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(54) Title: POLYPEPTIDES HAVING CELLOBIOHYDROLASE ACTIVITY AND POLYNUCLEOTIDES ENCODING SAME

(57) Abstract: Disclosed are isolated polypeptides having cellobiohydrolase activity, catalytic domains, carbohydrate binding domains and polynucleotides encoding the polypeptides, catalytic domains or carbohydrate binding domains. Furthermore, nucleic acid constructs, vectors and host cells comprising the polynucleotides as well as methods of producing and using the polypeptides, catalytic domains or carbohydrate binding domains are disclosed.



POLYPEPTIDES HAVING CELLOBIOHYDROLASE ACTIVITY AND POLYNUCLEOTIDES ENCODING SAME

Statement as to Rights to Inventions Made Under Federally Sponsored Research and Development

This invention was made with Government support under Cooperative Agreement DE-FC36-08GO18080 awarded by the Department of Energy. The government has certain rights in this invention.

Reference to a Sequence Listing

This application contains a Sequence Listing in computer readable form, which is incorporated herein by reference.

Background of the Invention

Field of the Invention

The present invention relates to polypeptides having cellobiohydrolase activity, catalytic domains, and carbohydrate binding domains, and polynucleotides encoding the polypeptides, catalytic domains, and carbohydrate binding domains. The invention also relates to nucleic acid constructs, vectors, and host cells comprising the polynucleotides as well as methods of producing and using the polypeptides, catalytic domains, and carbohydrate binding domains.

Description of the Related Art

Cellulose is a polymer of the simple sugar glucose covalently linked by beta-1,4-bonds. Many microorganisms produce enzymes that hydrolyze beta-linked glucans. These enzymes include endoglucanases, cellobiohydrolases, and beta-glucosidases. Endoglucanases digest the cellulose polymer at random locations, opening it to attack by cellobiohydrolases. Cellobiohydrolases sequentially release molecules of cellobiose from the ends of the cellulose polymer. Cellobiose is a water-soluble beta-1,4-linked dimer of glucose. Beta-glucosidases hydrolyze cellobiose to glucose.

The conversion of lignocellulosic feedstocks into ethanol has the advantages of the ready availability of large amounts of feedstock, the desirability of avoiding burning or land filling the materials, and the cleanliness of the ethanol fuel. Wood, agricultural residues, herbaceous crops, and municipal solid wastes have been considered as feedstocks for ethanol production. These materials primarily consist of cellulose, hemicellulose, and lignin. Once the lignocellulose

is converted to fermentable sugars, e.g., glucose, the fermentable sugars can easily be fermented by yeast into ethanol.

US2011045546-A1 discloses a *Chrysosporium lucknowense* cellobiohydrolase. US2010159494-A1 discloses a *Chaetomium thermophilum* cellobiohydrolase.

5 There is a need in the art for new polypeptides having cellobiohydrolase activity for use in the degradation of cellulosic materials.

The present invention provides polypeptides having cellobiohydrolase activity and polynucleotides encoding the polypeptides.

10 Summary of the Invention

The present invention relates to isolated polypeptides having cellobiohydrolase activity selected from the group consisting of:

(a) a polypeptide having at least 80% sequence identity to the mature polypeptide of SEQ ID NO: 4 or at least 89% sequence identity to the mature polypeptide of SEQ ID NO: 2;

15 (b) a polypeptide encoded by a polynucleotide that hybridizes under at least medium stringency conditions, at least medium-high stringency conditions, at least high stringency conditions, or at least very high stringency conditions with (i) the mature polypeptide coding sequence of SEQ ID NO: 3 or the mature polypeptide coding sequence of SEQ ID NO: 1, (ii) the cDNA sequence of SEQ ID NO: 3 or the cDNA sequence of SEQ ID NO: 1, or (iii) the full-length complement of (i) or (ii);

20 (c) a polypeptide encoded by a polynucleotide having at least 80% sequence identity to the mature polypeptide coding sequence of SEQ ID NO: 3 or the cDNA sequence thereof; a polypeptide encoded by a polynucleotide having at least 89% sequence identity to the mature polypeptide coding sequence of SEQ ID NO: 1 or the cDNA sequence thereof;

25 (d) a variant of the mature polypeptide of SEQ ID NO: 4 or the mature polypeptide of SEQ ID NO: 2 comprising a substitution, deletion, and/or insertion at one or more (e.g., several) positions; and

(e) a fragment of the polypeptide of (a), (b), (c), or (d) that has cellobiohydrolase activity.

30 The present invention also relates to isolated polypeptides comprising a catalytic domain selected from the group consisting of:

(a) a catalytic domain having at least 80% sequence identity to amino acids 106 to 469 of SEQ ID NO: 4, or a catalytic domain having at least 89% sequence identity to amino acids 44 to 393 of SEQ ID NO: 2;

(b) a catalytic domain encoded by a polynucleotide that hybridizes under at least medium stringency conditions, at least medium-high stringency conditions, at least high stringency conditions, or at least very high stringency conditions with (i) nucleotides 400 to 1659 of SEQ ID NO: 3, or nucleotides 130 to 1376 of SEQ ID NO: 1, (ii) the cDNA sequence thereof, or (iii) the full-length complement of (i) or (ii);

(c) a catalytic domain encoded by a polynucleotide having at least 80% sequence identity to nucleotides 400 to 1659 of SEQ ID NO: 3, or the cDNA sequence thereof, or a catalytic domain encoded by a polynucleotide having at least 89% sequence identity to nucleotides 130 to 1376 of SEQ ID NO: 1 or the cDNA sequence thereof;

(d) a variant of amino acids 106 to 469 of SEQ ID NO: 4 or amino acids 44 to 393 of SEQ ID NO: 2 comprising a substitution, deletion, and/or insertion at one or more (*e.g.*, several) positions; and

(e) a fragment of the catalytic domain of (a), (b), (c), or (d) that has cellobiohydrolase activity.

The present invention also relates to isolated polypeptides comprising a carbohydrate binding domain selected from the group consisting of:

(a) a carbohydrate binding domain having at least 80% sequence identity to amino acids 24 to 63 of SEQ ID NO: 4;

(b) a carbohydrate binding domain encoded by a polynucleotide that hybridizes under at least medium stringency conditions, at least medium-high stringency conditions, at least high stringency conditions, or at least very high stringency conditions with (i) nucleotides 70 to 273 of SEQ ID NO: 3, (ii) the cDNA sequence thereof, or (iii) the full-length complement of (i) or (ii);

(c) a carbohydrate binding domain encoded by a polynucleotide having at least 80% sequence identity to nucleotides 70 to 273 of SEQ ID NO: 3 or the cDNA sequence thereof;

(d) a variant of amino acids 24 to 63 of SEQ ID NO: 4 comprising a substitution, deletion, and/or insertion at one or more (*e.g.*, several) positions; and

(e) a fragment of the carbohydrate binding domain of (a), (b), (c), or (d) that has cellulose binding activity.

The present invention also relates to isolated polynucleotides encoding the polypeptides of the present invention; nucleic acid constructs; recombinant expression vectors; recombinant host cells comprising the polynucleotides; and methods of producing the polypeptides.

The present invention also relates to processes for degrading or converting a cellulosic material, comprising: treating the cellulosic material with an enzyme composition in the

presence of a polypeptide having cellobiohydrolase activity of the present invention. In one aspect, the method further comprises recovering the degraded or converted cellulosic material.

The present invention also relates to processes of producing a fermentation product, comprising: (a) saccharifying a cellulosic material with an enzyme composition in the presence of a polypeptide having cellobiohydrolase activity of the present invention; (b) fermenting the saccharified cellulosic material with one or more (e.g., several) fermenting microorganisms to produce the fermentation product; and (c) recovering the fermentation product from the fermentation.

The present invention also relates to processes of fermenting a cellulosic material, comprising: fermenting the cellulosic material with one or more (e.g., several) fermenting microorganisms, wherein the cellulosic material is saccharified with an enzyme composition in the presence of a polypeptide having cellobiohydrolase activity of the present invention. In one aspect, the fermenting of the cellulosic material produces a fermentation product. In another aspect, the method further comprises recovering the fermentation product from the fermentation.

The present invention also relates to a polynucleotide encoding a signal peptide comprising or consisting of amino acids 1 to 17 of SEQ ID NO: 4, or amino acids 1 to 17 of SEQ ID NO: 2, which is operably linked to a gene encoding a protein; nucleic acid constructs, expression vectors, and recombinant host cells comprising the polynucleotides; and methods of producing a protein.

Brief Description of the Figures

Figure 1 shows the genomic DNA sequence (SEQ ID NO: 1) and the deduced amino acid sequence (SEQ ID NO: 2) of the gene encoding a *Corynascus thermophilus* polypeptide having cellobiohydrolase activity.

Figure 2 shows the genomic DNA sequence (SEQ ID NO: 3) and the deduced amino acid sequence (SEQ ID NO: 4) of the gene encoding a *Corynascus thermophilus* polypeptide having cellobiohydrolase activity.

Figure 3 shows a restriction map of plasmid pGH6_Mf1789.

Figure 4 shows a restriction map of plasmid pGH6_Mf4799.

Definitions

Acetylxyylan esterase: The term "acetylxyylan esterase" means a carboxylesterase (EC 3.1.1.72) that catalyzes the hydrolysis of acetyl groups from polymeric xyylan, acetylated xylose, acetylated glucose, alpha-naphthyl acetate, and *p*-nitrophenyl acetate. For purposes of the

present invention, acetylxylyan esterase activity is determined using 0.5 mM *p*-nitrophenylacetate as substrate in 50 mM sodium acetate pH 5.0 containing 0.01% TWEEN™ 20 (polyoxyethylene sorbitan monolaurate). One unit of acetylxylyan esterase is defined as the amount of enzyme capable of releasing 1 μmole of *p*-nitrophenolate anion per minute at pH 5, 25°C.

Allelic variant: The term “allelic variant” means any of two or more alternative forms of a gene occupying the same chromosomal locus. Allelic variation arises naturally through mutation, and may result in polymorphism within populations. Gene mutations can be silent (no change in the encoded polypeptide) or may encode polypeptides having altered amino acid sequences. An allelic variant of a polypeptide is a polypeptide encoded by an allelic variant of a gene.

Alpha-L-arabinofuranosidase: The term “alpha-L-arabinofuranosidase” means an alpha-L-arabinofuranoside arabinofuranohydrolase (EC 3.2.1.55) that catalyzes the hydrolysis of terminal non-reducing alpha-L-arabinofuranoside residues in alpha-L-arabinosides. The enzyme acts on alpha-L-arabinofuranosides, alpha-L-arabinans containing (1,3)- and/or (1,5)-linkages, arabinoxylans, and arabinogalactans. Alpha-L-arabinofuranosidase is also known as arabinosidase, alpha-arabinosidase, alpha-L-arabinosidase, alpha-arabinofuranosidase, polysaccharide alpha-L-arabinofuranosidase, alpha-L-arabinofuranoside hydrolase, L-arabinosidase, or alpha-L-arabinanase. For purposes of the present invention, alpha-L-arabinofuranosidase activity is determined using 5 mg of medium viscosity wheat arabinoxylan (Megazyme International Ireland, Ltd., Bray, Co. Wicklow, Ireland) per ml of 100 mM sodium acetate pH 5 in a total volume of 200 μl for 30 minutes at 40°C followed by arabinose analysis by AMINEX® HPX-87H column chromatography (Bio-Rad Laboratories, Inc., Hercules, CA, USA).

Alpha-glucuronidase: The term “alpha-glucuronidase” means an alpha-D-glucosiduronate glucuronohydrolase (EC 3.2.1.139) that catalyzes the hydrolysis of an alpha-D-glucuronoside to D-glucuronate and an alcohol. For purposes of the present invention, alpha-glucuronidase activity is determined according to de Vries, 1998, *J. Bacteriol.* 180: 243-249. One unit of alpha-glucuronidase equals the amount of enzyme capable of releasing 1 μmole of glucuronic or 4-O-methylglucuronic acid per minute at pH 5, 40°C.

Beta-glucosidase: The term “beta-glucosidase” means a beta-D-glucoside glucosidase (E.C. 3.2.1.21) that catalyzes the hydrolysis of terminal non-reducing beta-D-glucose residues with the release of beta-D-glucose. For purposes of the present invention, beta-glucosidase activity is determined using *p*-nitrophenyl-beta-D-glucopyranoside as substrate according to the procedure of Venturi *et al.*, 2002, Extracellular beta-D-glucosidase

from *Chaetomium thermophilum* var. *coprophilum*: production, purification and some biochemical properties, *J. Basic Microbiol.* 42: 55-66. One unit of beta-glucosidase is defined as 1.0 μ mole of *p*-nitrophenolate anion produced per minute at 25°C, pH 4.8 from 1 mM *p*-nitrophenyl-beta-D-glucopyranoside as substrate in 50 mM sodium citrate containing 0.01% TWEEN® 20.

Beta-xylosidase: The term "beta-xylosidase" means a beta-D-xyloside xylohydrolase (E.C. 3.2.1.37) that catalyzes the exo-hydrolysis of short beta (1→4)-xylooligosaccharides to remove successive D-xylose residues from non-reducing termini. For purposes of the present invention, one unit of beta-xylosidase is defined as 1.0 μ mole of *p*-nitrophenolate anion produced per minute at 40°C, pH 5 from 1 mM *p*-nitrophenyl-beta-D-xyloside as substrate in 100 mM sodium citrate containing 0.01% TWEEN® 20.

Carbohydrate binding domain: The term "carbohydrate binding domain" means the region of an enzyme that mediates binding of the enzyme to amorphous regions of a cellulose substrate. The carbohydrate binding domain (CBD) is typically found either at the N-terminal or at the C-terminal extremity of an enzyme. The term "carbohydrate binding domain" is also referred herein as "cellulose binding domain".

Catalytic domain: The term "catalytic domain" means the region of an enzyme containing the catalytic machinery of the enzyme.

cDNA: The term "cDNA" means a DNA molecule that can be prepared by reverse transcription from a mature, spliced, mRNA molecule obtained from a eukaryotic or prokaryotic cell. cDNA lacks intron sequences that may be present in the corresponding genomic DNA. The initial, primary RNA transcript is a precursor to mRNA that is processed through a series of steps, including splicing, before appearing as mature spliced mRNA.

Cellobiohydrolase: The term "cellobiohydrolase" means a 1,4-beta-D-glucan cellobiohydrolase (E.C. 3.2.1.91 and E.C. 3.2.1.176) that catalyzes the hydrolysis of 1,4-beta-D-glucosidic linkages in cellulose, cellooligosaccharides, or any beta-1,4-linked glucose containing polymer, releasing cellobiose from the reducing end (cellobiohydrolase I) or non-reducing end (cellobiohydrolase II) of the chain (Teeri, 1997, Crystalline cellulose degradation: New insight into the function of cellobiohydrolases, *Trends in Biotechnology* 15: 160-167; Teeri *et al.*, 1998, *Trichoderma reesei* cellobiohydrolases: why so efficient on crystalline cellulose?, *Biochem. Soc. Trans.* 26: 173-178). Cellobiohydrolase activity is determined according to the procedures described by Lever *et al.*, 1972, *Anal. Biochem.* 47: 273-279; van Tilbeurgh *et al.*, 1982, *FEBS Letters*, 149: 152-156; van Tilbeurgh and Claeysens, 1985, *FEBS Letters*, 187: 283-288; and Tomme *et al.*, 1988, *Eur. J. Biochem.* 170: 575-581. In the present invention, the Tomme *et al.*

method can be used to determine cellobiohydrolase activity. Alternatively, the cellobiohydrolase activity can be determined using microcrystalline cellulose according to the procedure described in Example 8 of the present invention.

The polypeptides of the present invention have at least 20%, e.g., at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, at least 90%, at least 95%, and 100% of the cellobiohydrolase activity of the mature polypeptide of SEQ ID NO: 4 or the mature polypeptide of SEQ ID NO: 2.

Cellulolytic enzyme or cellulase: The term "cellulolytic enzyme" or "cellulase" means one or more (e.g., several) enzymes that hydrolyze a cellulosic material. Such enzymes include endoglucanase(s), cellobiohydrolase(s), beta-glucosidase(s), or combinations thereof. The two basic approaches for measuring cellulolytic activity include: (1) measuring the total cellulolytic activity, and (2) measuring the individual cellulolytic activities (endoglucanases, cellobiohydrolases, and beta-glucosidases) as reviewed in Zhang *et al.*, Outlook for cellulase improvement: Screening and selection strategies, 2006, *Biotechnology Advances* 24: 452-481. Total cellulolytic activity is usually measured using insoluble substrates, including Whatman No. 1 filter paper, microcrystalline cellulose, bacterial cellulose, algal cellulose, cotton, pretreated lignocellulose, etc. The most common total cellulolytic activity assay is the filter paper assay using Whatman No. 1 filter paper as the substrate. The assay was established by the International Union of Pure and Applied Chemistry (IUPAC) (Ghose, 1987, Measurement of cellulase activities, *Pure Appl. Chem.* 59: 257-68).

For purposes of the present invention, cellulolytic enzyme activity is determined by measuring the increase in hydrolysis of a cellulosic material by cellulolytic enzyme(s) under the following conditions: 1-50 mg of cellulolytic enzyme protein/g of cellulose in PCS (or other pretreated cellulosic material) for 3-7 days at a suitable temperature, e.g., 50°C, 55°C, or 60°C, compared to a control hydrolysis without addition of cellulolytic enzyme protein. Typical conditions are 1 ml reactions, washed or unwashed PCS, 5% insoluble solids, 50 mM sodium acetate pH 5, 1 mM MnSO₄, 50°C, 55°C, or 60°C, 72 hours, sugar analysis by AMINEX® HPX-87H column (Bio-Rad Laboratories, Inc., Hercules, CA, USA).

Cellulosic material: The term "cellulosic material" means any material containing cellulose. The predominant polysaccharide in the primary cell wall of biomass is cellulose, the second most abundant is hemicellulose, and the third is pectin. The secondary cell wall, produced after the cell has stopped growing, also contains polysaccharides and is strengthened by polymeric lignin covalently cross-linked to hemicellulose. Cellulose is a homopolymer of anhydrocellobiose and thus a linear beta-(1-4)-D-glucan, while hemicelluloses include a variety

of compounds, such as xylans, xyloglucans, arabinoxylans, and mannans in complex branched structures with a spectrum of substituents. Although generally polymorphous, cellulose is found in plant tissue primarily as an insoluble crystalline matrix of parallel glucan chains. Hemicelluloses usually hydrogen bond to cellulose, as well as to other hemicelluloses, which help stabilize the cell wall matrix.

Cellulose is generally found, for example, in the stems, leaves, hulls, husks, and cobs of plants or leaves, branches, and wood of trees. The cellulosic material can be, but is not limited to, agricultural residue, herbaceous material (including energy crops), municipal solid waste, pulp and paper mill residue, waste paper, and wood (including forestry residue) (see, for example, Wiselogle *et al.*, 1995, in Handbook on Bioethanol (Charles E. Wyman, editor), pp.105-118, Taylor & Francis, Washington D.C.; Wyman, 1994, *Bioresource Technology* 50: 3-16; Lynd, 1990, *Applied Biochemistry and Biotechnology* 24/25: 695-719; Mosier *et al.*, 1999, Recent Progress in Bioconversion of Lignocellulosics, in *Advances in Biochemical Engineering/Biotechnology*, T. Scheper, managing editor, Volume 65, pp.23-40, Springer-Verlag, New York). It is understood herein that the cellulose may be in the form of lignocellulose, a plant cell wall material containing lignin, cellulose, and hemicellulose in a mixed matrix. In a preferred aspect, the cellulosic material is any biomass material. In another preferred aspect, the cellulosic material is lignocellulose, which comprises cellulose, hemicelluloses, and lignin.

In one aspect, the cellulosic material is agricultural residue. In another aspect, the cellulosic material is herbaceous material (including energy crops). In another aspect, the cellulosic material is municipal solid waste. In another aspect, the cellulosic material is pulp and paper mill residue. In another aspect, the cellulosic material is waste paper. In another aspect, the cellulosic material is wood (including forestry residue).

In another aspect, the cellulosic material is arundo. In another aspect, the cellulosic material is bagasse. In another aspect, the cellulosic material is bamboo. In another aspect, the cellulosic material is corn cob. In another aspect, the cellulosic material is corn fiber. In another aspect, the cellulosic material is corn stover. In another aspect, the cellulosic material is miscanthus. In another aspect, the cellulosic material is orange peel. In another aspect, the cellulosic material is rice straw. In another aspect, the cellulosic material is switchgrass. In another aspect, the cellulosic material is wheat straw.

