penta-1,3-dienyl]-1,1-dimethyl-1H-benzo[e]indolium triphenylbutylborate, 6-hydroxy-2,4,5,7-tetraiodo-3-oxo-9,9a-dihydro-3H-xanthene-9-carbonitrile, 2,2-dimethoxy-2-phenylacetophenone, 2-hydroxy-2-methylpropiophenone, or 9,10-

phenanthrenequinone. Where the activating the polymerizable group includes adding an oxidant to the polymerizable group, the initiator may include, but is not limited to, ceric ammonium nitrate (CAN). In some embodiments, the step of activating the polymerizable group includes heating the polymerizable group to a temperature of about 40°C to about 120°C.

[0056] Depending on the application, the method of modifying lignin with one or more antimicrobial polycations to form a lignin derivative may further include at least partially depolymerizing the lignin before forming the lignin derivative. Alternatively, the at least partially depolymerizing the lignin derivative may occur after formation of the lignin derivative. In some embodiments, the depolymerizing includes treating the lignin or the lignin derivative with an acid catalyst. In other embodiments, the depolymerizing includes treating the lignin or the lignin derivative with a basic catalyst. In some embodiments, the depolymerizing includes subjecting the lignin or the lignin derivative to a hydrogenolysis reaction. In other embodiments, the hydrogenolysis reaction is conducted in the presence of a transition metal catalyst. In some embodiments, the transition metal catalyst includes nickel. In other embodiments, the transition metal catalyst further includes a carbene ligand. In some embodiments, the carbene ligand is selected from the group consisting of *N,N'*-bis(2,6-diisopropylphenyl)-4,5-dihydroimidazol-2-ylidene (SIPr), bis(1,3-(2,4,6-trimethylphenyl)imidazol-2-ylidene) (IMes), (*N,N'*-bis(2,6-diisopropylphenyl)imidazol-2-ylidene) (IPr), *N,N'*-bis(adamantyl)imidazol-2-ylidene (IAd), 1,3-di-*tert*-butylimidazol-2-ylidene (ItBu), 1,3-dicyclohexyl-1,3-dihydro-2H-imidazol-2-ylidene (ICy), and 1,3-diisopropyl-4,5-dimethylimidazol-2-ylidene (iPrIM). In other embodiments, the carbene ligand is *N,N'*-bis(2,6-diisopropylphenyl)-4,5-dihydroimidazol-2-ylidene (SIPr). In one embodiment, the carbene ligand is *N,N'*-bis(2,6-diisopropylphenyl)-4,5-dihydroimidazol-2-ylidene (SIPr).

[0057] According to another aspect, a method is provided for coating an article with a lignin derivative, where the method includes contacting an article with one or more groups of Formula I:



In Formula I, G^1 is absent or a polymerizable group; G is absent or a polymeric group; R^1 is a bond, alkylene, (alkyleneoxy)_q, (alkyleneamino)_q, (alkyleneoxyarylene)_q or (alkyleneoxyarylene)alkylene(aryleneoxyalkylene)_q moiety.; R^2 is H or alkyl; and R^3 is a polycation.

[0058] In some embodiments, the article may be antimicrobial packaging, a food packaging, pharmaceutical, cosmetic, or perfume. In some embodiments, the article is a moldable thermoplastic material. In other embodiments, the article is a cloth, a garment, a coating, packaging, paper product (*e.g.*, cardboard), drywall (*i.e.*, plasterboard, wallboard, or gypsum board for construction), medical equipment or a toy.

[0059] The present technology, thus generally described, will be understood more readily by reference to the following Examples, which are provided by way of illustration and are not intended to be limiting of the present technology.

EXAMPLES

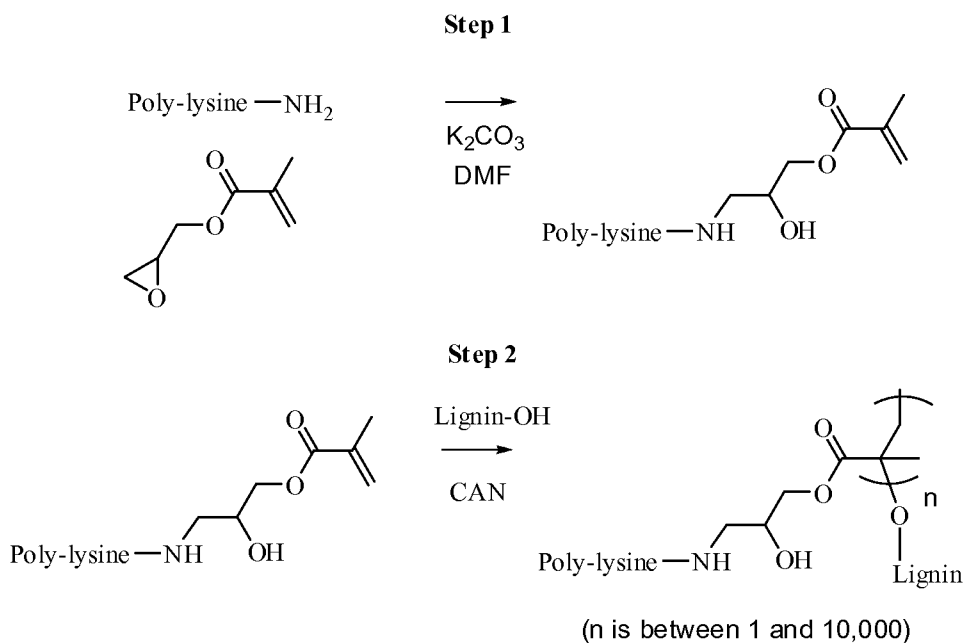
[0060] It will be appreciated that where reaction conditions (*e.g.*, temperatures, times, mole ratios of reactants, solvents, pressures, *etc.*) are given, other conditions can also be used unless otherwise stated. Optimum reaction conditions may vary with the particular reactants or solvent used, but such conditions can be determined by one skilled in the art by routine optimization procedures.