In another aspect, the cellulosic material is aspen. In another aspect, the cellulosic material is eucalyptus. In another aspect, the cellulosic material is fir. In another aspect, the cellulosic material is pine. In another aspect, the cellulosic material is poplar. In another aspect,

the cellulosic material is spruce. In another aspect, the cellulosic material is willow.

In another aspect, the cellulosic material is algal cellulose. In another aspect, the cellulosic material is bacterial cellulose. In another aspect, the cellulosic material is cotton linter. In another aspect, the cellulosic material is filter paper. In another aspect, the cellulosic material is microcrystalline cellulose. In another aspect, the cellulosic material is phosphoric-acid treated cellulose.

In another aspect, the cellulosic material is an aquatic biomass. As used herein the term "aquatic biomass" means biomass produced in an aquatic environment by a photosynthesis process. The aquatic biomass can be algae, emergent plants, floating-leaf plants, or submerged plants.

The cellulosic material may be used as is or may be subjected to pretreatment, using conventional methods known in the art, as described herein. In a preferred aspect, the cellulosic material is pretreated.

Coding sequence: The term "coding sequence" means a polynucleotide, which directly specifies the amino acid sequence of a polypeptide. The boundaries of the coding sequence are generally determined by an open reading frame, which begins with a start codon such as ATG, GTG, or TTG and ends with a stop codon such as TAA, TAG, or TGA. The coding sequence may be a genomic DNA, cDNA, synthetic DNA, or a combination thereof.

Control sequences: The term "control sequences" means nucleic acid sequences necessary for expression of a polynucleotide encoding a mature polypeptide of the present invention. Each control sequence may be native (*i.e.*, from the same gene) or foreign (*i.e.*, from a different gene) to the polynucleotide encoding the polypeptide or native or foreign to each other. Such control sequences include, but are not limited to, a leader, polyadenylation sequence, propeptide sequence, promoter, signal peptide sequence, and transcription terminator. At a minimum, the control sequences include a promoter, and transcriptional and translational stop signals. The control sequences may be provided with linkers for the purpose of introducing specific restriction sites facilitating ligation of the control sequences with the coding region of the polynucleotide encoding a polypeptide.

Endoglucanase: The term "endoglucanase" means an endo-1,4-(1,3;1,4)-beta-D-glucan 4-glucanohydrolase (E.C. 3.2.1.4) that catalyzes endohydrolysis of 1,4-beta-D-glycosidic linkages in cellulose, cellulose derivatives (such as carboxymethyl cellulose and hydroxyethyl cellulose), lichenin, beta-1,4 bonds in mixed beta-1,3 glucans such as cereal beta-D-glucans or xyloglucans, and other plant material containing cellulosic components. Endoglucanase activity can be determined by measuring reduction in substrate viscosity or increase in reducing ends

determined by a reducing sugar assay (Zhang *et al.*, 2006, *Biotechnology Advances* 24: 452-481). For purposes of the present invention, endoglucanase activity is determined using carboxymethyl cellulose (CMC) as substrate according to the procedure of Ghose, 1987, *Pure and Appl. Chem.* 59: 257-268, at pH 5, 40°C.

5 **Expression:** The term “expression” includes any step involved in the production of a polypeptide including, but not limited to, transcription, post-transcriptional modification, translation, post-translational modification, and secretion.

10 **Expression vector:** The term “expression vector” means a linear or circular DNA molecule that comprises a polynucleotide encoding a polypeptide and is operably linked to control sequences that provide for its expression.

15 **Family 61 glycoside hydrolase:** The term “Family 61 glycoside hydrolase” or “Family GH61” or “GH61” means a polypeptide falling into the glycoside hydrolase Family 61 according to Henrissat B., 1991, A classification of glycosyl hydrolases based on amino-acid sequence similarities, *Biochem. J.* 280: 309-316, and Henrissat B., and Bairoch A., 1996, Updating the
20 sequence-based classification of glycosyl hydrolases, *Biochem. J.* 316: 695-696. The enzymes in this family were originally classified as a glycoside hydrolase family based on measurement of very weak endo-1,4-beta-D-glucanase activity in one family member. The structure and mode of action of these enzymes are non-canonical and they cannot be considered as bona fide glycosidases. However, they are kept in the CAZy classification on the basis of their capacity to
25 enhance the breakdown of lignocellulose when used in conjunction with a cellulase or a mixture of cellulases.

30 **Feruloyl esterase:** The term “feruloyl esterase” means a 4-hydroxy-3-methoxycinnamoyl-sugar hydrolase (EC 3.1.1.73) that catalyzes the hydrolysis of 4-hydroxy-3-methoxycinnamoyl (feruloyl) groups from esterified sugar, which is usually arabinose in natural
25 biomass substrates, to produce ferulate (4-hydroxy-3-methoxycinnamate). Feruloyl esterase is also known as ferulic acid esterase, hydroxycinnamoyl esterase, FAE-III, cinnamoyl ester hydrolase, FAEA, cinnAE, FAE-I, or FAE-II. For purposes of the present invention, feruloyl esterase activity is determined using 0.5 mM *p*-nitrophenylferulate as substrate in 50 mM sodium acetate pH 5.0. One unit of feruloyl esterase equals the amount of enzyme capable of
30 releasing 1 μmole of *p*-nitrophenolate anion per minute at pH 5, 25°C.

Fragment: The term “fragment” means a polypeptide or a catalytic domain or carbohydrate binding domain having one or more (e.g., several) amino acids absent from the amino and/or carboxyl terminus of a mature polypeptide or domain; wherein the fragment has cellobiohydrolase activity or cellulose binding activity. In one aspect, a fragment contains at

least 382 amino acid residues, e.g., at least 405 amino acid residues or at least 428 amino acid residues of SEQ ID NO: 4. In another aspect, a fragment contains at least 319 amino acid residues, e.g., at least 338 amino acid residues or at least 357 amino acid residues of SEQ ID NO: 2.

5 **Hemicellulolytic enzyme or hemicellulase:** The term “hemicellulolytic enzyme” or “hemicellulase” means one or more (e.g., several) enzymes that hydrolyze a hemicellulosic material. See, for example, Shallom, D. and Shoham, Y. Microbial hemicellulases. *Current Opinion In Microbiology*, 2003, 6(3): 219-228). Hemicellulases are key components in the degradation of plant biomass. Examples of hemicellulases include, but are not limited to, an
10 acetylmannan esterase, an acetylxyln esterase, an arabinanase, an arabinofuranosidase, a coumaric acid esterase, a feruloyl esterase, a galactosidase, a glucuronidase, a glucuronoyl esterase, a mannanase, a mannosidase, a xylanase, and a xylosidase. The substrates of these enzymes, the hemicelluloses, are a heterogeneous group of branched and linear polysaccharides that are bound via hydrogen bonds to the cellulose microfibrils in the plant cell
15 wall, crosslinking them into a robust network. Hemicelluloses are also covalently attached to lignin, forming together with cellulose a highly complex structure. The variable structure and organization of hemicelluloses require the concerted action of many enzymes for its complete degradation. The catalytic modules of hemicellulases are either glycoside hydrolases (GHs) that hydrolyze glycosidic bonds, or carbohydrate esterases (CEs), which hydrolyze ester linkages of
20 acetate or ferulic acid side groups. These catalytic modules, based on homology of their primary sequence, can be assigned into GH and CE families. Some families, with an overall similar fold, can be further grouped into clans, marked alphabetically (e.g., GH-A). A most informative and updated classification of these and other carbohydrate active enzymes is available in the Carbohydrate-Active Enzymes (CAZy) database. Hemicellulolytic enzyme activities can be
25 measured according to Ghose and Bisaria, 1987, *Pure & Appl. Chem.* 59: 1739-1752, at a suitable temperature, e.g., 50°C, 55°C, or 60°C, and pH, e.g., 5.0 or 5.5.

High stringency conditions: The term “high stringency conditions” means for probes of at least 100 nucleotides in length, prehybridization and hybridization at 42°C in 5X SSPE, 0.3% SDS, 200 micrograms/ml sheared and denatured salmon sperm DNA, and 50% formamide,
30 following standard Southern blotting procedures for 12 to 24 hours. The carrier material is finally washed three times each for 15 minutes using 2X SSC, 0.2% SDS at 65°C.

Host cell: The term “host cell” means any cell type that is susceptible to transformation, transfection, transduction, or the like with a nucleic acid construct or expression vector comprising a polynucleotide of the present invention. The term “host cell” encompasses any

progeny of a parent cell that is not identical to the parent cell due to mutations that occur during replication.

Isolated: The term "isolated" means a substance in a form or environment that does not occur in nature. Non-limiting examples of isolated substances include (1) any non-naturally occurring substance, (2) any substance including, but not limited to, any enzyme, variant, nucleic acid, protein, peptide or cofactor, that is at least partially removed from one or more or all of the naturally occurring constituents with which it is associated in nature; (3) any substance modified by the hand of man relative to that substance found in nature; or (4) any substance modified by increasing the amount of the substance relative to other components with which it is naturally associated (e.g., recombinant production in a host cell; multiple copies of a gene encoding the substance; and use of a stronger promoter than the promoter naturally associated with the gene encoding the substance).

Low stringency conditions: The term "low stringency conditions" means for probes of at least 100 nucleotides in length, prehybridization and hybridization at 42°C in 5X SSPE, 0.3% SDS, 200 micrograms/ml sheared and denatured salmon sperm DNA, and 25% formamide, following standard Southern blotting procedures for 12 to 24 hours. The carrier material is finally washed three times each for 15 minutes using 2X SSC, 0.2% SDS at 50°C.

Mature polypeptide: The term "mature polypeptide" means a polypeptide in its final form following translation and any post-translational modifications, such as N-terminal processing, C-terminal truncation, glycosylation, phosphorylation, etc. In one aspect, the mature polypeptide is amino acids 18 to 469 of SEQ ID NO: 4 (P24FVR) based on the SignalP program (Nielsen *et al.*, 1997, *Protein Engineering* 10: 1-6) that predicts amino acids 1 to 17 of SEQ ID NO: 4 are a signal peptide. In another aspect, the mature polypeptide is amino acids 18 to 394 of SEQ ID NO: 2 (P24FVQ) based on the SignalP program (Nielsen *et al.*, 1997, *Protein Engineering* 10: 1-6) that predicts amino acids 1 to 17 of SEQ ID NO: 2 are a signal peptide. It is known in the art that a host cell may produce a mixture of two or more different mature polypeptides (*i.e.*, with a different C-terminal and/or N-terminal amino acid) expressed by the same polynucleotide. It is also known in the art that different host cells process polypeptides differently, and thus, one host cell expressing a polynucleotide may produce a different mature polypeptide (e.g., having a different C-terminal and/or N-terminal amino acid) as compared to another host cell expressing the same polynucleotide.

Mature polypeptide coding sequence: The term "mature polypeptide coding sequence" means a polynucleotide that encodes a mature polypeptide having cellobiohydrolase activity. In one aspect, the mature polypeptide coding sequence is nucleotides 52 to 1659 of

SEQ ID NO: 3 or the cDNA sequence thereof based on the SignalP program (Nielsen *et al.*, 1997, *supra*) that predicts nucleotides 1 to 51 of SEQ ID NO: 3 encode a signal peptide. In another aspect, the mature polypeptide coding sequence is nucleotides 52 to 1379 of SEQ ID NO: 1 or the cDNA sequence thereof based on the SignalP program (Nielsen *et al.*, 1997, *supra*) that predicts nucleotides 1 to 51 of SEQ ID NO: 1 encode a signal peptide.

Medium stringency conditions: The term "medium stringency conditions" means for probes of at least 100 nucleotides in length, prehybridization and hybridization at 42°C in 5X SSPE, 0.3% SDS, 200 micrograms/ml sheared and denatured salmon sperm DNA, and 35% formamide, following standard Southern blotting procedures for 12 to 24 hours. The carrier material is finally washed three times each for 15 minutes using 2X SSC, 0.2% SDS at 55°C.

Medium-high stringency conditions: The term "medium-high stringency conditions" means for probes of at least 100 nucleotides in length, prehybridization and hybridization at 42°C in 5X SSPE, 0.3% SDS, 200 micrograms/ml sheared and denatured salmon sperm DNA, and 35% formamide, following standard Southern blotting procedures for 12 to 24 hours. The carrier material is finally washed three times each for 15 minutes using 2X SSC, 0.2% SDS at 60°C.

Nucleic acid construct: The term "nucleic acid construct" means a nucleic acid molecule, either single- or double-stranded, which is isolated from a naturally occurring gene or is modified to contain segments of nucleic acids in a manner that would not otherwise exist in nature or which is synthetic, which comprises one or more control sequences.

Operably linked: The term "operably linked" means a configuration in which a control sequence is placed at an appropriate position relative to the coding sequence of a polynucleotide such that the control sequence directs expression of the coding sequence.

Polypeptide having cellulolytic enhancing activity: The term "polypeptide having cellulolytic enhancing activity" means a GH61 polypeptide that catalyzes the enhancement of the hydrolysis of a cellulosic material by enzyme having cellulolytic activity. For purposes of the present invention, cellulolytic enhancing activity is determined by measuring the increase in reducing sugars or the increase of the total of cellobiose and glucose from the hydrolysis of a cellulosic material by cellulolytic enzyme under the following conditions: 1-50 mg of total protein/g of cellulose in pretreated corn stover (PCS), wherein total protein is comprised of 50-99.5% w/w cellulolytic enzyme protein and 0.5-50% w/w protein of a GH61 polypeptide having cellulolytic enhancing activity for 1-7 days at a suitable temperature, *e.g.*, 50°C, 55°C, or 60°C, and a suitable pH such 4-9, *e.g.*, 5.0 or 5.5, compared to a control hydrolysis with equal total protein loading without cellulolytic enhancing activity (1-50 mg of cellulolytic protein/g of

cellulose in PCS). In a preferred aspect, a mixture of CELLUCLAST® 1.5L (Novozymes A/S, Bagsværd, Denmark) in the presence of 2-3% of total protein weight *Aspergillus oryzae* beta-glucosidase (recombinantly produced in *Aspergillus oryzae* according to WO 02/095014) or 2-3% of total protein weight *Aspergillus fumigatus* beta-glucosidase (recombinantly produced in *Aspergillus oryzae* as described in WO 2002/095014) of cellulase protein loading is used as the source of the cellulolytic activity.

The GH61 polypeptides having cellulolytic enhancing activity enhance the hydrolysis of a cellulosic material catalyzed by enzyme having cellulolytic activity by reducing the amount of cellulolytic enzyme required to reach the same degree of hydrolysis preferably at least 1.01-fold, e.g., at least 1.05-fold, at least 1.10-fold, at least 1.25-fold, at least 1.5-fold, at least 2-fold, at least 3-fold, at least 4-fold, at least 5-fold, at least 10-fold, or at least 20-fold.

Pretreated corn stover: The term "PCS" or "Pretreated Corn Stover" means a cellulosic material derived from corn stover by treatment with heat and dilute sulfuric acid, alkaline pretreatment, or neutral pretreatment.

Sequence identity: The relatedness between two amino acid sequences or between two nucleotide sequences is described by the parameter "sequence identity".

For purposes of the present invention, the sequence identity between two amino acid sequences is determined using the Needleman-Wunsch algorithm (Needleman and Wunsch, 1970, *J. Mol. Biol.* 48: 443-453) as implemented in the Needle program of the EMBOSS package (EMBOSS: The European Molecular Biology Open Software Suite, Rice *et al.*, 2000, *Trends Genet.* 16: 276-277), preferably version 3.0.0, 5.0.0 or later. The parameters used are gap open penalty of 10, gap extension penalty of 0.5, and the EBLOSUM62 (EMBOSS version of BLOSUM62) substitution matrix. The output of Needle labeled "longest identity" (obtained using the -nobrief option) is used as the percent identity and is calculated as follows:

$$(\text{Identical Residues} \times 100) / (\text{Length of Alignment} - \text{Total Number of Gaps in Alignment})$$

For purposes of the present invention, the sequence identity between two deoxyribonucleotide sequences is determined using the Needleman-Wunsch algorithm (Needleman and Wunsch, 1970, *supra*) as implemented in the Needle program of the EMBOSS package (EMBOSS: The European Molecular Biology Open Software Suite, Rice *et al.*, 2000, *supra*), preferably version 3.0.0, 5.0.0 or later. The parameters used are gap open penalty of 10, gap extension penalty of 0.5, and the EDNAFULL (EMBOSS version of NCBI NUC4.4) substitution matrix. The output of Needle labeled "longest identity" (obtained using the -nobrief option) is used as the percent identity and is calculated as follows:

(Identical Deoxyribonucleotides x 100)/(Length of Alignment – Total Number of Gaps in Alignment)

Subsequence: The term “subsequence” means a polynucleotide having one or more (e.g., several) nucleotides absent from the 5' and/or 3' end of a mature polypeptide coding sequence or domain; wherein the subsequence encodes a fragment having cellobiohydrolase activity or cellulose binding activity. In one aspect, a subsequence contains at least 1146 nucleotides, e.g., at least 1215 nucleotides or at least 1284 nucleotides.of SEQ ID NO: 3. In another aspect, a subsequence contains at least 957 nucleotides, e.g., at least 1014 nucleotides or at least 1071 nucleotides.of SEQ ID NO: 1.

Variant: The term “variant” means a polypeptide having cellobiohydrolase activity comprising an alteration, i.e., a substitution, insertion, and/or deletion, at one or more (e.g., several) positions. A substitution means replacement of the amino acid occupying a position with a different amino acid; a deletion means removal of the amino acid occupying a position; and an insertion means adding an amino acid adjacent to and immediately following the amino acid occupying a position.

Very high stringency conditions: The term “very high stringency conditions” means for probes of at least 100 nucleotides in length, prehybridization and hybridization at 42°C in 5X SSPE, 0.3% SDS, 200 micrograms/ml sheared and denatured salmon sperm DNA, and 50% formamide, following standard Southern blotting procedures for 12 to 24 hours. The carrier material is finally washed three times each for 15 minutes using 2X SSC, 0.2% SDS at 70°C.

Very low stringency conditions: The term “very low stringency conditions” means for probes of at least 100 nucleotides in length, prehybridization and hybridization at 42°C in 5X SSPE, 0.3% SDS, 200 micrograms/ml sheared and denatured salmon sperm DNA, and 25% formamide, following standard Southern blotting procedures for 12 to 24 hours. The carrier material is finally washed three times each for 15 minutes using 2X SSC, 0.2% SDS at 45°C.

Xylan-containing material: The term “xylan-containing material” means any material comprising a plant cell wall polysaccharide containing a backbone of beta-(1-4)-linked xylose residues. Xylans of terrestrial plants are heteropolymers possessing a beta-(1-4)-D-xylopyranose backbone, which is branched by short carbohydrate chains. They comprise D-glucuronic acid or its 4-O-methyl ether, L-arabinose, and/or various oligosaccharides, composed of D-xylose, L-arabinose, D- or L-galactose, and D-glucose. Xylan-type polysaccharides can be divided into homoxylans and heteroxylans, which include glucuronoxylans, (arabino)glucuronoxylans, (glucurono)arabinoxylans, arabinoxylans, and complex heteroxylans. See, for example, Ebringerova *et al.*, 2005, *Adv. Polym. Sci.* 186: 1–67.

In the processes of the present invention, any material containing xylan may be used. In a preferred aspect, the xylan-containing material is lignocellulose.

Xylan degrading activity or xylanolytic activity: The term "xylan degrading activity" or "xylanolytic activity" means a biological activity that hydrolyzes xylan-containing material. The two basic approaches for measuring xylanolytic activity include: (1) measuring the total xylanolytic activity, and (2) measuring the individual xylanolytic activities (e.g., endoxylanases, beta-xylosidases, arabinofuranosidases, alpha-glucuronidases, acetylxylan esterases, feruloyl esterases, and alpha-glucuronyl esterases). Recent progress in assays of xylanolytic enzymes was summarized in several publications including Biely and Puchard, 2006, Recent progress in the assays of xylanolytic enzymes, *Journal of the Science of Food and Agriculture* 86(11): 1636-1647; Spanikova and Biely, 2006, Glucuronoyl esterase - Novel carbohydrate esterase produced by *Schizophyllum commune*, *FEBS Letters* 580(19): 4597-4601; Hermann, Vrsanska, Jurickova, Hirsch, Biely, and Kubicek, 1997, The beta-D-xylosidase of *Trichoderma reesei* is a multifunctional beta-D-xylan xylohydrolase, *Biochemical Journal* 321: 375-381.