[0061] **Example 1.** *Synthesis of a lignin derivative having polycations.* Lignin may be co-polymerized with a polycation such as poly-lysine as shown below in Scheme 1.

[0062] *Step 1:* Poly-lysine is converted to a polymerizable intermediate by reacting the nucleophilic poly-lysine with an electrophilic polymerizable moiety-containing reagent, such as 2-hydroxypropyl acrylate, to provide a polymerizable poly-lysine intermediate. This first step can be conducted in the absence or presence of a solvent (*e.g.*, tetrahydrofuran, dimethylformamide, *etc.*) and at a temperature of about 25°C to about 60°C.

[0063] *Step 2:* The polymerizable poly-lysine intermediate is then reacted with lignin and polymerized by combining the polymerizable poly-lysine intermediate with lignin in the presence of ceric ammonium nitrate (CAN). This step can be conducted in the absence or presence of a solvent (*e.g.*, tetrahydrofuran, dimethylformamide, *etc.*) and at a temperature of about 25°C to about 60°C.

Scheme 1



[0064] **Example 2.** *Packaging having lignin derivatives with polycations.* An article, such as polymer packaging, can be prepared, for example, by combining the lignin derivative

having polycations of Example 1 with a polymer (*e.g.*, polyester, polyolefin, or polyamide) to form a mixture, heating the mixture, and extruding the heated mixture to form the polymer packaging. Polyethylene pellets (0.95 kg) are combined with pellets of the lignin derivative having polycations of Example 1 (0.05 kg) and the resulting mixture is heated until it melts. The melted mixture is stirred and extruded into sheets (10 meters x 0.5 meters x 1 millimeter), cooled, and the cooled sheets rolled. The resulting sheets of polymer packaging, which includes polyethylene and the lignin derivative having polycations, is expected to demonstrate improved antimicrobial activity relative to sheets of polymer packaging made only from polyethylene.

[0065] **Example 3.** *Antimicrobial testing of articles having lignin derivatives with polycations.* The antimicrobial activity of the articles of this technology can be evaluated according to methods known to those of skill in the art, such as those described in U.S. patent publication No. 2011/0117176. For example, articles having lignin derivatives with polycations can be cut into square samples (*e.g.*, about 3.0 cm by 3.0 cm) and evaluated for antimicrobial activity according to the American Association of Textile and Color Chemists (AATCC) Test Method 100-1993, as published in the AATCC Technical Manual, 1997, pages 143-144. The Test Method may include, for example, a suitable strain of *Staphylococcus aureus*, Tryptic Soy Broth as the nutrient broth, and/or Tryptic Soy Agar as the nutrient agar. Samples of the articles having lignin derivatives with polycations may then be evaluated for percent reductions in *S. aureus* colony forming units (CFU) after, for example, a 24-hour exposure time at temperatures of about 25°C. It is contemplated that the articles having lignin derivatives with polycations will have greater antimicrobial properties (*e.g.*, percent reductions in *S. aureus* colony forming units) than corresponding articles that lack such lignin derivatives with polycations.

EQUIVALENTS

[0066] The embodiments, illustratively described herein may suitably be practiced in the absence of any element or elements, limitation or limitations, not specifically disclosed herein. Thus, for example, the terms ‘comprising,’ ‘including,’ ‘containing,’ *etc.* shall be read expansively and without limitation. Additionally, the terms and expressions employed herein

have been used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, but it is recognized that various modifications are possible within the scope of the claimed technology. Additionally, the phrase ‘consisting essentially of’ will be understood to include those elements specifically recited and those additional elements that do not materially affect the basic and novel characteristics of the claimed technology. The phrase ‘consisting of’ excludes any element not specified.

[0067] The present disclosure is not to be limited in terms of the particular embodiments described in this application, which are intended as illustrations of various aspects. Many modifications and variations can be made without departing from its spirit and scope, as will be apparent to those skilled in the art. Functionally equivalent compositions, apparatuses, and methods within the scope of the disclosure, in addition to those enumerated herein, will be apparent to those skilled in the art from the foregoing descriptions. Such modifications and variations are intended to fall within the scope of the appended claims. The present disclosure is to be limited only by the terms of the appended claims, along with the full scope of equivalents to which such claims are entitled. It is to be understood that this disclosure is not limited to particular methods, reagents, compounds compositions or biological systems, which can, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments only, and is not intended to be limiting.