Total xylan degrading activity can be measured by determining the reducing sugars formed from various types of xylan, including, for example, oat spelt, beechwood, and larchwood xylans, or by photometric determination of dyed xylan fragments released from various covalently dyed xylans. The most common total xylanolytic activity assay is based on production of reducing sugars from polymeric 4-O-methyl glucuronoxylan as described in Bailey, Biely, Poutanen, 1992, Interlaboratory testing of methods for assay of xylanase activity, *Journal of Biotechnology* 23(3): 257-270. Xylanase activity can also be determined with 0.2% AZCL-arabinoxylan as substrate in 0.01% TRITON® X-100 (4-(1,1,3,3-tetramethylbutyl)phenyl-polyethylene glycol) and 200 mM sodium phosphate buffer pH 6 at 37°C. One unit of xylanase activity is defined as 1.0 μmole of azurine produced per minute at 37°C, pH 6 from 0.2% AZCL-arabinoxylan as substrate in 200 mM sodium phosphate pH 6 buffer.

For purposes of the present invention, xylan degrading activity is determined by measuring the increase in hydrolysis of birchwood xylan (Sigma Chemical Co., Inc., St. Louis, MO, USA) by xylan-degrading enzyme(s) under the following typical conditions: 1 ml reactions, 5 mg/ml substrate (total solids), 5 mg of xylanolytic protein/g of substrate, 50 mM sodium acetate pH 5, 50°C, 24 hours, sugar analysis using *p*-hydroxybenzoic acid hydrazide (PHBAH) assay as described by Lever, 1972, A new reaction for colorimetric determination of carbohydrates, *Anal. Biochem* 47: 273-279.

Xylanase: The term "xylanase" means a 1,4-beta-D-xylan-xylohydrolase (E.C. 3.2.1.8) that catalyzes the endohydrolysis of 1,4-beta-D-xylosidic linkages in xylans. For purposes of the

present invention, xylanase activity is determined with 0.2% AZCL-arabinoxylan as substrate in 0.01% TRITON® X-100 and 200 mM sodium phosphate buffer pH 6 at 37°C. One unit of xylanase activity is defined as 1.0 μ mole of azurine produced per minute at 37°C, pH 6 from 0.2% AZCL-arabinoxylan as substrate in 200 mM sodium phosphate pH 6 buffer.

5

Detailed Description of the Invention

Polypeptides Having Cellobiohydrolase Activity

In an embodiment, the present invention relates to isolated polypeptides having a sequence identity to the mature polypeptide of SEQ ID NO: 4 of at least 80%, e.g., at least 81%,
10 at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%,
at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%,
at least 96%, at least 97%, at least 98%, at least 99%, or 100%, which have cellobiohydrolase
activity. In an embodiment, the present invention relates to isolated polypeptides having a
sequence identity to the mature polypeptide of SEQ ID NO: 2 of at least 89%, e.g., at least 90%,
15 at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%,
at least 98%, at least 99%, or 100%, which have cellobiohydrolase activity. In one aspect, the
polypeptides differ by up to 10 amino acids, e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10, from the mature
polypeptide of SEQ ID NO: 4, or the mature polypeptide of SEQ ID NO: 2.

A polypeptide of the present invention preferably comprises or consists of the amino acid
20 sequence of SEQ ID NO: 4 or SEQ ID NO: 2 or an allelic variant thereof; or is a fragment
thereof having cellobiohydrolase activity. In another aspect, the polypeptide comprises or
consists of the mature polypeptide of SEQ ID NO: 4 or the mature polypeptide of SEQ ID NO:
2. In another aspect, the polypeptide comprises or consists of amino acids 18 to 469 of SEQ ID
NO: 4, or amino acids 18 to 394 of SEQ ID NO: 2.

25 In another embodiment, the present invention relates to an isolated polypeptide having
cellobiohydrolase activity encoded by a polynucleotide that hybridizes under very low stringency
conditions, low stringency conditions, medium stringency conditions, medium-high stringency
conditions, high stringency conditions, or very high stringency conditions with (i) the mature
polypeptide coding sequence of SEQ ID NO: 3 or the mature polypeptide coding sequence of
30 SEQ ID NO: 1; (ii) the cDNA sequence of SEQ ID NO: 3 or the cDNA sequence of SEQ ID NO:
1, or (iii) the full-length complement of (i) or (ii) (Sambrook *et al.*, 1989, *Molecular Cloning, A
Laboratory Manual*, 2d edition, Cold Spring Harbor, New York).

The polynucleotide of SEQ ID NO: 3 or SEQ ID NO: 1, or a subsequence thereof, as
well as the polypeptide of SEQ ID NO: 4 or SEQ ID NO: 2, or a fragment thereof, may be used

to design nucleic acid probes to identify and clone DNA encoding polypeptides having cellobiohydrolase activity from strains of different genera or species according to methods well known in the art. In particular, such probes can be used for hybridization with the genomic DNA or cDNA of a cell of interest, following standard Southern blotting procedures, in order to identify and isolate the corresponding gene therein. Such probes can be considerably shorter than the entire sequence, but should be at least 15, e.g., at least 25, at least 35, or at least 70 nucleotides in length. Preferably, the nucleic acid probe is at least 100 nucleotides in length, e.g., at least 200 nucleotides, at least 300 nucleotides, at least 400 nucleotides, at least 500 nucleotides, at least 600 nucleotides, at least 700 nucleotides, at least 800 nucleotides, or at least 900 nucleotides in length. Both DNA and RNA probes can be used. The probes are typically labeled for detecting the corresponding gene (for example, with ^{32}P , ^3H , ^{35}S , biotin, or avidin). Such probes are encompassed by the present invention.

A genomic DNA or cDNA library prepared from such other strains may be screened for DNA that hybridizes with the probes described above and encodes a polypeptide having cellobiohydrolase activity. Genomic or other DNA from such other strains may be separated by agarose or polyacrylamide gel electrophoresis, or other separation techniques. DNA from the libraries or the separated DNA may be transferred to and immobilized on nitrocellulose or other suitable carrier material. In order to identify a clone or DNA that hybridizes with SEQ ID NO: 1 or SEQ ID NO: 3, or the mature polypeptide coding sequence thereof, or a subsequence thereof, the carrier material is used in a Southern blot.

For purposes of the present invention, hybridization indicates that the polynucleotides hybridize to a labeled nucleic acid probe corresponding to (i) SEQ ID NO: 3 or SEQ ID NO: 1; (ii) the mature polypeptide coding sequence of SEQ ID NO: 3 or the mature polypeptide coding sequence of SEQ ID NO: 1; (iii) the cDNA sequence of SEQ ID NO: 3 or the cDNA sequence of SEQ ID NO: 1; (iv) the full-length complement thereof; or (v) a subsequence thereof; under very low to very high stringency conditions. Molecules to which the nucleic acid probe hybridizes under these conditions can be detected using, for example, X-ray film or any other detection means known in the art.

In one aspect, the nucleic acid probe is a polynucleotide that encodes the polypeptide of SEQ ID NO: 4 or SEQ ID NO: 2; the mature polypeptide thereof; or a fragment thereof. In another aspect, the nucleic acid probe is SEQ ID NO: 3 or SEQ ID NO: 1; or the mature polypeptide coding sequence of SEQ ID NO: 3 or the mature polypeptide coding sequence of SEQ ID NO: 1; or the cDNA sequence of SEQ ID NO: 3 or the cDNA sequence of SEQ ID NO: 1.

In another embodiment, the present invention relates to isolated polypeptides having cellobiohydrolase activity encoded by polynucleotides having a sequence identity to the mature polypeptide coding sequence of SEQ ID NO: 3, or the cDNA sequence thereof, of at least 80%, e.g., at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100%; or the mature polypeptide coding sequence of SEQ ID NO: 1 or the cDNA sequence thereof, of at least 89%, e.g., at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100%.

In another embodiment, the present invention relates to variants of the mature polypeptide of SEQ ID NO: 4 or the mature polypeptide of SEQ ID NO: 2 comprising a substitution, deletion, and/or insertion at one or more (e.g., several) positions. In an aspect, the number of amino acid substitutions, deletions and/or insertions introduced into the mature polypeptide of SEQ ID NO: 4 or the mature polypeptide of SEQ ID NO: 2 is up to 10, e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10. The amino acid changes may be of a minor nature, that is conservative amino acid substitutions or insertions that do not significantly affect the folding and/or activity of the protein; small deletions, typically of 1-30 amino acids; small amino- or carboxyl-terminal extensions, such as an amino-terminal methionine residue; a small linker peptide of up to 20-25 residues; or a small extension that facilitates purification by changing net charge or another function, such as a poly-histidine tract, an antigenic epitope or a binding domain.

Examples of conservative substitutions are within the groups of basic amino acids (arginine, lysine and histidine), acidic amino acids (glutamic acid and aspartic acid), polar amino acids (glutamine and asparagine), hydrophobic amino acids (leucine, isoleucine and valine), aromatic amino acids (phenylalanine, tryptophan and tyrosine), and small amino acids (glycine, alanine, serine, threonine and methionine). Amino acid substitutions that do not generally alter specific activity are known in the art and are described, for example, by H. Neurath and R.L. Hill, 1979, *In, The Proteins*, Academic Press, New York. Common substitutions are Ala/Ser, Val/Ile, Asp/Glu, Thr/Ser, Ala/Gly, Ala/Thr, Ser/Asn, Ala/Val, Ser/Gly, Tyr/Phe, Ala/Pro, Lys/Arg, Asp/Asn, Leu/Ile, Leu/Val, Ala/Glu, and Asp/Gly.

Alternatively, the amino acid changes are of such a nature that the physico-chemical properties of the polypeptides are altered. For example, amino acid changes may improve the thermal stability of the polypeptide, alter the substrate specificity, change the pH optimum, and the like.

Essential amino acids in a polypeptide can be identified according to procedures known in the art, such as site-directed mutagenesis or alanine-scanning mutagenesis (Cunningham and Wells, 1989, *Science* 244: 1081-1085). In the latter technique, single alanine mutations are introduced at every residue in the molecule, and the resultant mutant molecules are tested for
5 cellobiohydrolase activity to identify amino acid residues that are critical to the activity of the molecule. See also, Hilton *et al.*, 1996, *J. Biol. Chem.* 271: 4699-4708. The active site of the enzyme or other biological interaction can also be determined by physical analysis of structure, as determined by such techniques as nuclear magnetic resonance, crystallography, electron diffraction, or photoaffinity labeling, in conjunction with mutation of putative contact site amino
10 acids. See, for example, de Vos *et al.*, 1992, *Science* 255: 306-312; Smith *et al.*, 1992, *J. Mol. Biol.* 224: 899-904; Wlodaver *et al.*, 1992, *FEBS Lett.* 309: 59-64. The identity of essential amino acids can also be inferred from an alignment with a related polypeptide.

Single or multiple amino acid substitutions, deletions, and/or insertions can be made and tested using known methods of mutagenesis, recombination, and/or shuffling, followed by a
15 relevant screening procedure, such as those disclosed by Reidhaar-Olson and Sauer, 1988, *Science* 241: 53-57; Bowie and Sauer, 1989, *Proc. Natl. Acad. Sci. USA* 86: 2152-2156; WO 95/17413; or WO 95/22625. Other methods that can be used include error-prone PCR, phage display (e.g., Lowman *et al.*, 1991, *Biochemistry* 30: 10832-10837; U.S. Patent No. 5,223,409; WO 92/06204), and region-directed mutagenesis (Derbyshire *et al.*, 1986, *Gene* 46: 145; Ner *et al.*, 1988, *DNA* 7: 127).
20

Mutagenesis/shuffling methods can be combined with high-throughput, automated screening methods to detect activity of cloned, mutagenized polypeptides expressed by host cells (Ness *et al.*, 1999, *Nature Biotechnology* 17: 893-896). Mutagenized DNA molecules that encode active polypeptides can be recovered from the host cells and rapidly sequenced using
25 standard methods in the art. These methods allow the rapid determination of the importance of individual amino acid residues in a polypeptide.

The polypeptide may be a hybrid polypeptide in which a region of one polypeptide is fused at the N-terminus or the C-terminus of a region of another polypeptide.

The polypeptide may be a fusion polypeptide or cleavable fusion polypeptide in which
30 another polypeptide is fused at the N-terminus or the C-terminus of the polypeptide of the present invention. A fusion polypeptide is produced by fusing a polynucleotide encoding another polypeptide to a polynucleotide of the present invention. Techniques for producing fusion polypeptides are known in the art, and include ligating the coding sequences encoding the polypeptides so that they are in frame and that expression of the fusion polypeptide is under

control of the same promoter(s) and terminator. Fusion polypeptides may also be constructed using intein technology in which fusion polypeptides are created post-translationally (Cooper *et al.*, 1993, *EMBO J.* 12: 2575-2583; Dawson *et al.*, 1994, *Science* 266: 776-779).

A fusion polypeptide can further comprise a cleavage site between the two polypeptides.

5 Upon secretion of the fusion protein, the site is cleaved releasing the two polypeptides. Examples of cleavage sites include, but are not limited to, the sites disclosed in Martin *et al.*, 2003, *J. Ind. Microbiol. Biotechnol.* 3: 568-576; Svetina *et al.*, 2000, *J. Biotechnol.* 76: 245-251; Rasmussen-Wilson *et al.*, 1997, *Appl. Environ. Microbiol.* 63: 3488-3493; Ward *et al.*, 1995, *Biotechnology* 13: 498-503; and Contreras *et al.*, 1991, *Biotechnology* 9: 378-381; Eaton *et al.*,
10 1986, *Biochemistry* 25: 505-512; Collins-Racie *et al.*, 1995, *Biotechnology* 13: 982-987; Carter *et al.*, 1989, *Proteins: Structure, Function, and Genetics* 6: 240-248; and Stevens, 2003, *Drug Discovery World* 4: 35-48.

Sources of Polypeptides Having Cellobiohydrolase Activity

15 A polypeptide having cellobiohydrolase activity of the present invention may be obtained from microorganisms of any genus. For purposes of the present invention, the term "obtained from" as used herein in connection with a given source shall mean that the polypeptide encoded by a polynucleotide is produced by the source or by a strain in which the polynucleotide from the source has been inserted. In one aspect, the polypeptide obtained from a given source is
20 secreted extracellularly.

The polypeptide may be a fungal polypeptide. In one aspect, the polypeptide is a *Corynascus* polypeptide. In another aspect, the polypeptide is a *Corynascus thermophilus* polypeptide.

25 It will be understood that for the aforementioned species, the invention encompasses both the perfect and imperfect states, and other taxonomic equivalents, *e.g.*, anamorphs, regardless of the species name by which they are known. Those skilled in the art will readily recognize the identity of appropriate equivalents.

30 Strains of these species are readily accessible to the public in a number of culture collections, such as the American Type Culture Collection (ATCC), Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH (DSMZ), Centraalbureau Voor Schimmelcultures (CBS), and Agricultural Research Service Patent Culture Collection, Northern Regional Research Center (NRRL).

The polypeptide may be identified and obtained from other sources including microorganisms isolated from nature (*e.g.*, soil, composts, water, etc.) or DNA samples obtained

directly from natural materials (e.g., soil, composts, water, etc.) using the above-mentioned probes. Techniques for isolating microorganisms and DNA directly from natural habitats are well known in the art. A polynucleotide encoding the polypeptide may then be obtained by similarly screening a genomic DNA or cDNA library of another microorganism or mixed DNA sample.

5 Once a polynucleotide encoding a polypeptide has been detected with the probe(s), the polynucleotide can be isolated or cloned by utilizing techniques that are known to those of ordinary skill in the art (see, e.g., Sambrook *et al.*, 1989, *supra*).

Catalytic Domains

10 In one embodiment, the present invention also relates to catalytic domains having a sequence identity to amino acids 106 to 469 of SEQ ID NO: 4 of at least 80%, e.g., at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100%, or to catalytic domains

15 having a sequence identity to amino acids 44 to 393 of SEQ ID NO: 2 of at least 89%, e.g., at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100%. In one aspect, the catalytic domains comprise amino acid sequences that differ by up to 10 amino acids, e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10, from amino acids 106 to 469 of SEQ ID NO: 4, or from amino acids 44 to 393 of SEQ ID NO: 2.

20 The catalytic domain preferably comprises or consists of amino acids 106 to 469 of SEQ ID NO: 4 or amino acids 44 to 393 of SEQ ID NO: 2 or an allelic variant thereof; or is a fragment thereof having cellobiohydrolase activity.

In another embodiment, the present invention also relates to catalytic domains encoded by polynucleotides that hybridize under at least medium stringency conditions, at least medium-

25 high stringency conditions, at least high stringency conditions, or at least very high stringency conditions (as defined above) with (i) the nucleotides 400 to 1659 of SEQ ID NO: 3, or the nucleotides 130 to 1376 of SEQ ID NO: 1, (ii) the cDNA sequence thereof, or (iii) the full-length complement of (i) or (ii) (Sambrook *et al.*, 1989, *supra*).

In another embodiment, the present invention also relates to catalytic domains encoded

30 by polynucleotides having a sequence identity to nucleotides 400 to 1659 of SEQ ID NO: 3 or the cDNA sequence thereof of at least 80%, e.g., at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100%. In another embodiment, the present invention also relates to

catalytic domains encoded by polynucleotides having a sequence identity to nucleotides 130 to 1376 of SEQ ID NO: 1 or the cDNA sequence thereof of at least 89%, e.g., at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100%.

5 The polynucleotide encoding the catalytic domain preferably comprises or consists of nucleotides 400 to 1659 of SEQ ID NO: 3 or nucleotides 130 to 1376 of SEQ ID NO: 1.

 In another embodiment, the present invention also relates to catalytic domain variants of amino acids 106 to 469 of SEQ ID NO: 4 or amino acids 44 to 393 of SEQ ID NO: 2, comprising a substitution, deletion, and/or insertion at one or more (e.g., several) positions. In one aspect,
10 the number of amino acid substitutions, deletions and/or insertions introduced into the sequence of amino acids 106 to 469 of SEQ ID NO: 4 or amino acids 44 to 393 of SEQ ID NO: 2 is up to 10, e.g., 1, 2, 3, 4, 5, 6, 8, 9, or 10.

Carbohydrate binding domains

15 In one embodiment, the present invention also relates to carbohydrate binding domains having a sequence identity to amino acids 24 to 63 of SEQ ID NO: 4 of at least 80%, e.g., at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100%. In one aspect, the
20 carbohydrate binding domains comprise amino acid sequences that differ by up to 10 amino acids, e.g., 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10, from amino acids 24 to 63 of SEQ ID NO: 4.

 The carbohydrate binding domain preferably comprises or consists of amino acids 24 to 63 of SEQ ID NO: 4 or an allelic variant thereof; or is a fragment thereof having cellulose binding activity.

25 In another embodiment, the present invention also relates to carbohydrate binding domains encoded by polynucleotides that hybridize under at least medium stringency conditions, at least medium-high stringency conditions, at least high stringency conditions, or at least very high stringency conditions (as defined above) with (i) the nucleotides 70 to 273 of SEQ ID NO: 3, (ii) the cDNA sequence thereof or (iii) the full-length complement of (i) or (ii)
30 (Sambrook *et al.*, 1989, *supra*).

 In another embodiment, the present invention also relates to carbohydrate binding domains encoded by polynucleotides having a sequence identity to nucleotides 70 to 273 of SEQ ID NO: 3 of at least 80%, e.g., at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at

least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100%.

The polynucleotide encoding the carbohydrate binding domain preferably comprises or consists of nucleotides 70 to 273 of SEQ ID NO: 3.

5 In another embodiment, the present invention also relates to carbohydrate binding domain variants of amino acids 24 to 63 of SEQ ID NO: 4 comprising a substitution, deletion, and/or insertion at one or more (e.g., several) positions. In one aspect, the number of amino acid substitutions, deletions and/or insertions introduced into the sequence of amino acids 24 to 63 of SEQ ID NO: 4 is up to 10, e.g., 1, 2, 3, 4, 5, 6, 8, 9, or 10.

10 A catalytic domain operably linked to the carbohydrate binding domain may be from a hydrolase, isomerase, ligase, lyase, oxidoreductase, or transferase, e.g., an aminopeptidase, amylase, carbohydrase, carboxypeptidase, catalase, cellobiohydrolase, cellulase, chitinase, cutinase, cyclodextrin glycosyltransferase, deoxyribonuclease, endoglucanase, esterase, alpha-galactosidase, beta-galactosidase, glucoamylase, alpha-glucosidase, beta-glucosidase, invertase, laccase, lipase, mannosidase, mutanase, oxidase, pectinolytic enzyme, peroxidase, phytase, polyphenoloxidase, proteolytic enzyme, ribonuclease, transglutaminase, xylanase, or beta-xylosidase. The polynucleotide encoding the catalytic domain may be obtained from any prokaryotic, eukaryotic, or other source.