[0068] In addition, where features or aspects of the disclosure are described in terms of Markush groups, those skilled in the art will recognize that the disclosure is also thereby described in terms of any individual member or subgroup of members of the Markush group.

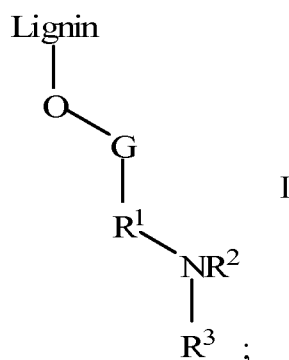
[0069] As will be understood by one skilled in the art, for any and all purposes, particularly in terms of providing a written description, all ranges disclosed herein also encompass any and all possible subranges and combinations of subranges thereof. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, tenths, *etc.* As a non-limiting example, each range discussed herein can be readily broken down into a lower third, middle third

and upper third, etc. As will also be understood by one skilled in the art all language such as ‘up to,’ ‘at least,’ ‘greater than,’ ‘less than,’ and the like, include the number recited and refer to ranges which can be subsequently broken down into subranges as discussed above. Similarly, the phrase “at least about” some value such as, *e.g.*, wt % includes at least the value and about the value. For example “at least about 1 wt%” means “at least 1 wt% or about 1 wt%.” Finally, as will be understood by one skilled in the art, a range includes each individual member.

[0070] While certain embodiments have been illustrated and described, it should be understood that changes and modifications can be made therein in accordance with ordinary skill in the art without departing from the technology in its broader aspects as defined in the following claims.

WHAT IS CLAIMED IS:

1. A lignin derivative, wherein the lignin derivative comprises one or more polycations.
2. The lignin derivative of Claim 1, wherein the lignin derivative is an antimicrobial agent.
3. The lignin derivative of Claim 1 or 2, wherein the lignin derivative comprises partially depolymerized lignin.
4. The lignin derivative of any one of Claims 1-3, wherein the lignin derivative is thermoplastic.
5. The lignin derivative of any one of Claims 1-4, wherein the lignin derivative is represented by Formula I:



wherein:

G is absent or a polymeric group;

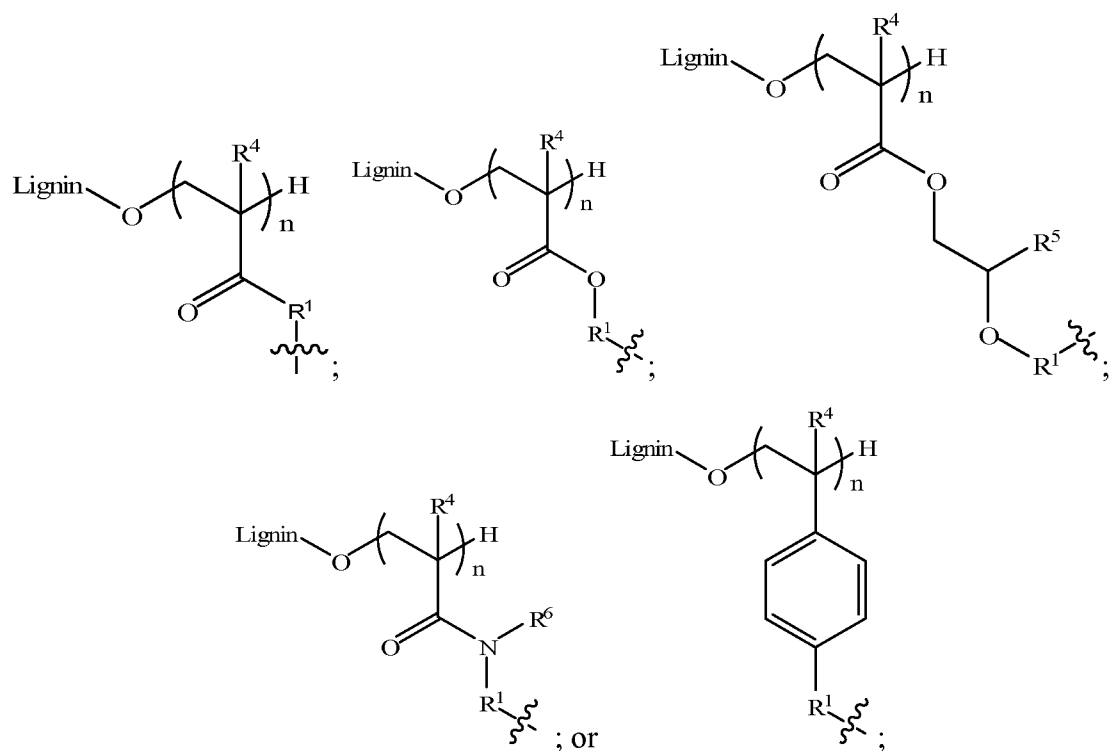
R^1 is a bond, alkylene, (alkyleneamino)_q, (alkyleneoxy)_q, (alkyleneoxyarylene)_q or (alkyleneoxyarylene)alkylene(aryleneoxyalkylene)_q moiety, wherein q is from 1 to 10;

R^2 is H or alkyl; and

R^3 is a polycation.