20 Polynucleotides

The present invention also relates to isolated polynucleotides encoding a polypeptide, a catalytic domain, or carbohydrate binding domain of the present invention, as described herein.

The techniques used to isolate or clone a polynucleotide are known in the art and include isolation from genomic DNA or cDNA, or a combination thereof. The cloning of the polynucleotides from genomic DNA can be effected, e.g., by using the well known polymerase chain reaction (PCR) or antibody screening of expression libraries to detect cloned DNA fragments with shared structural features. See, e.g., Innis *et al.*, 1990, *PCR: A Guide to Methods and Application*, Academic Press, New York. Other nucleic acid amplification procedures such as ligase chain reaction (LCR), ligation activated transcription (LAT) and polynucleotide-based amplification (NASBA) may be used. The polynucleotides may be cloned from a strain of *Corynascus*, or a related organism and thus, for example, may be an allelic or species variant of the polypeptide encoding region of the polynucleotide.

30 Modification of a polynucleotide encoding a polypeptide of the present invention may be necessary for synthesizing polypeptides substantially similar to the polypeptide. The term

“substantially similar” to the polypeptide refers to non-naturally occurring forms of the polypeptide. These polypeptides may differ in some engineered way from the polypeptide isolated from its native source, e.g., variants that differ in specific activity, thermostability, pH optimum, or the like. The variants may be constructed on the basis of the polynucleotide presented as the mature polypeptide coding sequence of SEQ ID NO: 3 or the cDNA sequence thereof, or the mature polypeptide coding sequence of SEQ ID NO: 1 or the cDNA sequence thereof, or a subsequence thereof, by introduction of nucleotide substitutions that do not result in a change in the amino acid sequence of the polypeptide, but which correspond to the codon usage of the host organism intended for production of the enzyme, or by introduction of nucleotide substitutions that may give rise to a different amino acid sequence. For a general description of nucleotide substitution, see, e.g., Ford *et al.*, 1991, *Protein Expression and Purification* 2: 95-107.

Nucleic Acid Constructs

The present invention also relates to nucleic acid constructs comprising a polynucleotide of the present invention operably linked to one or more (e.g., several) control sequences that direct the expression of the coding sequence in a suitable host cell under conditions compatible with the control sequences.

The polynucleotide may be manipulated in a variety of ways to provide for expression of the polypeptide. Manipulation of the polynucleotide prior to its insertion into a vector may be desirable or necessary depending on the expression vector. The techniques for modifying polynucleotides utilizing recombinant DNA methods are well known in the art.

The control sequence may be a promoter, a polynucleotide that is recognized by a host cell for expression of a polynucleotide encoding a polypeptide of the present invention. The promoter contains transcriptional control sequences that mediate the expression of the polypeptide. The promoter may be any polynucleotide that shows transcriptional activity in the host cell including mutant, truncated, and hybrid promoters, and may be obtained from genes encoding extracellular or intracellular polypeptides either homologous or heterologous to the host cell.

Examples of suitable promoters for directing transcription of the nucleic acid constructs of the present invention in a bacterial host cell are the promoters obtained from the *Bacillus amyloliquefaciens* alpha-amylase gene (*amyQ*), *Bacillus licheniformis* alpha-amylase gene (*amyL*), *Bacillus licheniformis* penicillinase gene (*penP*), *Bacillus stearothermophilus* maltogenic amylase gene (*amyM*), *Bacillus subtilis* levansucrase gene (*sacB*), *Bacillus subtilis* *xylA* and

xylB genes, *Bacillus thuringiensis cryIIIA* gene (Agaisse and Lereclus, 1994, *Molecular Microbiology* 13: 97-107), *E. coli lac* operon, *E. coli trc* promoter (Egon *et al.*, 1988, *Gene* 69: 301-315), *Streptomyces coelicolor* agarase gene (*dagA*), and prokaryotic beta-lactamase gene (Villa-Kamaroff *et al.*, 1978, *Proc. Natl. Acad. Sci. USA* 75: 3727-3731), as well as the *tac* promoter (DeBoer *et al.*, 1983, *Proc. Natl. Acad. Sci. USA* 80: 21-25). Further promoters are described in "Useful proteins from recombinant bacteria" in Gilbert *et al.*, 1980, *Scientific American* 242: 74-94; and in Sambrook *et al.*, 1989, *supra*. Examples of tandem promoters are disclosed in WO 99/43835.

Examples of suitable promoters for directing transcription of the nucleic acid constructs of the present invention in a filamentous fungal host cell are promoters obtained from the genes for *Aspergillus nidulans* acetamidase, *Aspergillus niger* neutral alpha-amylase, *Aspergillus niger* acid stable alpha-amylase, *Aspergillus niger* or *Aspergillus awamori* glucoamylase (*glaA*), *Aspergillus oryzae* TKA amylase, *Aspergillus oryzae* alkaline protease, *Aspergillus oryzae* triose phosphate isomerase, *Fusarium oxysporum* trypsin-like protease (WO 96/00787), *Fusarium venenatum* amyloglucosidase (WO 00/56900), *Fusarium venenatum* Daria (WO 00/56900), *Fusarium venenatum* Quinn (WO 00/56900), *Rhizomucor miehei* lipase, *Rhizomucor miehei* aspartic proteinase, *Trichoderma reesei* beta-glucosidase, *Trichoderma reesei* cellobiohydrolase I, *Trichoderma reesei* cellobiohydrolase II, *Trichoderma reesei* endoglucanase I, *Trichoderma reesei* endoglucanase II, *Trichoderma reesei* endoglucanase III, *Trichoderma reesei* endoglucanase V, *Trichoderma reesei* xylanase I, *Trichoderma reesei* xylanase II, *Trichoderma reesei* xylanase III, *Trichoderma reesei* beta-xylosidase, and *Trichoderma reesei* translation elongation factor, as well as the NA2-tpi promoter (a modified promoter from an *Aspergillus* neutral alpha-amylase gene in which the untranslated leader has been replaced by an untranslated leader from an *Aspergillus* triose phosphate isomerase gene; non-limiting examples include modified promoters from an *Aspergillus niger* neutral alpha-amylase gene in which the untranslated leader has been replaced by an untranslated leader from an *Aspergillus nidulans* or *Aspergillus oryzae* triose phosphate isomerase gene); and mutant, truncated, and hybrid promoters thereof. Other promoters are described in U.S. Patent No. 6,011,147.

In a yeast host, useful promoters are obtained from the genes for *Saccharomyces cerevisiae* enolase (ENO-1), *Saccharomyces cerevisiae* galactokinase (GAL1), *Saccharomyces cerevisiae* alcohol dehydrogenase/glyceraldehyde-3-phosphate dehydrogenase (ADH1, ADH2/GAP), *Saccharomyces cerevisiae* triose phosphate isomerase (TPI), *Saccharomyces cerevisiae* metallothionein (CUP1), and *Saccharomyces cerevisiae* 3-phosphoglycerate kinase.

Other useful promoters for yeast host cells are described by Romanos *et al.*, 1992, *Yeast* 8: 423-488.

The control sequence may also be a transcription terminator, which is recognized by a host cell to terminate transcription. The terminator is operably linked to the 3'-terminus of the polynucleotide encoding the polypeptide. Any terminator that is functional in the host cell may be used in the present invention.

Preferred terminators for bacterial host cells are obtained from the genes for *Bacillus clausii* alkaline protease (*aprH*), *Bacillus licheniformis* alpha-amylase (*amyL*), and *Escherichia coli* ribosomal RNA (*rmb*).

Preferred terminators for filamentous fungal host cells are obtained from the genes for *Aspergillus nidulans* acetamidase, *Aspergillus nidulans* anthranilate synthase, *Aspergillus niger* glucoamylase, *Aspergillus niger* alpha-glucosidase, *Aspergillus oryzae* TAKA amylase, *Fusarium oxysporum* trypsin-like protease, *Trichoderma reesei* beta-glucosidase, *Trichoderma reesei* cellobiohydrolase I, *Trichoderma reesei* cellobiohydrolase II, *Trichoderma reesei* endoglucanase I, *Trichoderma reesei* endoglucanase II, *Trichoderma reesei* endoglucanase III, *Trichoderma reesei* endoglucanase V, *Trichoderma reesei* xylanase I, *Trichoderma reesei* xylanase II, *Trichoderma reesei* xylanase III, *Trichoderma reesei* beta-xylosidase, and *Trichoderma reesei* translation elongation factor.

Preferred terminators for yeast host cells are obtained from the genes for *Saccharomyces cerevisiae* enolase, *Saccharomyces cerevisiae* cytochrome C (CYC1), and *Saccharomyces cerevisiae* glyceraldehyde-3-phosphate dehydrogenase. Other useful terminators for yeast host cells are described by Romanos *et al.*, 1992, *supra*.

The control sequence may also be an mRNA stabilizer region downstream of a promoter and upstream of the coding sequence of a gene which increases expression of the gene.

Examples of suitable mRNA stabilizer regions are obtained from a *Bacillus thuringiensis* *cryIIIA* gene (WO 94/25612) and a *Bacillus subtilis* SP82 gene (Hue *et al.*, 1995, *Journal of Bacteriology* 177: 3465-3471).

The control sequence may also be a leader, a nontranslated region of an mRNA that is important for translation by the host cell. The leader is operably linked to the 5'-terminus of the polynucleotide encoding the polypeptide. Any leader that is functional in the host cell may be used.

Preferred leaders for filamentous fungal host cells are obtained from the genes for *Aspergillus oryzae* TAKA amylase and *Aspergillus nidulans* triose phosphate isomerase.

Suitable leaders for yeast host cells are obtained from the genes for *Saccharomyces cerevisiae* enolase (ENO-1), *Saccharomyces cerevisiae* 3-phosphoglycerate kinase, *Saccharomyces cerevisiae* alpha-factor, and *Saccharomyces cerevisiae* alcohol dehydrogenase/glyceraldehyde-3-phosphate dehydrogenase (ADH2/GAP).

5 The control sequence may also be a polyadenylation sequence, a sequence operably linked to the 3'-terminus of the polynucleotide and, when transcribed, is recognized by the host cell as a signal to add polyadenosine residues to transcribed mRNA. Any polyadenylation sequence that is functional in the host cell may be used.

10 Preferred polyadenylation sequences for filamentous fungal host cells are obtained from the genes for *Aspergillus nidulans* anthranilate synthase, *Aspergillus niger* glucoamylase, *Aspergillus niger* alpha-glucosidase *Aspergillus oryzae* TAKA amylase, and *Fusarium oxysporum* trypsin-like protease.

Useful polyadenylation sequences for yeast host cells are described by Guo and Sherman, 1995, *Mol. Cellular Biol.* 15: 5983-5990.

15 The control sequence may also be a signal peptide coding region that encodes a signal peptide linked to the N-terminus of a polypeptide and directs the polypeptide into the cell's secretory pathway. The 5'-end of the coding sequence of the polynucleotide may inherently contain a signal peptide coding sequence naturally linked in translation reading frame with the segment of the coding sequence that encodes the polypeptide. Alternatively, the 5'-end of the
20 coding sequence may contain a signal peptide coding sequence that is foreign to the coding sequence. A foreign signal peptide coding sequence may be required where the coding sequence does not naturally contain a signal peptide coding sequence. Alternatively, a foreign signal peptide coding sequence may simply replace the natural signal peptide coding sequence in order to enhance secretion of the polypeptide. However, any signal peptide coding sequence
25 that directs the expressed polypeptide into the secretory pathway of a host cell may be used.

Effective signal peptide coding sequences for bacterial host cells are the signal peptide coding sequences obtained from the genes for *Bacillus* NCIB 11837 maltogenic amylase, *Bacillus licheniformis* subtilisin, *Bacillus licheniformis* beta-lactamase, *Bacillus stearothermophilus* alpha-amylase, *Bacillus stearothermophilus* neutral proteases (*nprT*, *nprS*,
30 *nprM*), and *Bacillus subtilis* *prsA*. Further signal peptides are described by Simonen and Palva, 1993, *Microbiological Reviews* 57: 109-137.

Effective signal peptide coding sequences for filamentous fungal host cells are the signal peptide coding sequences obtained from the genes for *Aspergillus niger* neutral amylase, *Aspergillus niger* glucoamylase, *Aspergillus oryzae* TAKA amylase, *Humicola insolens* cellulase,

Humicola insolens endoglucanase V, *Humicola lanuginosa* lipase, and *Rhizomucor miehei* aspartic proteinase.

Useful signal peptides for yeast host cells are obtained from the genes for *Saccharomyces cerevisiae* alpha-factor and *Saccharomyces cerevisiae* invertase. Other useful
5 signal peptide coding sequences are described by Romanos *et al.*, 1992, *supra*.

The control sequence may also be a propeptide coding sequence that encodes a propeptide positioned at the N-terminus of a polypeptide. The resultant polypeptide is known as a proenzyme or propolypeptide (or a zymogen in some cases). A propolypeptide is generally inactive and can be converted to an active polypeptide by catalytic or autocatalytic cleavage of
10 the propeptide from the propolypeptide. The propeptide coding sequence may be obtained from the genes for *Bacillus subtilis* alkaline protease (*aprE*), *Bacillus subtilis* neutral protease (*nprT*), *Myceliophthora thermophila* laccase (WO 95/33836), *Rhizomucor miehei* aspartic proteinase, and *Saccharomyces cerevisiae* alpha-factor.

Where both signal peptide and propeptide sequences are present, the propeptide
15 sequence is positioned next to the N-terminus of a polypeptide and the signal peptide sequence is positioned next to the N-terminus of the propeptide sequence.

It may also be desirable to add regulatory sequences that regulate expression of the polypeptide relative to the growth of the host cell. Examples of regulatory sequences are those that cause expression of the gene to be turned on or off in response to a chemical or physical
20 stimulus, including the presence of a regulatory compound. Regulatory sequences in prokaryotic systems include the *lac*, *tac*, and *trp* operator systems. In yeast, the ADH2 system or GAL1 system may be used. In filamentous fungi, the *Aspergillus niger* glucoamylase promoter, *Aspergillus oryzae* TAKA alpha-amylase promoter, and *Aspergillus oryzae* glucoamylase promoter, *Trichoderma reesei* cellobiohydrolase I promoter, and *Trichoderma*
25 *reesei* cellobiohydrolase II promoter may be used. Other examples of regulatory sequences are those that allow for gene amplification. In eukaryotic systems, these regulatory sequences include the dihydrofolate reductase gene that is amplified in the presence of methotrexate, and the metallothionein genes that are amplified with heavy metals. In these cases, the polynucleotide encoding the polypeptide would be operably linked to the regulatory sequence.

Expression Vectors

The present invention also relates to recombinant expression vectors comprising a polynucleotide of the present invention, a promoter, and transcriptional and translational stop signals. The various nucleotide and control sequences may be joined together to produce a

recombinant expression vector that may include one or more (e.g., several) convenient restriction sites to allow for insertion or substitution of the polynucleotide encoding the polypeptide at such sites. Alternatively, the polynucleotide may be expressed by inserting the polynucleotide or a nucleic acid construct comprising the polynucleotide into an appropriate vector for expression. In creating the expression vector, the coding sequence is located in the vector so that the coding sequence is operably linked with the appropriate control sequences for expression.

The recombinant expression vector may be any vector (e.g., a plasmid or virus) that can be conveniently subjected to recombinant DNA procedures and can bring about expression of the polynucleotide. The choice of the vector will typically depend on the compatibility of the vector with the host cell into which the vector is to be introduced. The vector may be a linear or closed circular plasmid.

The vector may be an autonomously replicating vector, i.e., a vector that exists as an extrachromosomal entity, the replication of which is independent of chromosomal replication, e.g., a plasmid, an extrachromosomal element, a minichromosome, or an artificial chromosome. The vector may contain any means for assuring self-replication. Alternatively, the vector may be one that, when introduced into the host cell, is integrated into the genome and replicated together with the chromosome(s) into which it has been integrated. Furthermore, a single vector or plasmid or two or more vectors or plasmids that together contain the total DNA to be introduced into the genome of the host cell, or a transposon, may be used.

The vector preferably contains one or more (e.g., several) selectable markers that permit easy selection of transformed, transfected, transduced, or the like cells. A selectable marker is a gene the product of which provides for biocide or viral resistance, resistance to heavy metals, prototrophy to auxotrophs, and the like.

Examples of bacterial selectable markers are *Bacillus licheniformis* or *Bacillus subtilis* *dal* genes, or markers that confer antibiotic resistance such as ampicillin, chloramphenicol, kanamycin, neomycin, spectinomycin, or tetracycline resistance. Suitable markers for yeast host cells include, but are not limited to, ADE2, HIS3, LEU2, LYS2, MET3, TRP1, and URA3. Selectable markers for use in a filamentous fungal host cell include, but are not limited to, *adeA* (phosphoribosylaminoimidazole-succinocarboxamide synthase), *adeB* (phosphoribosylaminoimidazole synthase), *amdS* (acetamidase), *argB* (ornithine carbamoyltransferase), *bar* (phosphinothricin acetyltransferase), *hph* (hygromycin phosphotransferase), *niaD* (nitrate reductase), *pyrG* (orotidine-5'-phosphate decarboxylase), *sC* (sulfate adenylyltransferase), and *trpC* (anthranilate synthase), as well as equivalents thereof. Preferred for use in an *Aspergillus*

cell are *Aspergillus nidulans* or *Aspergillus oryzae* *amdS* and *pyrG* genes and a *Streptomyces hygroscopicus* *bar* gene. Preferred for use in a *Trichoderma* cell are *adeA*, *adeB*, *amdS*, *hph*, and *pyrG* genes.

The selectable marker may be a dual selectable marker system as described in WO 2010/039889. In one aspect, the dual selectable marker is a *hph-tk* dual selectable marker system.

The vector preferably contains an element(s) that permits integration of the vector into the host cell's genome or autonomous replication of the vector in the cell independent of the genome.

For integration into the host cell genome, the vector may rely on the polynucleotide's sequence encoding the polypeptide or any other element of the vector for integration into the genome by homologous or non-homologous recombination. Alternatively, the vector may contain additional polynucleotides for directing integration by homologous recombination into the genome of the host cell at a precise location(s) in the chromosome(s). To increase the likelihood of integration at a precise location, the integrational elements should contain a sufficient number of nucleic acids, such as 100 to 10,000 base pairs, 400 to 10,000 base pairs, and 800 to 10,000 base pairs, which have a high degree of sequence identity to the corresponding target sequence to enhance the probability of homologous recombination. The integrational elements may be any sequence that is homologous with the target sequence in the genome of the host cell. Furthermore, the integrational elements may be non-encoding or encoding polynucleotides. On the other hand, the vector may be integrated into the genome of the host cell by non-homologous recombination.

For autonomous replication, the vector may further comprise an origin of replication enabling the vector to replicate autonomously in the host cell in question. The origin of replication may be any plasmid replicator mediating autonomous replication that functions in a cell. The term "origin of replication" or "plasmid replicator" means a polynucleotide that enables a plasmid or vector to replicate *in vivo*.

Examples of bacterial origins of replication are the origins of replication of plasmids pBR322, pUC19, pACYC177, and pACYC184 permitting replication in *E. coli*, and pUB110, pE194, pTA1060, and pAM β 1 permitting replication in *Bacillus*.

Examples of origins of replication for use in a yeast host cell are the 2 micron origin of replication, ARS1, ARS4, the combination of ARS1 and CEN3, and the combination of ARS4 and CEN6.

Examples of origins of replication useful in a filamentous fungal cell are AMA1 and ANS1 (Gems *et al.*, 1991, *Gene* 98: 61-67; Cullen *et al.*, 1987, *Nucleic Acids Res.* 15: 9163-9175; WO 00/24883). Isolation of the AMA1 gene and construction of plasmids or vectors comprising the gene can be accomplished according to the methods disclosed in WO 00/24883.

More than one copy of a polynucleotide of the present invention may be inserted into a host cell to increase production of a polypeptide. An increase in the copy number of the polynucleotide can be obtained by integrating at least one additional copy of the sequence into the host cell genome or by including an amplifiable selectable marker gene with the polynucleotide where cells containing amplified copies of the selectable marker gene, and thereby additional copies of the polynucleotide, can be selected for by cultivating the cells in the presence of the appropriate selectable agent.

The procedures used to ligate the elements described above to construct the recombinant expression vectors of the present invention are well known to one skilled in the art (see, e.g., Sambrook *et al.*, 1989, *supra*).

Host Cells

The present invention also relates to recombinant host cells, comprising a polynucleotide of the present invention operably linked to one or more (e.g., several) control sequences that direct the production of a polypeptide of the present invention. A construct or vector comprising a polynucleotide is introduced into a host cell so that the construct or vector is maintained as a chromosomal integrant or as a self-replicating extra-chromosomal vector as described earlier. The term "host cell" encompasses any progeny of a parent cell that is not identical to the parent cell due to mutations that occur during replication. The choice of a host cell will to a large extent depend upon the gene encoding the polypeptide and its source.

The host cell may be any cell useful in the recombinant production of a polypeptide of the present invention, e.g., a prokaryote or a eukaryote.

The prokaryotic host cell may be any Gram-positive or Gram-negative bacterium. Gram-positive bacteria include, but are not limited to, *Bacillus*, *Clostridium*, *Enterococcus*, *Geobacillus*, *Lactobacillus*, *Lactococcus*, *Oceanobacillus*, *Staphylococcus*, *Streptococcus*, and *Streptomyces*. Gram-negative bacteria include, but are not limited to, *Campylobacter*, *E. coli*, *Flavobacterium*, *Fusobacterium*, *Helicobacter*, *Ilyobacter*, *Neisseria*, *Pseudomonas*, *Salmonella*, and *Ureaplasma*.

The bacterial host cell may be any *Bacillus* cell including, but not limited to, *Bacillus alkalophilus*, *Bacillus amyloliquefaciens*, *Bacillus brevis*, *Bacillus circulans*, *Bacillus clausii*,

Bacillus coagulans, *Bacillus firmus*, *Bacillus lautus*, *Bacillus lentus*, *Bacillus licheniformis*, *Bacillus megaterium*, *Bacillus pumilus*, *Bacillus stearothermophilus*, *Bacillus subtilis*, and *Bacillus thuringiensis* cells.

The bacterial host cell may also be any *Streptococcus* cell including, but not limited to, *Streptococcus equisimilis*, *Streptococcus pyogenes*, *Streptococcus uberis*, and *Streptococcus equi* subsp. *Zooepidemicus* cells.

The bacterial host cell may also be any *Streptomyces* cell including, but not limited to, *Streptomyces achromogenes*, *Streptomyces avermitilis*, *Streptomyces coelicolor*, *Streptomyces griseus*, and *Streptomyces lividans* cells.

The introduction of DNA into a *Bacillus* cell may be effected by protoplast transformation (see, e.g., Chang and Cohen, 1979, *Mol. Gen. Genet.* 168: 111-115), competent cell transformation (see, e.g., Young and Spizizen, 1961, *J. Bacteriol.* 81: 823-829, or Dubnau and Davidoff-Abelson, 1971, *J. Mol. Biol.* 56: 209-221), electroporation (see, e.g., Shigekawa and Dower, 1988, *Biotechniques* 6: 742-751), or conjugation (see, e.g., Koehler and Thorne, 1987, *J. Bacteriol.* 169: 5271-5278). The introduction of DNA into an *E. coli* cell may be effected by protoplast transformation (see, e.g., Hanahan, 1983, *J. Mol. Biol.* 166: 557-580) or electroporation (see, e.g., Dower et al., 1988, *Nucleic Acids Res.* 16: 6127-6145). The introduction of DNA into a *Streptomyces* cell may be effected by protoplast transformation, electroporation (see, e.g., Gong et al., 2004, *Folia Microbiol. (Praha)* 49: 399-405), conjugation (see, e.g., Mazodier et al., 1989, *J. Bacteriol.* 171: 3583-3585), or transduction (see, e.g., Burke et al., 2001, *Proc. Natl. Acad. Sci. USA* 98: 6289-6294). The introduction of DNA into a *Pseudomonas* cell may be effected by electroporation (see, e.g., Choi et al., 2006, *J. Microbiol. Methods* 64: 391-397) or conjugation (see, e.g., Pinedo and Smets, 2005, *Appl. Environ. Microbiol.* 71: 51-57). The introduction of DNA into a *Streptococcus* cell may be effected by natural competence (see, e.g., Perry and Kuramitsu, 1981, *Infect. Immun.* 32: 1295-1297), protoplast transformation (see, e.g., Catt and Jollick, 1991, *Microbios* 68: 189-207), electroporation (see, e.g., Buckley et al., 1999, *Appl. Environ. Microbiol.* 65: 3800-3804), or conjugation (see, e.g., Clewell, 1981, *Microbiol. Rev.* 45: 409-436). However, any method known in the art for introducing DNA into a host cell can be used.

The host cell may also be a eukaryote, such as a mammalian, insect, plant, or fungal cell.

The host cell may be a fungal cell. "Fungi" as used herein includes the phyla Ascomycota, Basidiomycota, Chytridiomycota, and Zygomycota as well as the Oomycota and

all mitosporic fungi (as defined by Hawksworth *et al.*, In, *Ainsworth and Bisby's Dictionary of The Fungi*, 8th edition, 1995, CAB International, University Press, Cambridge, UK).

The fungal host cell may be a yeast cell. "Yeast" as used herein includes ascosporeogenous yeast (Endomycetales), basidiosporeogenous yeast, and yeast belonging to the Fungi Imperfecti (Blastomycetes). Since the classification of yeast may change in the future, for the purposes of this invention, yeast shall be defined as described in *Biology and Activities of Yeast* (Skinner, Passmore, and Davenport, editors, Soc. App. Bacteriol. Symposium Series No. 9, 1980).

The yeast host cell may be a *Candida*, *Hansenula*, *Kluyveromyces*, *Pichia*, *Saccharomyces*, *Schizosaccharomyces*, or *Yarrowia* cell, such as a *Kluyveromyces lactis*, *Saccharomyces carlsbergensis*, *Saccharomyces cerevisiae*, *Saccharomyces diastaticus*, *Saccharomyces douglasii*, *Saccharomyces kluyveri*, *Saccharomyces norbensis*, *Saccharomyces oviformis*, or *Yarrowia lipolytica* cell.

The fungal host cell may be a filamentous fungal cell. "Filamentous fungi" include all filamentous forms of the subdivision Eumycota and Oomycota (as defined by Hawksworth *et al.*, 1995, *supra*). The filamentous fungi are generally characterized by a mycelial wall composed of chitin, cellulose, glucan, chitosan, mannan, and other complex polysaccharides. Vegetative growth is by hyphal elongation and carbon catabolism is obligately aerobic. In contrast, vegetative growth by yeasts such as *Saccharomyces cerevisiae* is by budding of a unicellular thallus and carbon catabolism may be fermentative.

The filamentous fungal host cell may be an *Acremonium*, *Aspergillus*, *Aureobasidium*, *Bjerkandera*, *Ceriporiopsis*, *Chrysosporium*, *Coprinus*, *Coriolus*, *Cryptococcus*, *Filibasidium*, *Fusarium*, *Humicola*, *Magnaporthe*, *Mucor*, *Myceliophthora*, *Neocallimastix*, *Neurospora*, *Paecilomyces*, *Penicillium*, *Phanerochaete*, *Phlebia*, *Piromyces*, *Pleurotus*, *Schizophyllum*, *Talaromyces*, *Thermoascus*, *Thielavia*, *Tolypocladium*, *Trametes*, or *Trichoderma* cell.

For example, the filamentous fungal host cell may be an *Aspergillus awamori*, *Aspergillus foetidus*, *Aspergillus fumigatus*, *Aspergillus japonicus*, *Aspergillus nidulans*, *Aspergillus niger*, *Aspergillus oryzae*, *Bjerkandera adusta*, *Ceriporiopsis aneirina*, *Ceriporiopsis caregiea*, *Ceriporiopsis gilvescens*, *Ceriporiopsis pannocinta*, *Ceriporiopsis rivulosa*, *Ceriporiopsis subrufa*, *Ceriporiopsis subvermispora*, *Chrysosporium inops*, *Chrysosporium keratinophilum*, *Chrysosporium lucknowense*, *Chrysosporium merdarium*, *Chrysosporium pannicola*, *Chrysosporium queenslandicum*, *Chrysosporium tropicum*, *Chrysosporium zonatum*, *Coprinus cinereus*, *Coriolus hirsutus*, *Fusarium bactridioides*, *Fusarium cerealis*, *Fusarium crookwellense*, *Fusarium culmorum*, *Fusarium graminearum*, *Fusarium graminum*, *Fusarium*

heterosporum, *Fusarium negundi*, *Fusarium oxysporum*, *Fusarium reticulatum*, *Fusarium roseum*, *Fusarium sambucinum*, *Fusarium sarcochroum*, *Fusarium sporotrichioides*, *Fusarium sulphureum*, *Fusarium torulosum*, *Fusarium trichothecioides*, *Fusarium venenatum*, *Humicola insolens*, *Humicola lanuginosa*, *Mucor miehei*, *Myceliophthora thermophila*, *Neurospora crassa*,
5 *Penicillium purpurogenum*, *Phanerochaete chrysosporium*, *Phlebia radiata*, *Pleurotus eryngii*,
Thielavia terrestris, *Trametes villosa*, *Trametes versicolor*, *Trichoderma harzianum*,
Trichoderma koningii, *Trichoderma longibrachiatum*, *Trichoderma reesei*, or *Trichoderma viride*
cell.

Fungal cells may be transformed by a process involving protoplast formation,
10 transformation of the protoplasts, and regeneration of the cell wall in a manner known *per se*.
Suitable procedures for transformation of *Aspergillus* and *Trichoderma* host cells are described
in EP 238023, Yelton *et al.*, 1984, *Proc. Natl. Acad. Sci. USA* 81: 1470-1474, and Christensen
et al., 1988, *Bio/Technology* 6: 1419-1422. Suitable methods for transforming *Fusarium* species
are described by Malardier *et al.*, 1989, *Gene* 78: 147-156, and WO 96/00787. Yeast may be
15 transformed using the procedures described by Becker and Guarente, *In* Abelson, J.N. and
Simon, M.I., editors, *Guide to Yeast Genetics and Molecular Biology, Methods in Enzymology*,
Volume 194, pp 182-187, Academic Press, Inc., New York; Ito *et al.*, 1983, *J. Bacteriol.* 153:
163; and Hinnen *et al.*, 1978, *Proc. Natl. Acad. Sci. USA* 75: 1920.

20 **Methods of Production**

The present invention also relates to methods of producing a polypeptide of the present
invention, comprising (a) cultivating a cell, which in its wild-type form produces the polypeptide,
under conditions conducive for production of the polypeptide; and optionally (b) recovering the
polypeptide. In one aspect, the cell is a *Corynascus* cell. In another aspect, the cell is a
25 *Corynascus thermophilus* cell. In another aspect, the cell is a *Corynascus thermophilus*
NN000308 cell.

The present invention also relates to methods of producing a polypeptide of the present
invention, comprising (a) cultivating a recombinant host cell of the present invention under
conditions conducive for production of the polypeptide; and optionally (b) recovering the
30 polypeptide.

The host cells are cultivated in a nutrient medium suitable for production of the
polypeptide using methods known in the art. For example, the cells may be cultivated by shake
flask cultivation, or small-scale or large-scale fermentation (including continuous, batch, fed-
batch, or solid state fermentations) in laboratory or industrial fermentors in a suitable medium

and under conditions allowing the polypeptide to be expressed and/or isolated. The cultivation takes place in a suitable nutrient medium comprising carbon and nitrogen sources and inorganic salts, using procedures known in the art. Suitable media are available from commercial suppliers or may be prepared according to published compositions (e.g., in catalogues of the American Type Culture Collection). If the polypeptide is secreted into the nutrient medium, the polypeptide can be recovered directly from the medium. If the polypeptide is not secreted, it can be recovered from cell lysates.

The polypeptide may be detected using methods known in the art that are specific for the polypeptides. These detection methods include, but are not limited to, use of specific antibodies, formation of an enzyme product, or disappearance of an enzyme substrate. For example, an enzyme assay may be used to determine the activity of the polypeptide.

The polypeptide may be recovered using methods known in the art. For example, the polypeptide may be recovered from the nutrient medium by conventional procedures including, but not limited to, collection, centrifugation, filtration, extraction, spray-drying, evaporation, or precipitation. In one aspect, a whole fermentation broth comprising the polypeptide is recovered.

The polypeptide may be purified by a variety of procedures known in the art including, but not limited to, chromatography (e.g., ion exchange, affinity, hydrophobic, chromatofocusing, and size exclusion), electrophoretic procedures (e.g., preparative isoelectric focusing), differential solubility (e.g., ammonium sulfate precipitation), SDS-PAGE, or extraction (see, e.g., *Protein Purification*, Janson and Ryden, editors, VCH Publishers, New York, 1989) to obtain substantially pure polypeptides.

In an alternative aspect, the polypeptide is not recovered, but rather a host cell of the present invention expressing the polypeptide is used as a source of the polypeptide.

Plants

The present invention also relates to isolated plants, e.g., a transgenic plant, plant part, or plant cell, comprising a polynucleotide of the present invention so as to express and produce a polypeptide or domain in recoverable quantities. The polypeptide or domain may be recovered from the plant or plant part. Alternatively, the plant or plant part containing the polypeptide or domain may be used as such for improving the quality of a food or feed, e.g., improving nutritional value, palatability, and rheological properties, or to destroy an antinutritive factor.

The transgenic plant can be dicotyledonous (a dicot) or monocotyledonous (a monocot). Examples of monocot plants are grasses, such as meadow grass (blue grass, *Poa*), forage

grass such as *Festuca*, *Lolium*, temperate grass, such as *Agrostis*, and cereals, e.g., wheat, oats, rye, barley, rice, sorghum, and maize (corn).

Examples of dicot plants are tobacco, legumes, such as lupins, potato, sugar beet, pea, bean and soybean, and cruciferous plants (family Brassicaceae), such as cauliflower, rape seed, and the closely related model organism *Arabidopsis thaliana*.

Examples of plant parts are stem, callus, leaves, root, fruits, seeds, and tubers as well as the individual tissues comprising these parts, e.g., epidermis, mesophyll, parenchyme, vascular tissues, meristems. Specific plant cell compartments, such as chloroplasts, apoplasts, mitochondria, vacuoles, peroxisomes and cytoplasm are also considered to be a plant part. Furthermore, any plant cell, whatever the tissue origin, is considered to be a plant part. Likewise, plant parts such as specific tissues and cells isolated to facilitate the utilization of the invention are also considered plant parts, e.g., embryos, endosperms, aleurone and seed coats.

Also included within the scope of the present invention are the progeny of such plants, plant parts, and plant cells.

The transgenic plant or plant cell expressing the polypeptide or domain may be constructed in accordance with methods known in the art. In short, the plant or plant cell is constructed by incorporating one or more expression constructs encoding the polypeptide or domain into the plant host genome or chloroplast genome and propagating the resulting modified plant or plant cell into a transgenic plant or plant cell.

The expression construct is conveniently a nucleic acid construct that comprises a polynucleotide encoding a polypeptide or domain operably linked with appropriate regulatory sequences required for expression of the polynucleotide in the plant or plant part of choice. Furthermore, the expression construct may comprise a selectable marker useful for identifying plant cells into which the expression construct has been integrated and DNA sequences necessary for introduction of the construct into the plant in question (the latter depends on the DNA introduction method to be used).

The choice of regulatory sequences, such as promoter and terminator sequences and optionally signal or transit sequences, is determined, for example, on the basis of when, where, and how the polypeptide or domain is desired to be expressed. For instance, the expression of the gene encoding a polypeptide or domain may be constitutive or inducible, or may be developmental, stage or tissue specific, and the gene product may be targeted to a specific tissue or plant part such as seeds or leaves. Regulatory sequences are, for example, described by Tague *et al.*, 1988, *Plant Physiology* 86: 506.

For constitutive expression, the 35S-CaMV, the maize ubiquitin 1, or the rice actin 1 promoter may be used (Franck *et al.*, 1980, *Cell* 21: 285-294; Christensen *et al.*, 1992, *Plant Mol. Biol.* 18: 675-689; Zhang *et al.*, 1991, *Plant Cell* 3: 1155-1165). Organ-specific promoters may be, for example, a promoter from storage sink tissues such as seeds, potato tubers, and fruits (Edwards and Coruzzi, 1990, *Ann. Rev. Genet.* 24: 275-303), or from metabolic sink tissues such as meristems (Ito *et al.*, 1994, *Plant Mol. Biol.* 24: 863-878), a seed specific promoter such as the glutelin, prolamin, globulin, or albumin promoter from rice (Wu *et al.*, 1998, *Plant Cell Physiol.* 39: 885-889), a *Vicia faba* promoter from the legumin B4 and the unknown seed protein gene from *Vicia faba* (Conrad *et al.*, 1998, *J. Plant Physiol.* 152: 708-711), a promoter from a seed oil body protein (Chen *et al.*, 1998, *Plant Cell Physiol.* 39: 935-941), the storage protein *napA* promoter from *Brassica napus*, or any other seed specific promoter known in the art, e.g., as described in WO 91/14772. Furthermore, the promoter may be a leaf specific promoter such as the *rbcs* promoter from rice or tomato (Kyoizuka *et al.*, 1993, *Plant Physiol.* 102: 991-1000), the chlorella virus adenine methyltransferase gene promoter (Mitra and Higgins, 1994, *Plant Mol. Biol.* 26: 85-93), the *aldP* gene promoter from rice (Kagaya *et al.*, 1995, *Mol. Gen. Genet.* 248: 668-674), or a wound inducible promoter such as the potato *pin2* promoter (Xu *et al.*, 1993, *Plant Mol. Biol.* 22: 573-588). Likewise, the promoter may be induced by abiotic treatments such as temperature, drought, or alterations in salinity or induced by exogenously applied substances that activate the promoter, e.g., ethanol, oestrogens, plant hormones such as ethylene, abscisic acid, and gibberellic acid, and heavy metals.

A promoter enhancer element may also be used to achieve higher expression of a polypeptide or domain in the plant. For instance, the promoter enhancer element may be an intron that is placed between the promoter and the polynucleotide encoding a polypeptide or domain. For instance, Xu *et al.*, 1993, *supra*, disclose the use of the first intron of the rice actin 1 gene to enhance expression.

The selectable marker gene and any other parts of the expression construct may be chosen from those available in the art.

The nucleic acid construct is incorporated into the plant genome according to conventional techniques known in the art, including *Agrobacterium*-mediated transformation, virus-mediated transformation, microinjection, particle bombardment, biolistic transformation, and electroporation (Gasser *et al.*, 1990, *Science* 244: 1293; Potrykus, 1990, *Bio/Technology* 8: 535; Shimamoto *et al.*, 1989, *Nature* 338: 274).

Agrobacterium tumefaciens-mediated gene transfer is a method for generating transgenic dicots (for a review, see Hooykas and Schilperoort, 1992, *Plant Mol. Biol.* 19: 15-38)

and for transforming monocots, although other transformation methods may be used for these plants. A method for generating transgenic monocots is particle bombardment (microscopic gold or tungsten particles coated with the transforming DNA) of embryonic calli or developing embryos (Christou, 1992, *Plant J.* 2: 275-281; Shimamoto, 1994, *Curr. Opin. Biotechnol.* 5: 158-162; Vasil *et al.*, 1992, *Bio/Technology* 10: 667-674). An alternative method for transformation of monocots is based on protoplast transformation as described by Omirulleh *et al.*, 1993, *Plant Mol. Biol.* 21: 415-428. Additional transformation methods include those described in U.S. Patent Nos. 6,395,966 and 7,151,204 (both of which are herein incorporated by reference in their entirety).

Following transformation, the transformants having incorporated the expression construct are selected and regenerated into whole plants according to methods well known in the art. Often the transformation procedure is designed for the selective elimination of selection genes either during regeneration or in the following generations by using, for example, co-transformation with two separate T-DNA constructs or site specific excision of the selection gene by a specific recombinase.

In addition to direct transformation of a particular plant genotype with a construct of the present invention, transgenic plants may be made by crossing a plant having the construct to a second plant lacking the construct. For example, a construct encoding a polypeptide or domain can be introduced into a particular plant variety by crossing, without the need for ever directly transforming a plant of that given variety. Therefore, the present invention encompasses not only a plant directly regenerated from cells which have been transformed in accordance with the present invention, but also the progeny of such plants. As used herein, progeny may refer to the offspring of any generation of a parent plant prepared in accordance with the present invention. Such progeny may include a DNA construct prepared in accordance with the present invention. Crossing results in the introduction of a transgene into a plant line by cross pollinating a starting line with a donor plant line. Non-limiting examples of such steps are described in U.S. Patent No. 7,151,204.