6. The lignin derivative of Claim 5, wherein G comprises a group selected from a polyacrylate, polyalkylacrylate, polymethacrylate, polyacrylamide, polyolefin, polyepoxide, polyurethane, and polyurea.

7. The lignin derivative of Claim 5, wherein G is absent.
8. The lignin derivative of Claim 5 or 6, wherein Lignin-OGR¹- is a group of formula:



wherein:

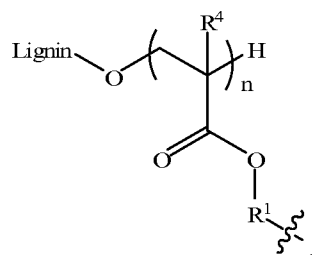
R⁴ is H, alkyl, alkenyl, alkynyl, alkoxy, ester, or CN;

R⁵ is H or alkyl;

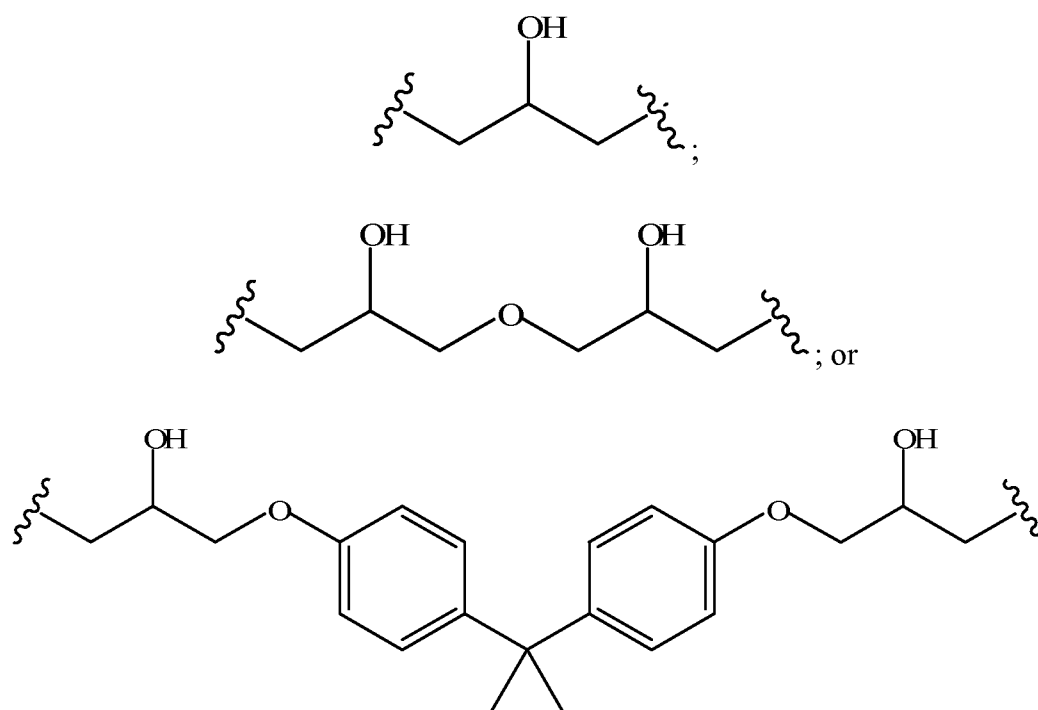
R⁶ is H or alkyl; and

n is from 1 to 1000.

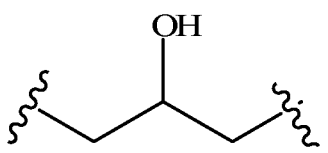
9. The lignin derivative of Claim 5, 6, or 8, wherein Lignin-OGR¹- is a group of formula:



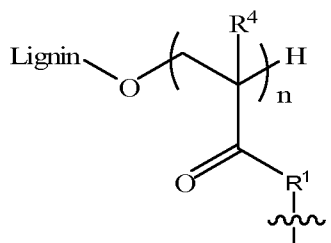
10. The lignin derivative of Claim 8, wherein R^2 , R^4 , R^5 , and R^6 is each independently H or C_1 - C_4 alkyl.
11. The lignin derivative of any one of Claims 5-10, wherein R^1 is an alkylene, (alkyleneoxy)_q, (alkyleneoxyarylene)_q or (alkyleneoxyarylene)alkylene(aryleneoxyalkylene)_q moiety.
12. The lignin derivative of any one of Claims 5-11, wherein R^1 is



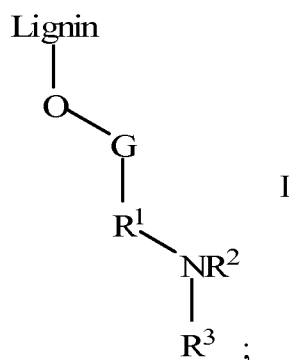
13. The lignin derivative of any one of Claims 5-12, wherein R^1 is