Plants may be generated through a process of backcross conversion. For example, plants include plants referred to as a backcross converted genotype, line, inbred, or hybrid.

Genetic markers may be used to assist in the introgression of one or more transgenes of the invention from one genetic background into another. Marker assisted selection offers advantages relative to conventional breeding in that it can be used to avoid errors caused by phenotypic variations. Further, genetic markers may provide data regarding the relative degree of elite germplasm in the individual progeny of a particular cross. For example, when a plant

with a desired trait which otherwise has a non-agronomically desirable genetic background is crossed to an elite parent, genetic markers may be used to select progeny which not only possess the trait of interest, but also have a relatively large proportion of the desired germplasm. In this way, the number of generations required to introgress one or more traits into a particular genetic background is minimized.

The present invention also relates to methods of producing a polypeptide or domain of the present invention comprising (a) cultivating a transgenic plant or a plant cell comprising a polynucleotide or domain encoding the polypeptide under conditions conducive for production of the polypeptide or domain; and optionally (b) recovering the polypeptide or domain.

Removal or Reduction of Cellobiohydrolase Activity

The present invention also relates to methods of producing a mutant of a parent cell, which comprises disrupting or deleting a polynucleotide, or a portion thereof, encoding a polypeptide of the present invention, which results in the mutant cell producing less of the polypeptide than the parent cell when cultivated under the same conditions.

The mutant cell may be constructed by reducing or eliminating expression of the polynucleotide using methods well known in the art, for example, insertions, disruptions, replacements, or deletions. In a preferred aspect, the polynucleotide is inactivated. The polynucleotide to be modified or inactivated may be, for example, the coding region or a part thereof essential for activity, or a regulatory element required for expression of the coding region. An example of such a regulatory or control sequence may be a promoter sequence or a functional part thereof, *i.e.*, a part that is sufficient for affecting expression of the polynucleotide. Other control sequences for possible modification include, but are not limited to, a leader, polyadenylation sequence, propeptide sequence, signal peptide sequence, transcription terminator, and transcriptional activator.

Modification or inactivation of the polynucleotide may be performed by subjecting the parent cell to mutagenesis and selecting for mutant cells in which expression of the polynucleotide has been reduced or eliminated. The mutagenesis, which may be specific or random, may be performed, for example, by use of a suitable physical or chemical mutagenizing agent, by use of a suitable oligonucleotide, or by subjecting the DNA sequence to PCR generated mutagenesis. Furthermore, the mutagenesis may be performed by use of any combination of these mutagenizing agents.

Examples of a physical or chemical mutagenizing agent suitable for the present purpose include ultraviolet (UV) irradiation, hydroxylamine, N-methyl-N'-nitro-N-nitrosoguanidine

(MNNG), O-methyl hydroxylamine, nitrous acid, ethyl methane sulphonate (EMS), sodium bisulphite, formic acid, and nucleotide analogues.

When such agents are used, the mutagenesis is typically performed by incubating the parent cell to be mutagenized in the presence of the mutagenizing agent of choice under suitable conditions, and screening and/or selecting for mutant cells exhibiting reduced or no expression of the gene.

Modification or inactivation of the polynucleotide may also be accomplished by insertion, substitution, or deletion of one or more nucleotides in the gene or a regulatory element required for transcription or translation thereof. For example, nucleotides may be inserted or removed so as to result in the introduction of a stop codon, the removal of the start codon, or a change in the open reading frame. Such modification or inactivation may be accomplished by site-directed mutagenesis or PCR generated mutagenesis in accordance with methods known in the art. Although, in principle, the modification may be performed *in vivo*, *i.e.*, directly on the cell expressing the polynucleotide to be modified, it is preferred that the modification be performed *in vitro* as exemplified below.

An example of a convenient way to eliminate or reduce expression of a polynucleotide is based on techniques of gene replacement, gene deletion, or gene disruption. For example, in the gene disruption method, a nucleic acid sequence corresponding to the endogenous polynucleotide is mutagenized *in vitro* to produce a defective nucleic acid sequence that is then transformed into the parent cell to produce a defective gene. By homologous recombination, the defective nucleic acid sequence replaces the endogenous polynucleotide. It may be desirable that the defective polynucleotide also encodes a marker that may be used for selection of transformants in which the polynucleotide has been modified or destroyed. In an aspect, the polynucleotide is disrupted with a selectable marker such as those described herein.

The present invention also relates to methods of inhibiting the expression of a polypeptide having cellobiohydrolase activity in a cell, comprising administering to the cell or expressing in the cell a double-stranded RNA (dsRNA) molecule, wherein the dsRNA comprises a subsequence of a polynucleotide of the present invention. In a preferred aspect, the dsRNA is about 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25 or more duplex nucleotides in length.

The dsRNA is preferably a small interfering RNA (siRNA) or a micro RNA (miRNA). In a preferred aspect, the dsRNA is small interfering RNA for inhibiting transcription. In another preferred aspect, the dsRNA is micro RNA for inhibiting translation.

The present invention also relates to such double-stranded RNA (dsRNA) molecules, comprising a portion of the mature polypeptide coding sequence of SEQ ID NO: 1 or the mature

polypeptide coding sequence of SEQ ID NO: 3 for inhibiting expression of the polypeptide in a cell. While the present invention is not limited by any particular mechanism of action, the dsRNA can enter a cell and cause the degradation of a single-stranded RNA (ssRNA) of similar or identical sequences, including endogenous mRNAs. When a cell is exposed to dsRNA, mRNA from the homologous gene is selectively degraded by a process called RNA interference (RNAi).

The dsRNAs of the present invention can be used in gene-silencing. In one aspect, the invention provides methods to selectively degrade RNA using a dsRNAi of the present invention. The process may be practiced *in vitro*, *ex vivo* or *in vivo*. In one aspect, the dsRNA molecules can be used to generate a loss-of-function mutation in a cell, an organ or an animal. Methods for making and using dsRNA molecules to selectively degrade RNA are well known in the art; see, for example, U.S. Patent Nos. 6,489,127; 6,506,559; 6,511,824; and 6,515,109.

The present invention further relates to a mutant cell of a parent cell that comprises a disruption or deletion of a polynucleotide encoding the polypeptide or a control sequence thereof or a silenced gene encoding the polypeptide, which results in the mutant cell producing less of the polypeptide or no polypeptide compared to the parent cell.

The polypeptide-deficient mutant cells are particularly useful as host cells for expression of native and heterologous polypeptides. Therefore, the present invention further relates to methods of producing a native or heterologous polypeptide, comprising (a) cultivating the mutant cell under conditions conducive for production of the polypeptide; and optionally (b) recovering the polypeptide. The term "heterologous polypeptides" means polypeptides that are not native to the host cell, *e.g.*, a variant of a native protein. The host cell may comprise more than one copy of a polynucleotide encoding the native or heterologous polypeptide.

The methods used for cultivation and purification of the product of interest may be performed by methods known in the art.

The methods of the present invention for producing an essentially cellobiohydrolase activity-free product are of particular interest in the production of eukaryotic polypeptides, in particular fungal proteins such as enzymes. The cellobiohydrolase activity-deficient cells may also be used to express heterologous proteins of pharmaceutical interest such as hormones, growth factors, receptors, and the like. The term "eukaryotic polypeptides" includes not only native polypeptides, but also those polypeptides, *e.g.*, enzymes, which have been modified by amino acid substitutions, deletions or additions, or other such modifications to enhance activity, thermostability, pH tolerance and the like.

In a further aspect, the present invention relates to a protein product essentially free from cellobiohydrolase activity that is produced by a method of the present invention.

Fermentation Broth Formulations or Cell Compositions

5 The present invention also relates to a fermentation broth formulation or a cell composition comprising a polypeptide of the present invention. The fermentation broth product further comprises additional ingredients used in the fermentation process, such as, for example, cells (including, the host cells containing the gene encoding the polypeptide of the present invention which are used to produce the polypeptide of interest), cell debris, biomass, fermentation media and/or fermentation products. In some embodiments, the composition is a cell-killed whole broth containing organic acid(s), killed cells and/or cell debris, and culture medium.

10 The term "fermentation broth" as used herein refers to a preparation produced by cellular fermentation that undergoes no or minimal recovery and/or purification. For example, fermentation broths are produced when microbial cultures are grown to saturation, incubated under carbon-limiting conditions to allow protein synthesis (e.g., expression of enzymes by host cells) and secretion into cell culture medium. The fermentation broth can contain unfractionated or fractionated contents of the fermentation materials derived at the end of the fermentation. Typically, the fermentation broth is unfractionated and comprises the spent culture medium and cell debris present after the microbial cells (e.g., filamentous fungal cells) are removed, e.g., by centrifugation. In some embodiments, the fermentation broth contains spent cell culture medium, extracellular enzymes, and viable and/or nonviable microbial cells.

15 In an embodiment, the fermentation broth formulation and cell compositions comprise a first organic acid component comprising at least one 1-5 carbon organic acid and/or a salt thereof and a second organic acid component comprising at least one 6 or more carbon organic acid and/or a salt thereof. In a specific embodiment, the first organic acid component is acetic acid, formic acid, propionic acid, a salt thereof, or a mixture of two or more of the foregoing and the second organic acid component is benzoic acid, cyclohexanecarboxylic acid, 4-methylvaleric acid, phenylacetic acid, a salt thereof, or a mixture of two or more of the foregoing.

20 In one aspect, the composition contains an organic acid(s), and optionally further contains killed cells and/or cell debris. In one embodiment, the killed cells and/or cell debris are removed from a cell-killed whole broth to provide a composition that is free of these components.

The fermentation broth formulations or cell compositions may further comprise a preservative and/or anti-microbial (e.g., bacteriostatic) agent, including, but not limited to, sorbitol, sodium chloride, potassium sorbate, and others known in the art.

5 The fermentation broth formulations or cell compositions may further comprise multiple enzymatic activities, such as one or more (e.g., several) enzymes selected from the group consisting of a cellulase, a GH61 polypeptide having cellulolytic enhancing activity, a hemicellulase, an esterase, an expansin, a laccase, a ligninolytic enzyme, a pectinase, a peroxidase, a protease, and a swollenin. The fermentation broth formulations or cell compositions may also comprise one or more (e.g., several) enzymes selected from the group
10 consisting of a hydrolase, an isomerase, a ligase, a lyase, an oxidoreductase, or a transferase, e.g., an alpha-galactosidase, alpha-glucosidase, aminopeptidase, amylase, beta-galactosidase, beta-glucosidase, beta-xylosidase, carbohydrazase, carboxypeptidase, catalase, cellobiohydrolase, cellulase, chitinase, cutinase, cyclodextrin glycosyltransferase, deoxyribonuclease, endoglucanase, esterase, glucoamylase, invertase, laccase, lipase,
15 mannosidase, mutanase, oxidase, pectinolytic enzyme, peroxidase, phytase, polyphenoloxidase, proteolytic enzyme, ribonuclease, transglutaminase, or xylanase.

The cell-killed whole broth or composition may contain the unfractionated contents of the fermentation materials derived at the end of the fermentation. Typically, the cell-killed whole broth or composition contains the spent culture medium and cell debris present after the
20 microbial cells (e.g., filamentous fungal cells) are grown to saturation, incubated under carbon-limiting conditions to allow protein synthesis (e.g., expression of cellulase and/or glucosidase enzyme(s)). In some embodiments, the cell-killed whole broth or composition contains the spent cell culture medium, extracellular enzymes, and killed filamentous fungal cells. In some embodiments, the microbial cells present in the cell-killed whole broth or composition can be
25 permeabilized and/or lysed using methods known in the art.

A whole broth or cell composition as described herein is typically a liquid, but may contain insoluble components, such as killed cells, cell debris, culture media components, and/or insoluble enzyme(s). In some embodiments, insoluble components may be removed to provide a clarified liquid composition.

30 The whole broth formulations and cell compositions of the present invention may be produced by a method described in WO 90/15861 or WO 2010/096673.

Examples are given below of preferred uses of the compositions of the present invention. The dosage of the composition and other conditions under which the composition is used may be determined on the basis of methods known in the art.

Enzyme Compositions

The present invention also relates to compositions comprising a polypeptide of the present invention. Preferably, the compositions are enriched in such a polypeptide. The term “enriched” indicates that the cellobiohydrolase activity of the composition has been increased, e.g., with an enrichment factor of at least 1.1.

The compositions may comprise a polypeptide of the present invention as the major enzymatic component, e.g., a mono-component composition. Alternatively, the compositions may comprise multiple enzymatic activities, such as one or more (e.g., several) enzymes selected from the group consisting of a cellulase, a GH61 polypeptide having cellulolytic enhancing activity, a hemicellulase, an esterase, an expansin, a laccase, a ligninolytic enzyme, a pectinase, a peroxidase, a protease, and a swollenin. The compositions may also comprise one or more (e.g., several) enzymes selected from the group consisting of a hydrolase, an isomerase, a ligase, a lyase, an oxidoreductase, or a transferase, e.g., an alpha-galactosidase, alpha-glucosidase, aminopeptidase, amylase, beta-galactosidase, beta-glucosidase, beta-xylosidase, carbohydrase, carboxypeptidase, catalase, cellobiohydrolase, cellulase, chitinase, cutinase, cyclodextrin glycosyltransferase, deoxyribonuclease, endoglucanase, esterase, glucoamylase, invertase, laccase, lipase, mannosidase, mutanase, oxidase, pectinolytic enzyme, peroxidase, phytase, polyphenoloxidase, proteolytic enzyme, ribonuclease, transglutaminase, or xylanase. The compositions may be prepared in accordance with methods known in the art and may be in the form of a liquid or a dry composition. The compositions may be stabilized in accordance with methods known in the art.

Examples are given below of preferred uses of the compositions of the present invention. The dosage of the composition and other conditions under which the composition is used may be determined on the basis of methods known in the art.

Uses

The present invention is also directed to the following processes for using the polypeptides having cellobiohydrolase activity, or compositions thereof.

The present invention also relates to processes for degrading or converting a cellulosic material, comprising: treating the cellulosic material with an enzyme composition in the presence of a polypeptide having cellobiohydrolase activity of the present invention. In one aspect, the processes further comprise recovering the degraded or converted cellulosic material. Soluble products of degradation or conversion of the cellulosic material can be separated from insoluble cellulosic material using method known in the art such as, for example, centrifugation,

filtration, or gravity settling.

The present invention also relates to processes of producing a fermentation product, comprising: (a) saccharifying a cellulosic material with an enzyme composition in the presence of a polypeptide having cellobiohydrolase activity of the present invention; (b) fermenting the
5 saccharified cellulosic material with one or more (e.g., several) fermenting microorganisms to produce the fermentation product; and (c) recovering the fermentation product from the fermentation.

The present invention also relates to processes of fermenting a cellulosic material, comprising: fermenting the cellulosic material with one or more (e.g., several) fermenting
10 microorganisms, wherein the cellulosic material is saccharified with an enzyme composition in the presence of a polypeptide having cellobiohydrolase activity of the present invention. In one aspect, the fermenting of the cellulosic material produces a fermentation product. In another aspect, the processes further comprise recovering the fermentation product from the fermentation.

The processes of the present invention can be used to saccharify the cellulosic material to fermentable sugars and to convert the fermentable sugars to many useful fermentation products, e.g., fuel, potable ethanol, and/or platform chemicals (e.g., acids, alcohols, ketones, gases, and the like). The production of a desired fermentation product from the cellulosic material typically involves pretreatment, enzymatic hydrolysis (saccharification), and
15 20 fermentation.

The processing of the cellulosic material according to the present invention can be accomplished using methods conventional in the art. Moreover, the processes of the present invention can be implemented using any conventional biomass processing apparatus configured to operate in accordance with the invention.

Hydrolysis (saccharification) and fermentation, separate or simultaneous, include, but are not limited to, separate hydrolysis and fermentation (SHF); simultaneous saccharification and fermentation (SSF); simultaneous saccharification and co-fermentation (SSCF); hybrid hydrolysis and fermentation (HHF); separate hydrolysis and co-fermentation (SHCF); hybrid hydrolysis and co-fermentation (HHCF); and direct microbial conversion (DMC), also sometimes
25 30 called consolidated bioprocessing (CBP). SHF uses separate process steps to first enzymatically hydrolyze the cellulosic material to fermentable sugars, e.g., glucose, cellobiose, and pentose monomers, and then ferment the fermentable sugars to ethanol. In SSF, the enzymatic hydrolysis of the cellulosic material and the fermentation of sugars to ethanol are combined in one step (Philippidis, G. P., 1996, Cellulose bioconversion technology, in

Handbook on Bioethanol: Production and Utilization, Wyman, C. E., ed., Taylor & Francis, Washington, DC, 179-212). SSCF involves the co-fermentation of multiple sugars (Sheehan, J., and Himmel, M., 1999, *Enzymes, energy and the environment: A strategic perspective on the U.S. Department of Energy's research and development activities for bioethanol*, *Biotechnol. Prog.* 15: 817-827). HHF involves a separate hydrolysis step, and in addition a simultaneous saccharification and hydrolysis step, which can be carried out in the same reactor. The steps in an HHF process can be carried out at different temperatures, *i.e.*, high temperature enzymatic saccharification followed by SSF at a lower temperature that the fermentation strain can tolerate. DMC combines all three processes (enzyme production, hydrolysis, and fermentation) in one or more (e.g., several) steps where the same organism is used to produce the enzymes for conversion of the cellulosic material to fermentable sugars and to convert the fermentable sugars into a final product (Lynd, L. R., Weimer, P. J., van Zyl, W. H., and Pretorius, I. S., 2002, *Microbial cellulose utilization: Fundamentals and biotechnology*, *Microbiol. Mol. Biol. Reviews* 66: 506-577). It is understood herein that any method known in the art comprising pretreatment, enzymatic hydrolysis (saccharification), fermentation, or a combination thereof, can be used in the practicing the processes of the present invention.

A conventional apparatus can include a fed-batch stirred reactor, a batch stirred reactor, a continuous flow stirred reactor with ultrafiltration, and/or a continuous plug-flow column reactor (Fernanda de Castilhos Corazza, Flávio Faria de Moraes, Gisella Maria Zanin and Ivo Neitzel, 2003, *Optimal control in fed-batch reactor for the cellobiose hydrolysis*, *Acta Scientiarum. Technology* 25: 33-38; Gusakov, A. V., and Sinitsyn, A. P., 1985, *Kinetics of the enzymatic hydrolysis of cellulose: 1. A mathematical model for a batch reactor process*, *Enz. Microb. Technol.* 7: 346-352), an attrition reactor (Ryu, S. K., and Lee, J. M., 1983, *Bioconversion of waste cellulose by using an attrition bioreactor*, *Biotechnol. Bioeng.* 25: 53-65), or a reactor with intensive stirring induced by an electromagnetic field (Gusakov, A. V., Sinitsyn, A. P., Davydkin, I. Y., Davydkin, V. Y., Protas, O. V., 1996, *Enhancement of enzymatic cellulose hydrolysis using a novel type of bioreactor with intensive stirring induced by electromagnetic field*, *Appl. Biochem. Biotechnol.* 56: 141-153). Additional reactor types include fluidized bed, upflow blanket, immobilized, and extruder type reactors for hydrolysis and/or fermentation.

Pretreatment. In practicing the processes of the present invention, any pretreatment process known in the art can be used to disrupt plant cell wall components of the cellulosic material (Chandra *et al.*, 2007, *Substrate pretreatment: The key to effective enzymatic hydrolysis of lignocellulosics?*, *Adv. Biochem. Engin./Biotechnol.* 108: 67-93; Galbe and Zacchi, 2007, *Pretreatment of lignocellulosic materials for efficient bioethanol production*, *Adv. Biochem.*

Engin./Biotechnol. 108: 41-65; Hendriks and Zeeman, 2009, Pretreatments to enhance the digestibility of lignocellulosic biomass, *Bioresource Technol.* 100: 10-18; Mosier *et al.*, 2005, Features of promising technologies for pretreatment of lignocellulosic biomass, *Bioresource Technol.* 96: 673-686; Taherzadeh and Karimi, 2008, Pretreatment of lignocellulosic wastes to improve ethanol and biogas production: A review, *Int. J. of Mol. Sci.* 9: 1621-1651; Yang and Wyman, 2008, Pretreatment: the key to unlocking low-cost cellulosic ethanol, *Biofuels Bioproducts and Biorefining-Biofpr.* 2: 26-40).

The cellulosic material can also be subjected to particle size reduction, sieving, pre-soaking, wetting, washing, and/or conditioning prior to pretreatment using methods known in the art.