14. The lignin derivative of Claim 5, wherein R^1 is a bond and Lignin-OGR¹ - is



15. The lignin derivative of any one of Claims 5-14, wherein R^3 is a polypeptide having at least one or more amino acid residues selected from lysine, histidine, arginine, tryptophan, ornithine, 2,4-diaminobutyric acid and 2,3-diaminopropionic acid, and wherein at least one basic residue of the polypeptide is protonated.
16. The lignin derivative of any one of Claims 5-14, wherein R^3 is selected from poly(methylene-co-guanidine), poly-L-lysine, ϵ -poly-L-lysine, poly-L-ornithine, poly-L-arginine, poly-L-histidine, poly-L-tryptophan, poly-2,4-diaminobutyric acid, poly-2,3-diaminopropionic acid, and a protamine.
17. The lignin derivative of any one of Claims 5-16, wherein R^3 is poly(methylene-co-guanidine) or ϵ -poly-L-lysine.
18. An article comprising a lignin derivative, wherein the lignin derivative comprises one or more polycations.
19. The article of Claims 18, wherein the lignin derivative is represented by Formula I:



wherein:

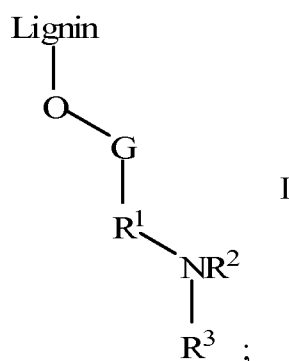
G is absent or a polymeric group;

R^1 is a bond, alkylene, (alkyleneamino)_q, (alkyleneoxy)_q, (alkyleneoxyarylene)_q or (alkyleneoxyarylene)alkylene(aryleneoxyalkylene)_q moiety, wherein q is from 1 to 10;

R^2 is H or alkyl; and

R^3 is a polycation.

20. The article of Claims 18, comprising the lignin derivative of anyone of claims 6-17.
21. A method of inhibiting microbial growth, the method comprising: contacting one or more microbes with an article comprising a lignin derivative, wherein the lignin derivative is represented by Formula I:



wherein:

G^1 is absent or a polymerizable group;

G is absent or a polymeric group;

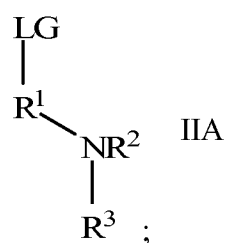
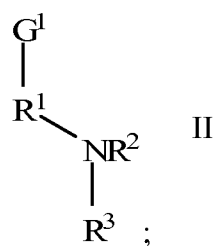
R^1 is a bond, alkylene, (alkyleneamino)_q, (alkyleneoxy)_q, (alkyleneoxyarylene)_q or (alkyleneoxyarylene)alkylene (aryleneoxyalkylene)_q moiety, wherein q is from 1 to 10;

R^2 is H or alkyl; and

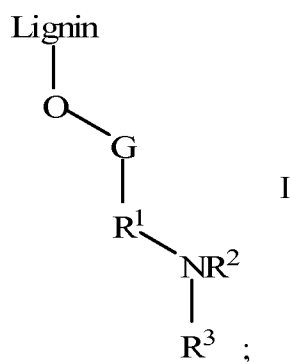
R^3 is a polycation.

22. The method of Claim 21, wherein the one or more microbes comprise bacteria.
23. The method of Claim 21, wherein the one or more microbes comprise fungi.

24. A method for preparing a lignin derivative, the method comprising:
 contacting a lignin-containing material with one or more groups of Formula II or
 IIA:



to form the lignin derivative wherein the lignin derivative is represented by
 Formula I:



wherein:

G^1 is absent or a polymerizable group;

G is absent or a polymeric group;

LG is a leaving group;

R^1 is a bond, alkylene, (alkyleneamino)_q, (alkyleneoxy)_q,
 (alkyleneoxyarylene)_q or (alkyleneoxyarylene)alkylene
 (aryleneoxyalkylene)_q moiety, wherein q is from 1 to 10;

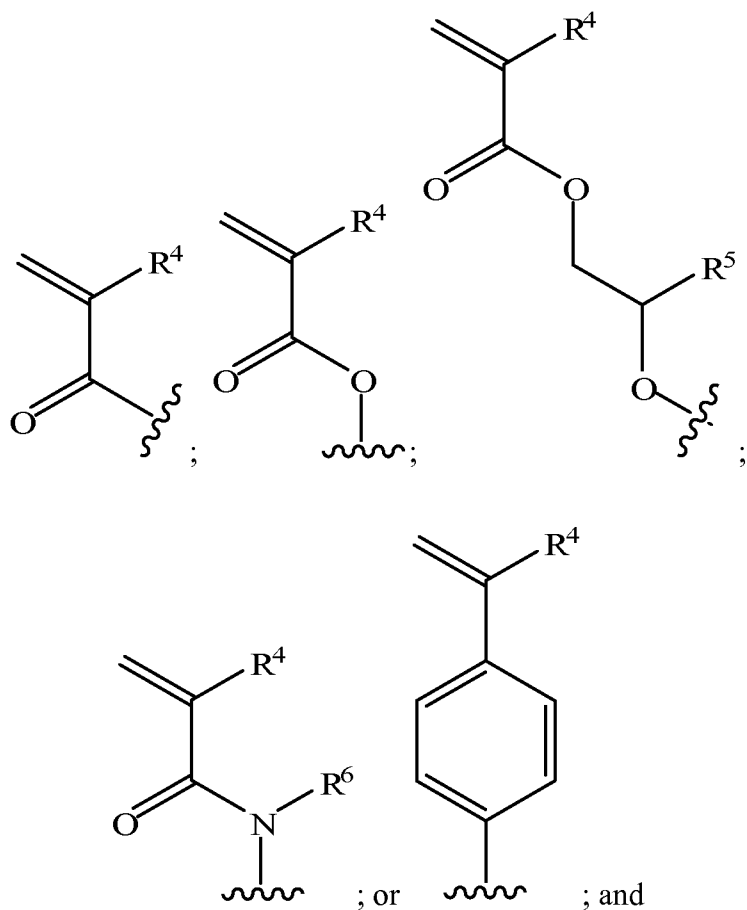
R^2 is H or alkyl; and

R^3 is a polycation.

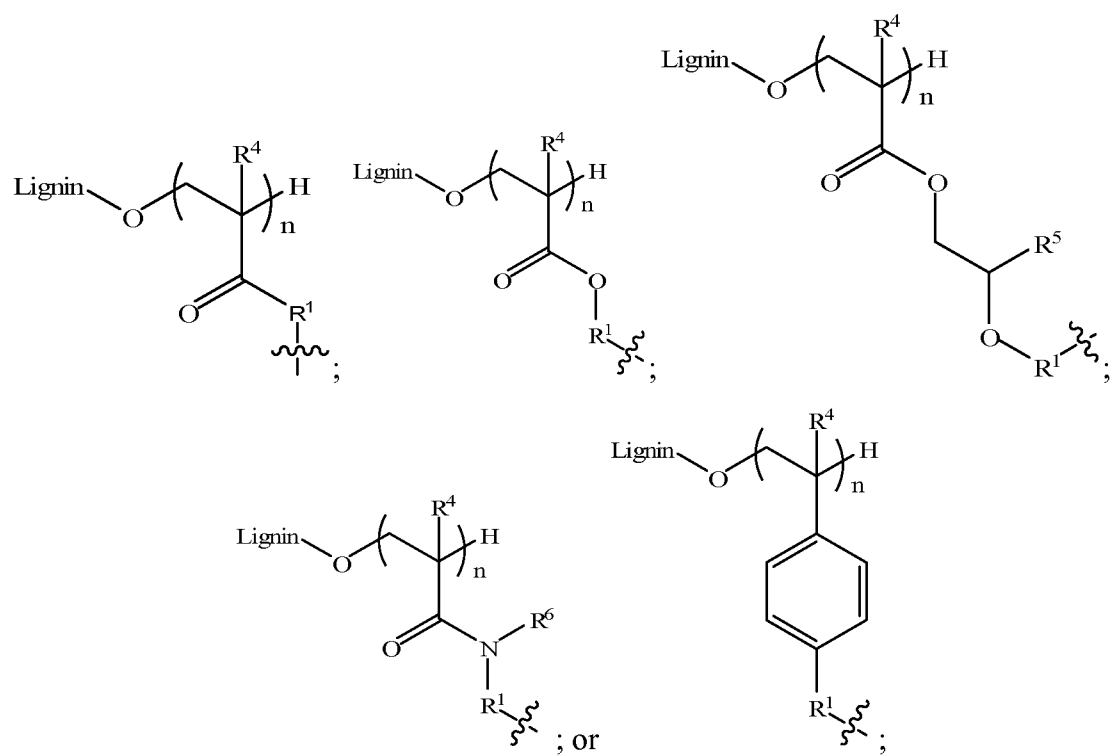
25. The method of Claim 24, wherein G^1 and G are absent.

26. The method of Claim 24, wherein

G^1 is a group of formula:



Lignin-OGR¹- is a group of formula:



wherein:

R^4 is H, alkyl, alkenyl, alkynyl, alkoxy, ester, or CN;

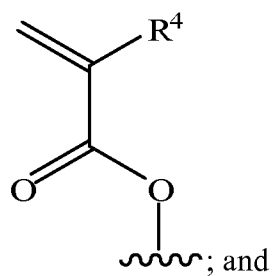
R^5 is H or alkyl;

R^6 is H or alkyl; and

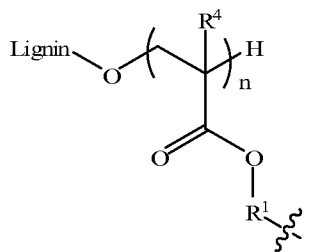
n is from 1 to 1000.