Conventional pretreatments include, but are not limited to, steam pretreatment (with or without explosion), dilute acid pretreatment, hot water pretreatment, alkaline pretreatment, lime pretreatment, wet oxidation, wet explosion, ammonia fiber explosion, organosolv pretreatment, and biological pretreatment. Additional pretreatments include ammonia percolation, ultrasound, electroporation, microwave, supercritical CO₂, supercritical H₂O, ozone, ionic liquid, and gamma irradiation pretreatments.

The cellulosic material can be pretreated before hydrolysis and/or fermentation. Pretreatment is preferably performed prior to the hydrolysis. Alternatively, the pretreatment can be carried out simultaneously with enzyme hydrolysis to release fermentable sugars, such as glucose, xylose, and/or cellobiose. In most cases the pretreatment step itself results in some conversion of biomass to fermentable sugars (even in absence of enzymes).

Steam Pretreatment. In steam pretreatment, the cellulosic material is heated to disrupt the plant cell wall components, including lignin, hemicellulose, and cellulose to make the cellulose and other fractions, *e.g.*, hemicellulose, accessible to enzymes. The cellulosic material is passed to or through a reaction vessel where steam is injected to increase the temperature to the required temperature and pressure and is retained therein for the desired reaction time. Steam pretreatment is preferably performed at 140-250°C, *e.g.*, 160-200°C or 170-190°C, where the optimal temperature range depends on addition of a chemical catalyst. Residence time for the steam pretreatment is preferably 1-60 minutes, *e.g.*, 1-30 minutes, 1-20 minutes, 3-12 minutes, or 4-10 minutes, where the optimal residence time depends on temperature range and addition of a chemical catalyst. Steam pretreatment allows for relatively high solids loadings, so that the cellulosic material is generally only moist during the pretreatment. The steam pretreatment is often combined with an explosive discharge of the material after the pretreatment, which is known as steam explosion, that is, rapid flashing to atmospheric pressure

and turbulent flow of the material to increase the accessible surface area by fragmentation (Duff and Murray, 1996, *Bioresource Technology* 85: 1-33; Galbe and Zacchi, 2002, *Appl. Microbiol. Biotechnol.* 59: 618-628; U.S. Patent Application No. 20020164730). During steam pretreatment, hemicellulose acetyl groups are cleaved and the resulting acid autocatalyzes partial hydrolysis of the hemicellulose to monosaccharides and oligosaccharides. Lignin is removed to only a limited extent.

Chemical Pretreatment: The term "chemical treatment" refers to any chemical pretreatment that promotes the separation and/or release of cellulose, hemicellulose, and/or lignin. Such a pretreatment can convert crystalline cellulose to amorphous cellulose. Examples of suitable chemical pretreatment processes include, for example, dilute acid pretreatment, lime pretreatment, wet oxidation, ammonia fiber/freeze explosion (AFEX), ammonia percolation (APR), ionic liquid, and organosolv pretreatments.

A catalyst such as H_2SO_4 or SO_2 (typically 0.3 to 5% w/w) is often added prior to steam pretreatment, which decreases the time and temperature, increases the recovery, and improves enzymatic hydrolysis (Ballesteros *et al.*, 2006, *Appl. Biochem. Biotechnol.* 129-132: 496-508; Varga *et al.*, 2004, *Appl. Biochem. Biotechnol.* 113-116: 509-523; Sassner *et al.*, 2006, *Enzyme Microb. Technol.* 39: 756-762). In dilute acid pretreatment, the cellulosic material is mixed with dilute acid, typically H_2SO_4 , and water to form a slurry, heated by steam to the desired temperature, and after a residence time flashed to atmospheric pressure. The dilute acid pretreatment can be performed with a number of reactor designs, e.g., plug-flow reactors, counter-current reactors, or continuous counter-current shrinking bed reactors (Duff and Murray, 1996, *supra*; Schell *et al.*, 2004, *Bioresource Technol.* 91: 179-188; Lee *et al.*, 1999, *Adv. Biochem. Eng. Biotechnol.* 65: 93-115).

Several methods of pretreatment under alkaline conditions can also be used. These alkaline pretreatments include, but are not limited to, sodium hydroxide, lime, wet oxidation, ammonia percolation (APR), and ammonia fiber/freeze explosion (AFEX).

Lime pretreatment is performed with calcium oxide or calcium hydroxide at temperatures of 85-150°C and residence times from 1 hour to several days (Wyman *et al.*, 2005, *Bioresource Technol.* 96: 1959-1966; Mosier *et al.*, 2005, *Bioresource Technol.* 96: 673-686). WO 2006/110891, WO 2006/110899, WO 2006/110900, and WO 2006/110901 disclose pretreatment methods using ammonia.

Wet oxidation is a thermal pretreatment performed typically at 180-200°C for 5-15 minutes with addition of an oxidative agent such as hydrogen peroxide or over-pressure of oxygen (Schmidt and Thomsen, 1998, *Bioresource Technol.* 64: 139-151; Palonen *et al.*, 2004, *Appl. Biochem.*

Biotechnol. 117: 1-17; Varga *et al.*, 2004, *Biotechnol. Bioeng.* 88: 567-574; Martin *et al.*, 2006, *J. Chem. Technol. Biotechnol.* 81: 1669-1677). The pretreatment is performed preferably at 1-40% dry matter, e.g., 2-30% dry matter or 5-20% dry matter, and often the initial pH is increased by the addition of alkali such as sodium carbonate.

5 A modification of the wet oxidation pretreatment method, known as wet explosion (combination of wet oxidation and steam explosion) can handle dry matter up to 30%. In wet explosion, the oxidizing agent is introduced during pretreatment after a certain residence time. The pretreatment is then ended by flashing to atmospheric pressure (WO 2006/032282).

10 Ammonia fiber explosion (AFEX) involves treating the cellulosic material with liquid or gaseous ammonia at moderate temperatures such as 90-150°C and high pressure such as 17-20 bar for 5-10 minutes, where the dry matter content can be as high as 60% (Gollapalli *et al.*, 2002, *Appl. Biochem. Biotechnol.* 98: 23-35; Chundawat *et al.*, 2007, *Biotechnol. Bioeng.* 96: 219-231; Alizadeh *et al.*, 2005, *Appl. Biochem. Biotechnol.* 121: 1133-1141; Teymouri *et al.*, 2005, *Bioresource Technol.* 96: 2014-2018). During AFEX pretreatment cellulose and hemicelluloses
15 remain relatively intact. Lignin-carbohydrate complexes are cleaved.

 Organosolv pretreatment delignifies the cellulosic material by extraction using aqueous ethanol (40-60% ethanol) at 160-200°C for 30-60 minutes (Pan *et al.*, 2005, *Biotechnol. Bioeng.* 90: 473-481; Pan *et al.*, 2006, *Biotechnol. Bioeng.* 94: 851-861; Kurabi *et al.*, 2005, *Appl. Biochem. Biotechnol.* 121: 219-230). Sulphuric acid is usually added as a catalyst. In organosolv
20 pretreatment, the majority of hemicellulose and lignin is removed.

 Other examples of suitable pretreatment methods are described by Schell *et al.*, 2003, *Appl. Biochem. and Biotechnol.* Vol. 105-108, p. 69-85, and Mosier *et al.*, 2005, *Bioresource Technology* 96: 673-686, and U.S. Published Application 2002/0164730.

 In one aspect, the chemical pretreatment is preferably carried out as a dilute acid
25 treatment, and more preferably as a continuous dilute acid treatment. The acid is typically sulfuric acid, but other acids can also be used, such as acetic acid, citric acid, nitric acid, phosphoric acid, tartaric acid, succinic acid, hydrogen chloride, or mixtures thereof. Mild acid treatment is conducted in the pH range of preferably 1-5, e.g., 1-4 or 1-2.5. In one aspect, the acid concentration is in the range from preferably 0.01 to 10 wt % acid, e.g., 0.05 to 5 wt % acid or 0.1 to 2 wt % acid. The acid
30 is contacted with the cellulosic material and held at a temperature in the range of preferably 140-200°C, e.g., 165-190°C, for periods ranging from 1 to 60 minutes.

 In another aspect, pretreatment takes place in an aqueous slurry. In preferred aspects, the cellulosic material is present during pretreatment in amounts preferably between 10-80 wt %, e.g., 20-70 wt % or 30-60 wt %, such as around 40 wt %. The pretreated cellulosic

material can be unwashed or washed using any method known in the art, e.g., washed with water.

Mechanical Pretreatment or Physical Pretreatment: The term "mechanical pretreatment" or "physical pretreatment" refers to any pretreatment that promotes size reduction of particles. For example, such pretreatment can involve various types of grinding or milling (e.g., dry milling, wet milling, or vibratory ball milling).

The cellulosic material can be pretreated both physically (mechanically) and chemically. Mechanical or physical pretreatment can be coupled with steaming/steam explosion, hydrothermolysis, dilute or mild acid treatment, high temperature, high pressure treatment, irradiation (e.g., microwave irradiation), or combinations thereof. In one aspect, high pressure means pressure in the range of preferably about 100 to about 400 psi, e.g., about 150 to about 250 psi. In another aspect, high temperature means temperatures in the range of about 100 to about 300°C, e.g., about 140 to about 200°C. In a preferred aspect, mechanical or physical pretreatment is performed in a batch-process using a steam gun hydrolyzer system that uses high pressure and high temperature as defined above, e.g., a Sunds Hydrolyzer available from Sunds Defibrator AB, Sweden. The physical and chemical pretreatments can be carried out sequentially or simultaneously, as desired.

Accordingly, in a preferred aspect, the cellulosic material is subjected to physical (mechanical) or chemical pretreatment, or any combination thereof, to promote the separation and/or release of cellulose, hemicellulose, and/or lignin.

Biological Pretreatment: The term "biological pretreatment" refers to any biological pretreatment that promotes the separation and/or release of cellulose, hemicellulose, and/or lignin from the cellulosic material. Biological pretreatment techniques can involve applying lignin-solubilizing microorganisms and/or enzymes (see, for example, Hsu, T.-A., 1996, Pretreatment of biomass, in *Handbook on Bioethanol: Production and Utilization*, Wyman, C. E., ed., Taylor & Francis, Washington, DC, 179-212; Ghosh and Singh, 1993, Physicochemical and biological treatments for enzymatic/microbial conversion of cellulosic biomass, *Adv. Appl. Microbiol.* 39: 295-333; McMillan, J. D., 1994, Pretreating lignocellulosic biomass: a review, in *Enzymatic Conversion of Biomass for Fuels Production*, Himmel, M. E., Baker, J. O., and Overend, R. P., eds., ACS Symposium Series 566, American Chemical Society, Washington, DC, chapter 15; Gong, C. S., Cao, N. J., Du, J., and Tsao, G. T., 1999, Ethanol production from renewable resources, in *Advances in Biochemical Engineering/Biotechnology*, Scheper, T., ed., Springer-Verlag Berlin Heidelberg, Germany, 65: 207-241; Olsson and Hahn-Hagerdal, 1996, Fermentation of lignocellulosic hydrolysates for ethanol production, *Enz. Microb. Tech.* 18: 312-

331; and Vallander and Eriksson, 1990, Production of ethanol from lignocellulosic materials: State of the art, *Adv. Biochem. Eng./Biotechnol.* 42: 63-95).

Saccharification. In the hydrolysis step, also known as saccharification, the cellulosic material, e.g., pretreated, is hydrolyzed to break down cellulose and/or hemicellulose to fermentable sugars, such as glucose, cellobiose, xylose, xylulose, arabinose, mannose, galactose, and/or soluble oligosaccharides. The hydrolysis is performed enzymatically by an enzyme composition as described herein in the presence of a polypeptide having cellobiohydrolase activity of the present invention. The enzyme components of the compositions can be added simultaneously or sequentially.

Enzymatic hydrolysis is preferably carried out in a suitable aqueous environment under conditions that can be readily determined by one skilled in the art. In one aspect, hydrolysis is performed under conditions suitable for the activity of the enzyme components, i.e., optimal for the enzyme components. The hydrolysis can be carried out as a fed batch or continuous process where the cellulosic material is fed gradually to, for example, an enzyme containing hydrolysis solution.

The saccharification is generally performed in stirred-tank reactors or fermentors under controlled pH, temperature, and mixing conditions. Suitable process time, temperature and pH conditions can readily be determined by one skilled in the art. For example, the saccharification can last up to 200 hours, but is typically performed for preferably about 12 to about 120 hours, e.g., about 16 to about 72 hours or about 24 to about 48 hours. The temperature is in the range of preferably about 25°C to about 70°C, e.g., about 30°C to about 65°C, about 40°C to about 60°C, or about 50°C to about 55°C. The pH is in the range of preferably about 3 to about 8, e.g., about 3.5 to about 7, about 4 to about 6, or about 5.0 to about 5.5. The dry solids content is in the range of preferably about 5 to about 50 wt %, e.g., about 10 to about 40 wt % or about 20 to about 30 wt %.

The enzyme compositions can comprise any protein useful in degrading the cellulosic material.

In one aspect, the enzyme composition comprises or further comprises one or more (e.g., several) proteins/polypeptides selected from the group consisting of a cellulase, a GH61 polypeptide having cellulolytic enhancing activity, a hemicellulase, an esterase, an expansin, a laccase, a ligninolytic enzyme, a pectinase, a peroxidase, a protease, and a swollenin. In another aspect, the cellulase is preferably one or more (e.g., several) enzymes selected from the group consisting of an endoglucanase, a cellobiohydrolase, and a beta-glucosidase. In another aspect, the hemicellulase is preferably one or more (e.g., several) enzymes selected

from the group consisting of an acetylmannan esterase, an acetylxylan esterase, an arabinanase, an arabinofuranosidase, a coumaric acid esterase, a feruloyl esterase, a galactosidase, a glucuronidase, a glucuronoyl esterase, a mannanase, a mannosidase, a xylanase, and a xylosidase.

5 In another aspect, the enzyme composition comprises one or more (e.g., several) cellulolytic enzymes. In another aspect, the enzyme composition comprises or further comprises one or more (e.g., several) hemicellulolytic enzymes. In another aspect, the enzyme composition comprises one or more (e.g., several) cellulolytic enzymes and one or more (e.g., several) hemicellulolytic enzymes. In another aspect, the enzyme composition comprises one or more (e.g., several) enzymes selected from the group of cellulolytic enzymes and hemicellulolytic enzymes. In another aspect, the enzyme composition comprises an endoglucanase. In another aspect, the enzyme composition comprises a cellobiohydrolase. In another aspect, the enzyme composition comprises a beta-glucosidase. In another aspect, the enzyme composition comprises a polypeptide having cellulolytic enhancing activity. In another aspect, the enzyme composition comprises an endoglucanase and a polypeptide having cellulolytic enhancing activity. In another aspect, the enzyme composition comprises a cellobiohydrolase and a polypeptide having cellulolytic enhancing activity. In another aspect, the enzyme composition comprises a beta-glucosidase and a polypeptide having cellulolytic enhancing activity. In another aspect, the enzyme composition comprises an endoglucanase and a cellobiohydrolase. In another aspect, the enzyme composition comprises an endoglucanase and a beta-glucosidase. In another aspect, the enzyme composition comprises a cellobiohydrolase and a beta-glucosidase. In another aspect, the enzyme composition comprises an endoglucanase, a cellobiohydrolase, and a polypeptide having cellulolytic enhancing activity. In another aspect, the enzyme composition comprises an endoglucanase, a beta-glucosidase, and a polypeptide having cellulolytic enhancing activity. In another aspect, the enzyme composition comprises a cellobiohydrolase, a beta-glucosidase, and a polypeptide having cellulolytic enhancing activity. In another aspect, the enzyme composition comprises an endoglucanase, a cellobiohydrolase, and a beta-glucosidase. In another aspect, the enzyme composition comprises an endoglucanase, a cellobiohydrolase, a beta-glucosidase, and a polypeptide having cellulolytic enhancing activity.

 In another aspect, the enzyme composition comprises an acetylmannan esterase. In another aspect, the enzyme composition comprises an acetylxylan esterase. In another aspect, the enzyme composition comprises an arabinanase (e.g., alpha-L-arabinanase). In another aspect, the enzyme composition comprises an arabinofuranosidase (e.g., alpha-L-

arabinofuranosidase). In another aspect, the enzyme composition comprises a coumaric acid esterase. In another aspect, the enzyme composition comprises a feruloyl esterase. In another aspect, the enzyme composition comprises a galactosidase (e.g., alpha-galactosidase and/or beta-galactosidase). In another aspect, the enzyme composition comprises a glucuronidase (e.g., alpha-D-glucuronidase). In another aspect, the enzyme composition comprises a glucuronoyl esterase. In another aspect, the enzyme composition comprises a mannanase. In another aspect, the enzyme composition comprises a mannosidase (e.g., beta-mannosidase). In another aspect, the enzyme composition comprises a xylanase. In a preferred aspect, the xylanase is a Family 10 xylanase. In another aspect, the enzyme composition comprises a xylosidase (e.g., beta-xylosidase).

In another aspect, the enzyme composition comprises an esterase. In another aspect, the enzyme composition comprises an expansin. In another aspect, the enzyme composition comprises a laccase. In another aspect, the enzyme composition comprises a ligninolytic enzyme. In a preferred aspect, the ligninolytic enzyme is a manganese peroxidase. In another preferred aspect, the ligninolytic enzyme is a lignin peroxidase. In another preferred aspect, the ligninolytic enzyme is a H₂O₂-producing enzyme. In another aspect, the enzyme composition comprises a pectinase. In another aspect, the enzyme composition comprises a peroxidase. In another aspect, the enzyme composition comprises a protease. In another aspect, the enzyme composition comprises a swollenin.

In the processes of the present invention, the enzyme(s) can be added prior to or during saccharification, saccharification and fermentation, or fermentation.

One or more (e.g., several) components of the enzyme composition may be wild-type proteins, recombinant proteins, or a combination of wild-type proteins and recombinant proteins. For example, one or more (e.g., several) components may be native proteins of a cell, which is used as a host cell to express recombinantly one or more (e.g., several) other components of the enzyme composition. One or more (e.g., several) components of the enzyme composition may be produced as monocomponents, which are then combined to form the enzyme composition. The enzyme composition may be a combination of multicomponent and monocomponent protein preparations.

The enzymes used in the processes of the present invention may be in any form suitable for use, such as, for example, a fermentation broth formulation or a cell composition, a cell lysate with or without cellular debris, a semi-purified or purified enzyme preparation, or a host cell as a source of the enzymes. The enzyme composition may be a dry powder or granulate, a non-dusting granulate, a liquid, a stabilized liquid, or a stabilized protected enzyme. Liquid

enzyme preparations may, for instance, be stabilized by adding stabilizers such as a sugar, a sugar alcohol or another polyol, and/or lactic acid or another organic acid according to established processes.

The optimum amounts of the enzymes and a polypeptide having cellobiohydrolase activity depend on several factors including, but not limited to, the mixture of cellulolytic and/or hemicellulolytic enzyme components, the cellulosic material, the concentration of cellulosic material, the pretreatment(s) of the cellulosic material, temperature, time, pH, and inclusion of fermenting organism (e.g., yeast for Simultaneous Saccharification and Fermentation).

In one aspect, an effective amount of cellulolytic or hemicellulolytic enzyme to the cellulosic material is about 0.5 to about 50 mg, e.g., about 0.5 to about 40 mg, about 0.5 to about 25 mg, about 0.75 to about 20 mg, about 0.75 to about 15 mg, about 0.5 to about 10 mg, or about 2.5 to about 10 mg per g of the cellulosic material.

In another aspect, an effective amount of a polypeptide having cellobiohydrolase activity to the cellulosic material is about 0.01 to about 50.0 mg, e.g., about 0.01 to about 40 mg, about 0.01 to about 30 mg, about 0.01 to about 20 mg, about 0.01 to about 10 mg, about 0.01 to about 5 mg, about 0.025 to about 1.5 mg, about 0.05 to about 1.25 mg, about 0.075 to about 1.25 mg, about 0.1 to about 1.25 mg, about 0.15 to about 1.25 mg, or about 0.25 to about 1.0 mg per g of the cellulosic material.

In another aspect, an effective amount of a polypeptide having cellobiohydrolase activity to cellulolytic or hemicellulolytic enzyme is about 0.005 to about 1.0 g, e.g., about 0.01 to about 1.0 g, about 0.15 to about 0.75 g, about 0.15 to about 0.5 g, about 0.1 to about 0.5 g, about 0.1 to about 0.25 g, or about 0.05 to about 0.2 g per g of cellulolytic or hemicellulolytic enzyme.