27. The method of Claim 26, wherein

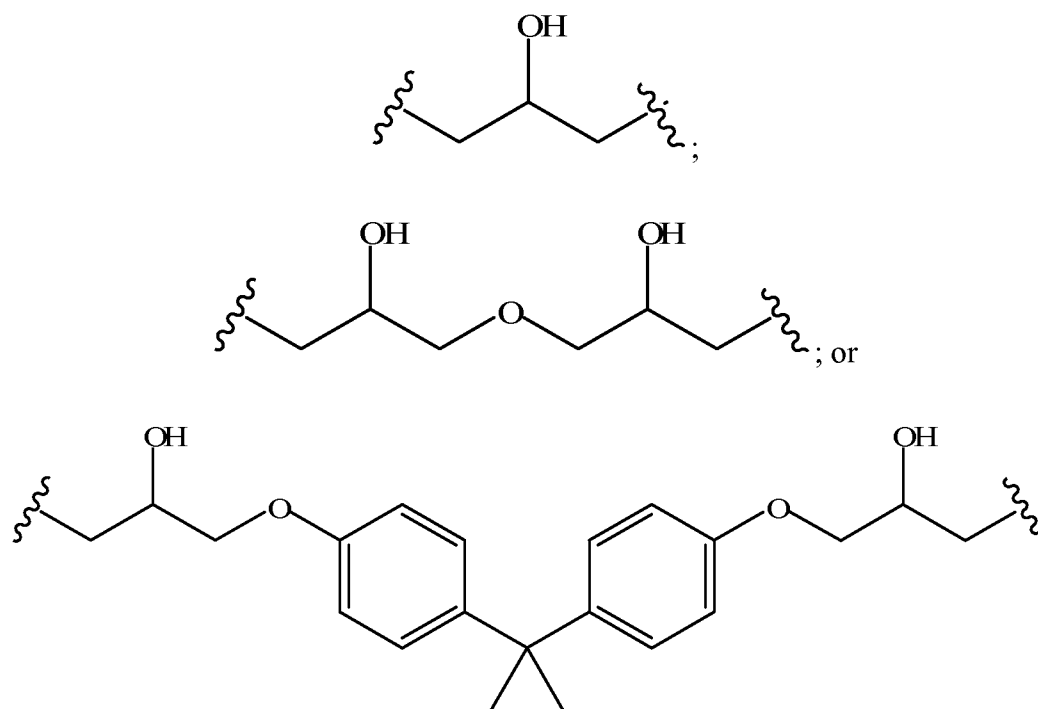
G^1 is a group of formula:



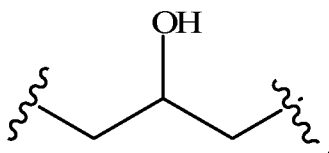
Lignin-OGR¹- is a group of formula:



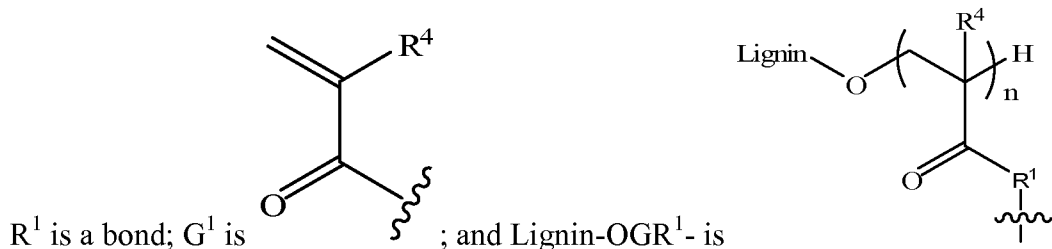
28. The method of Claim 26 or 27, wherein R^2 , R^4 , R^5 , and R^6 is each independently H or C_1 - C_4 alkyl.
29. The method of any one of Claims 24-28, wherein R^1 is an alkylene, (alkyleneoxy) $_q$, (alkyleneoxyarylene) $_q$ or (alkyleneoxyarylene)alkylene(aryleneoxyalkylene) $_q$ moiety.
30. The method of any one of Claims 24-29, wherein R^1 is



31. The method of any one of Claims 24-30, wherein R^1 is



32. The method of Claim 26, wherein

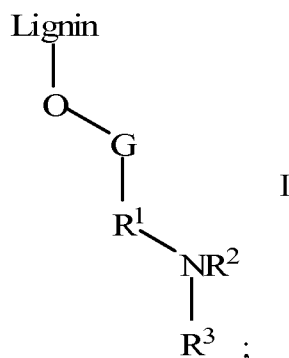


33. The method of any one of Claims 24-32, wherein R^3 is a polypeptide having at least one or more amino acid residue selected from lysine, histidine, arginine, tryptophan, ornithine, 2,4-diaminobutyric acid, 2,3-diaminopropionic acid, and combinations thereof, where at least one basic residue of the polypeptide is protonated.
34. The method of any one of Claims 24-32, wherein R^3 is selected from poly(methylene-co-guanidine), poly-L-lysine, ϵ -poly-L-lysine, poly-L-ornithine, poly-L-arginine, poly-L-histidine, poly-L-tryptophan, poly-2,4-diaminobutyric acid, poly-2,3-diaminopropionic acid, and a protamine.
35. The method of Claim 34, wherein R^3 is poly(methylene-co-guanidine) or ϵ -poly-L-lysine.
36. The method of any one of Claims 24-35, wherein the contacting step is a polymerization conducted in the presence of heat, UV light, a thermal initiator, a photochemical initiator, an oxidant, or a combination thereof.
37. The method of any one of Claims 24-35, wherein the thermal or photochemical initiator is an azonitrile, acyl peroxide, azobisisobutyronitrile, lauroyl peroxide, ammonium persulfate, benzoyl peroxide, 2,2-dimethoxy-2-phenylacetophenone, 2-hydroxy-2-methylpropiophenone, 9,10-phenanthrenequinone, 6-hydroxy-2,4,5,7-tetraiodo-3-oxo-

3H-xanthene-9-carbonitrile, or 3-butyl-2-[5-(3,3-dimethyl-1-propyl-1,3-dihydro-indol-2-ylidene)-penta-1,3-dienyl]-1,1-dimethyl-1H-benzo[e]indolium triphenylbutylborate.

38. The method of Claim 36, wherein the contacting step is a polymerization conducted in the presence of an oxidant, and the oxidant is ceric ammonium nitrate (CAN).
39. The method of any one of Claims 24-38, further comprising the step of at least partially depolymerizing the lignin before the step of contacting the lignin.
40. The method of any one of Claims 24-38, further comprising the step of at least partially depolymerizing the lignin derivative after the step of contacting the lignin.
41. The method of Claim 39 or 40, wherein the depolymerizing step comprises a hydrogenolysis reaction.
42. The method of Claim 41, wherein the hydrogenolysis reaction is conducted in the presence of a transition metal catalyst.
43. The method of Claim 42, wherein the transition metal catalyst comprises nickel.
44. The method of Claim 42 or 43, wherein the transition metal catalyst further comprises a carbene ligand.
45. The method of Claim 44, wherein the carbene ligand is selected from the group consisting of *N,N'*-bis(2,6-diisopropylphenyl)-4,5-dihydroimidazol-2-ylidene (SIPr), bis(1,3-(2,4,6-trimethylphenyl)imidazol-2-ylidene) (IMes), (*N,N'*-bis(2,6-diisopropylphenyl)imidazol-2-ylidene) (IPr), *N,N'*-bis(adamantyl)imidazol-2-ylidene (IAd), 1,3-di-tert-butylimidazol-2-ylidene (ItBu), 1,3-dicyclohexyl-1,3-dihydro-2H-imidazol-2-ylidene (ICy), and 1,3-diisopropyl-4,5-dimethylimidazol-2-ylidene (iPrIM).
46. The method of Claim 44 or 45, wherein the carbene ligand is *N,N'*-bis(2,6-diisopropylphenyl)-4,5-dihydroimidazol-2-ylidene (SIPr).

47. A method of coating an article with a lignin derivative, wherein the method comprises contacting an article with one or more groups of Formula I:



wherein:

G^1 is absent or a polymerizable group;

G is absent or a polymeric group;

R^1 is a bond, alkylene, (alkyleneamino)_q, (alkyleneoxy)_q,
 (alkyleneoxyarylene)_q or (alkyleneoxyarylene)alkylene
 (aryleneoxyalkylene)_q moiety, wherein q is from 1 to 10;

R^2 is H or alkyl; and

R^3 is a polycation.

48. The article of Claim 47, wherein the article is a packaging, pharmaceutical, cosmetic, perfume, thermoplastic, garment, paper product, drywall, medical equipment, or toy.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 12/44547

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - C08K 5/13; A01N 25/00 (2012.01)

USPC - 524/72; 424/405

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)

IPC(8): C08K 5/13; A01N 25/00 (2012.01)

USPC: 524/74; 424/405

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

IPC(8): C08K5/13; C08G8/28; A01N25/00 (2012.01)

USPC: 524/73-74, 799; 514/772

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

PubWEST;PGPB, USPT, EPAB, JPAB, Google Scholar, Dialog

lignin, polycation, peptide, amino acid, histone, microbial, fungal, bacterial, carbene

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2009/0044292 A1 (TIEN et al.) 12 February 2009 (12.02.2009) para[0126]-para[0129]	1-3, 18-19, 21-28, 32 and 47-48
Y	US 6,727,347 B1 (SZEZO) 27 April 2004 (27.04.2004) col 1, ln 10-30, col 11, ln 6-15	1-3, 18-19, 21-28, 32 and 47-48
Y	US 2009/0208366 A1 (SUBRAMANIAN) 20 August 2009 (20.08.2009) para [0015], [0024]	18-19 and 47-48
Y	US 5,512,276 A (LANG et al.) 30 April 1996 (30.04.1996) col 5, ln 20-35, col 7-col 8 Table 1	19, 21-28, 32 and 47-48

☐ Further documents are listed in the continuation of Box C.


* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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

14 August 2012 (14.08.2012)

Date of mailing of the international search report

31 AUG 2012

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents
P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-3201

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PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 12/44547

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:

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.: 4-17, 20, 29-31 and 33-46
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:

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.:

Remark on Protest

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