The polypeptides having cellulolytic enzyme activity or hemicellulolytic enzyme activity as well as other proteins/polypeptides useful in the degradation of the cellulosic material, e.g., GH61 polypeptides having cellulolytic enhancing activity (collectively hereinafter "polypeptides having enzyme activity") can be derived or obtained from any suitable origin, including, bacterial, fungal, yeast, plant, or mammalian origin. The term "obtained" also means herein that the enzyme may have been produced recombinantly in a host organism employing methods described herein, wherein the recombinantly produced enzyme is either native or foreign to the host organism or has a modified amino acid sequence, e.g., having one or more (e.g., several) amino acids that are deleted, inserted and/or substituted, i.e., a recombinantly produced enzyme that is a mutant and/or a fragment of a native amino acid sequence or an enzyme produced by nucleic acid shuffling processes known in the art. Encompassed within the meaning of a native enzyme are natural variants and within the meaning of a foreign enzyme

are variants obtained recombinantly, such as by site-directed mutagenesis or shuffling.

A polypeptide having enzyme activity may be a bacterial polypeptide. For example, the polypeptide may be a Gram-positive bacterial polypeptide such as a *Bacillus*, *Streptococcus*, *Streptomyces*, *Staphylococcus*, *Enterococcus*, *Lactobacillus*, *Lactococcus*, *Clostridium*,
5 *Geobacillus*, *Caldicellulosiruptor*, *Acidothermus*, *Thermobifidia*, or *Oceanobacillus* polypeptide having enzyme activity, or a Gram negative bacterial polypeptide such as an *E. coli*, *Pseudomonas*, *Salmonella*, *Campylobacter*, *Helicobacter*, *Flavobacterium*, *Fusobacterium*, *Ilyobacter*, *Neisseria*, or *Ureaplasma* polypeptide having enzyme activity.

In one aspect, the polypeptide is a *Bacillus alkalophilus*, *Bacillus amyloliquefaciens*,
10 *Bacillus brevis*, *Bacillus circulans*, *Bacillus clausii*, *Bacillus coagulans*, *Bacillus firmus*, *Bacillus lautus*, *Bacillus lentus*, *Bacillus licheniformis*, *Bacillus megaterium*, *Bacillus pumilus*, *Bacillus stearothermophilus*, *Bacillus subtilis*, or *Bacillus thuringiensis* polypeptide having enzyme activity.

In another aspect, the polypeptide is a *Streptococcus equisimilis*, *Streptococcus*
15 *pyogenes*, *Streptococcus uberis*, or *Streptococcus equi* subsp. *Zooepidemicus* polypeptide having enzyme activity.

In another aspect, the polypeptide is a *Streptomyces achromogenes*, *Streptomyces*
avermitilis, *Streptomyces coelicolor*, *Streptomyces griseus*, or *Streptomyces lividans* polypeptide having enzyme activity.

The polypeptide having enzyme activity may also be a fungal polypeptide, and more preferably a yeast polypeptide such as a *Candida*, *Kluyveromyces*, *Pichia*, *Saccharomyces*, *Schizosaccharomyces*, or *Yarrowia* polypeptide having enzyme activity; or more preferably a filamentous fungal polypeptide such as an *Acremonium*, *Agaricus*, *Altemaria*, *Aspergillus*, *Aureobasidium*, *Botryosphaeria*, *Ceriporiopsis*, *Chaetomidium*, *Chrysosporium*, *Claviceps*,
20 *Cochliobolus*, *Coprinopsis*, *Coptotermes*, *Corynascus*, *Cryphonectria*, *Cryptococcus*, *Diplodia*, *Exidia*, *Filibasidium*, *Fusarium*, *Gibberella*, *Holomastigotoides*, *Humicola*, *Irpex*, *Lentinula*, *Leptosphaeria*, *Magnaporthe*, *Melanocarpus*, *Meripilus*, *Mucor*, *Myceliophthora*, *Neocallimastix*,
25 *Neurospora*, *Paecilomyces*, *Penicillium*, *Phanerochaete*, *Piromyces*, *Poitrasia*, *Pseudoplectania*, *Pseudotrichonympha*, *Rhizomucor*, *Schizophyllum*, *Scytalidium*, *Talaromyces*, *Thermoascus*,
30 *Thielavia*, *Tolypocladium*, *Trichoderma*, *Trichophaea*, *Verticillium*, *Volvariella*, or *Xylaria* polypeptide having enzyme activity.

In one aspect, the polypeptide is a *Saccharomyces carlsbergensis*, *Saccharomyces cerevisiae*, *Saccharomyces diastaticus*, *Saccharomyces douglasii*, *Saccharomyces kluyveri*, *Saccharomyces norbensis*, or *Saccharomyces oviformis* polypeptide having enzyme activity.

In another aspect, the polypeptide is an *Acremonium cellulolyticus*, *Aspergillus aculeatus*, *Aspergillus awamori*, *Aspergillus fumigatus*, *Aspergillus foetidus*, *Aspergillus japonicus*, *Aspergillus nidulans*, *Aspergillus niger*, *Aspergillus oryzae*, *Chrysosporium keratinophilum*, *Chrysosporium lucknowense*, *Chrysosporium tropicum*, *Chrysosporium merdarium*, *Chrysosporium inops*, *Chrysosporium pannicola*, *Chrysosporium queenslandicum*, *Chrysosporium zonatum*, *Fusarium bactridioides*, *Fusarium cerealis*, *Fusarium crookwellense*, *Fusarium culmorum*, *Fusarium graminearum*, *Fusarium graminum*, *Fusarium heterosporum*, *Fusarium negundi*, *Fusarium oxysporum*, *Fusarium reticulatum*, *Fusarium roseum*, *Fusarium sambucinum*, *Fusarium sarcochroum*, *Fusarium sporotrichioides*, *Fusarium sulphureum*, *Fusarium torulosum*, *Fusarium trichothecioides*, *Fusarium venenatum*, *Humicola grisea*, *Humicola insolens*, *Humicola lanuginosa*, *Irpex lacteus*, *Mucor miehei*, *Myceliophthora thermophila*, *Neurospora crassa*, *Penicillium funiculosum*, *Penicillium purpurogenum*, *Phanerochaete chrysosporium*, *Thielavia achromatica*, *Thielavia albomyces*, *Thielavia albopilosa*, *Thielavia australeinsis*, *Thielavia fimetii*, *Thielavia microspora*, *Thielavia ovispora*, *Thielavia peruviana*, *Thielavia spededonium*, *Thielavia setosa*, *Thielavia subthermophila*, *Thielavia terrestris*, *Trichoderma harzianum*, *Trichoderma koningii*, *Trichoderma longibrachiatum*, *Trichoderma reesei*, *Trichoderma viride*, or *Trichophaea saccata* polypeptide having enzyme activity.

Chemically modified or protein engineered mutants of polypeptides having enzyme activity may also be used.

One or more (e.g., several) components of the enzyme composition may be a recombinant component, i.e., produced by cloning of a DNA sequence encoding the single component and subsequent cell transformed with the DNA sequence and expressed in a host (see, for example, WO 91/17243 and WO 91/17244). The host is preferably a heterologous host (enzyme is foreign to host), but the host may under certain conditions also be a homologous host (enzyme is native to host). Monocomponent cellulolytic proteins may also be prepared by purifying such a protein from a fermentation broth.

In one aspect, the one or more (e.g., several) cellulolytic enzymes comprise a commercial cellulolytic enzyme preparation. Examples of commercial cellulolytic enzyme preparations suitable for use in the present invention include, for example, CELLIC® CTec (Novozymes A/S), CELLIC® CTec2 (Novozymes A/S), CELLIC® CTec3 (Novozymes A/S), CELLUCLAST™ (Novozymes A/S), NOVOZYM™ 188 (Novozymes A/S), CELLUZYME™ (Novozymes A/S), CEREFLO™ (Novozymes A/S), and ULTRAFLO™ (Novozymes A/S), ACCELERASE™ (Genencor Int.), LAMINEX™ (Genencor Int.), SPEZYME™ CP (Genencor

Int.), FILTRASE® NL (DSM); METHAPLUS® S/L 100 (DSM), ROHAMENT™ 7069 W (Röhm GmbH), FIBREZYME® LDI (Dyadic International, Inc.), FIBREZYME® LBR (Dyadic International, Inc.), or VISCOSTAR® 150L (Dyadic International, Inc.). The cellulase enzymes are added in amounts effective from about 0.001 to about 5.0 wt % of solids, e.g., about 0.025 to about 4.0 wt % of solids or about 0.005 to about 2.0 wt % of solids.

Examples of bacterial endoglucanases that can be used in the processes of the present invention, include, but are not limited to, an *Acidothermus cellulolyticus* endoglucanase (WO 91/05039; WO 93/15186; U.S. Patent No. 5,275,944; WO 96/02551; U.S. Patent No. 5,536,655, WO 00/70031, WO 05/093050); *Thermobifida fusca* endoglucanase III (WO 05/093050); and *Thermobifida fusca* endoglucanase V (WO 05/093050).

Examples of fungal endoglucanases that can be used in the present invention, include, but are not limited to, a *Trichoderma reesei* endoglucanase I (Penttilä *et al.*, 1986, *Gene* 45: 253-263, *Trichoderma reesei* Cel7B endoglucanase I (GENBANK™ accession no. M15665), *Trichoderma reesei* endoglucanase II (Saloheimo, *et al.*, 1988, *Gene* 63:11-22), *Trichoderma reesei* Cel5A endoglucanase II (GENBANK™ accession no. M19373), *Trichoderma reesei* endoglucanase III (Okada *et al.*, 1988, *Appl. Environ. Microbiol.* 64: 555-563, GENBANK™ accession no. AB003694), *Trichoderma reesei* endoglucanase V (Saloheimo *et al.*, 1994, *Molecular Microbiology* 13: 219-228, GENBANK™ accession no. Z33381), *Aspergillus aculeatus* endoglucanase (Ooi *et al.*, 1990, *Nucleic Acids Research* 18: 5884), *Aspergillus kawachii* endoglucanase (Sakamoto *et al.*, 1995, *Current Genetics* 27: 435-439), *Erwinia carotovora* endoglucanase (Saarilahti *et al.*, 1990, *Gene* 90: 9-14), *Fusarium oxysporum* endoglucanase (GENBANK™ accession no. L29381), *Humicola grisea* var. *thermoidea* endoglucanase (GENBANK™ accession no. AB003107), *Melanocarpus albomyces* endoglucanase (GENBANK™ accession no. MAL515703), *Neurospora crassa* endoglucanase (GENBANK™ accession no. XM_324477), *Humicola insolens* endoglucanase V, *Myceliophthora thermophila* CBS 117.65 endoglucanase, basidiomycete CBS 495.95 endoglucanase, basidiomycete CBS 494.95 endoglucanase, *Thielavia terrestris* NRRL 8126 CEL6B endoglucanase, *Thielavia terrestris* NRRL 8126 CEL6C endoglucanase, *Thielavia terrestris* NRRL 8126 CEL7C endoglucanase, *Thielavia terrestris* NRRL 8126 CEL7E endoglucanase, *Thielavia terrestris* NRRL 8126 CEL7F endoglucanase, *Cladorrhinum foecundissimum* ATCC 62373 CEL7A endoglucanase, and *Trichoderma reesei* strain No. VTT-D-80133 endoglucanase (GENBANK™ accession no. M15665).

Examples of cellobiohydrolases useful in the present invention include, but are not

limited to, *Aspergillus aculeatus* cellobiohydrolase II (WO 2011/059740), *Chaetomium thermophilum* cellobiohydrolase I, *Chaetomium thermophilum* cellobiohydrolase II, *Humicola insolens* cellobiohydrolase I, *Myceliophthora thermophila* cellobiohydrolase II (WO 2009/042871), *Thielavia hyrcanie* cellobiohydrolase II (WO 2010/141325), *Thielavia terrestris* cellobiohydrolase II (CEL6A, WO 2006/074435), *Trichoderma reesei* cellobiohydrolase I, *Trichoderma reesei* cellobiohydrolase II, and *Trichophaea saccata* cellobiohydrolase II (WO 2010/057086).

Examples of beta-glucosidases useful in the present invention include, but are not limited to, beta-glucosidases from *Aspergillus aculeatus* (Kawaguchi *et al.*, 1996, *Gene* 173: 287-288), *Aspergillus fumigatus* (WO 2005/047499), *Aspergillus niger* (Dan *et al.*, 2000, *J. Biol. Chem.* 275: 4973-4980), *Aspergillus oryzae* (WO 2002/095014), *Penicillium brasilianum* IBT 20888 (WO 2007/019442 and WO 2010/088387), *Thielavia terrestris* (WO 2011/035029), and *Trichophaea saccata* (WO 2007/019442).

The beta-glucosidase may be a fusion protein. In one aspect, the beta-glucosidase is an *Aspergillus oryzae* beta-glucosidase variant BG fusion protein (WO 2008/057637) or an *Aspergillus oryzae* beta-glucosidase fusion protein (WO 2008/057637).

Other useful endoglucanases, cellobiohydrolases, and beta-glucosidases are disclosed in numerous Glycosyl Hydrolase families using the classification according to Henrissat B., 1991, A classification of glycosyl hydrolases based on amino-acid sequence similarities, *Biochem. J.* 280: 309-316, and Henrissat B., and Bairoch A., 1996, Updating the sequence-based classification of glycosyl hydrolases, *Biochem. J.* 316: 695-696.

Other cellulolytic enzymes that may be used in the present invention are described in WO 98/13465, WO 98/015619, WO 98/015633, WO 99/06574, WO 99/10481, WO 99/025847, WO 99/031255, WO 2002/101078, WO 2003/027306, WO 2003/052054, WO 2003/052055, WO 2003/052056, WO 2003/052057, WO 2003/052118, WO 2004/016760, WO 2004/043980, WO 2004/048592, WO 2005/001065, WO 2005/028636, WO 2005/093050, WO 2005/093073, WO 2006/074005, WO 2006/117432, WO 2007/071818, WO 2007/071820, WO 2008/008070, WO 2008/008793, U.S. Patent No. 5,457,046, U.S. Patent No. 5,648,263, and U.S. Patent No. 5,686,593.

In the methods of the present invention, any GH61 polypeptide having cellulolytic enhancing activity can be used.

In a first aspect, the GH61 polypeptide having cellulolytic enhancing activity comprises the following motifs:

[ILMV]-P-X(4,5)-G-X-Y-[ILMV]-X-R-X-[EQ]-X(4)-[HNQ] (SEQ ID NO: 9 or SEQ ID NO:

10) and [FW]-[TF]-K-[AIV],

wherein X is any amino acid, X(4,5) is any amino acid at 4 or 5 contiguous positions, and X(4) is any amino acid at 4 contiguous positions.

The isolated polypeptide comprising the above-noted motifs may further comprise:

5 H-X(1,2)-G-P-X(3)-[YW]-[AILMV] (SEQ ID NO: 11 or SEQ ID NO: 12),

[EQ]-X-Y-X(2)-C-X-[EHQN]-[FILV]-X-[ILV] (SEQ ID NO: 13), or

H-X(1,2)-G-P-X(3)-[YW]-[AILMV] (SEQ ID NO: 11 or SEQ ID NO: 12) and [EQ]-X-Y-X(2)-C-X-[EHQN]-[FILV]-X-[ILV] (SEQ ID NO: 13),

wherein X is any amino acid, X(1,2) is any amino acid at 1 position or 2 contiguous positions, 10 X(3) is any amino acid at 3 contiguous positions, and X(2) is any amino acid at 2 contiguous positions. In the above motifs, the accepted IUPAC single letter amino acid abbreviation is employed.

In a preferred embodiment, the isolated GH61 polypeptide having cellulolytic enhancing activity further comprises H-X(1,2)-G-P-X(3)-[YW]-[AILMV] (SEQ ID NO: 11 or SEQ ID NO: 12).

15 In another preferred embodiment, the isolated GH61 polypeptide having cellulolytic enhancing activity further comprises [EQ]-X-Y-X(2)-C-X-[EHQN]-[FILV]-X-[ILV] (SEQ ID NO: 13). In another preferred embodiment, the isolated GH61 polypeptide having cellulolytic enhancing activity further comprises H-X(1,2)-G-P-X(3)-[YW]-[AILMV] (SEQ ID NO: 11 or SEQ ID NO: 12) and [EQ]-X-Y-X(2)-C-X-[EHQN]-[FILV]-X-[ILV] (SEQ ID NO: 13).

20 In a second aspect, isolated polypeptides having cellulolytic enhancing activity, comprise the following motif:

[ILMV]-P-X(4,5)-G-X-Y-[ILMV]-X-R-X-[EQ]-X(3)-A-[HNQ] (SEQ ID NO: 14 or SEQ ID NO: 15),

wherein X is any amino acid, X(4,5) is any amino acid at 4 or 5 contiguous positions, and 25 X(3) is any amino acid at 3 contiguous positions. In the above motif, the accepted IUPAC single letter amino acid abbreviation is employed.

Examples of GH61 polypeptides having cellulolytic enhancing activity useful in the methods of the present invention include, but are not limited to, GH61 polypeptides from *Thielavia terrestris* (WO 2005/074647, WO 2008/148131, and WO 2011/035027), *Thermoascus aurantiacus* (WO 2005/074656 and WO 2010/065830), *Trichoderma reesei* (WO 2007/089290), *Myceliophthora thermophila* (WO 2009/085935, WO 2009/085859, WO 2009/085864, WO 2009/085868), *Aspergillus fumigatus* (WO 2010/138754), GH61 polypeptides from *Penicillium pinophilum* (WO 2011/005867), *Thermoascus* sp. (WO 2011/039319), *Penicillium* sp. (WO 2011/041397), and *Thermoascus crustaceus* (WO 2011/041504).

In one aspect, the GH61 polypeptide having cellulolytic enhancing activity is used in the presence of a soluble activating divalent metal cation according to WO 2008/151043, e.g., manganese or copper.

In another aspect, the GH61 polypeptide having cellulolytic enhancing activity is used in the presence of a dioxy compound, a bicyclic compound, a heterocyclic compound, a nitrogen-containing compound, a quinone compound, a sulfur-containing compound, or a liquor obtained from a pretreated cellulosic material such as pretreated corn stover (PCS).

The dioxy compound may include any suitable compound containing two or more oxygen atoms. In some aspects, the dioxy compounds contain a substituted aryl moiety as described herein. The dioxy compounds may comprise one or more (e.g., several) hydroxyl and/or hydroxyl derivatives, but also include substituted aryl moieties lacking hydroxyl and hydroxyl derivatives. Non-limiting examples of the dioxy compounds include pyrocatechol or catechol; caffeic acid; 3,4-dihydroxybenzoic acid; 4-tert-butyl-5-methoxy-1,2-benzenediol; pyrogallol; gallic acid; methyl-3,4,5-trihydroxybenzoate; 2,3,4-trihydroxybenzophenone; 2,6-dimethoxyphenol; sinapinic acid; 3,5-dihydroxybenzoic acid; 4-chloro-1,2-benzenediol; 4-nitro-1,2-benzenediol; tannic acid; ethyl gallate; methyl glycolate; dihydroxyfumaric acid; 2-butyne-1,4-diol; (croconic acid; 1,3-propanediol; tartaric acid; 2,4-pentanediol; 3-ethoxy-1,2-propanediol; 2,4,4'-trihydroxybenzophenone; cis-2-butene-1,4-diol; 3,4-dihydroxy-3-cyclobutene-1,2-dione; dihydroxyacetone; acrolein acetal; methyl-4-hydroxybenzoate; 4-hydroxybenzoic acid; and methyl-3,5-dimethoxy-4-hydroxybenzoate; or a salt or solvate thereof.

The bicyclic compound may include any suitable substituted fused ring system as described herein. The compounds may comprise one or more (e.g., several) additional rings, and are not limited to a specific number of rings unless otherwise stated. In one aspect, the bicyclic compound is a flavonoid. In another aspect, the bicyclic compound is an optionally substituted isoflavonoid. In another aspect, the bicyclic compound is an optionally substituted flavylum ion, such as an optionally substituted anthocyanidin or optionally substituted anthocyanin, or derivative thereof. Non-limiting examples of the bicyclic compounds include epicatechin; quercetin; myricetin; taxifolin; kaempferol; morin; acacetin; naringenin; isorhamnetin; apigenin; cyanidin; cyanin; kuromanin; keracyanin; or a salt or solvate thereof.

The heterocyclic compound may be any suitable compound, such as an optionally substituted aromatic or non-aromatic ring comprising a heteroatom, as described herein. In one aspect, the heterocyclic is a compound comprising an optionally substituted heterocycloalkyl moiety or an optionally substituted heteroaryl moiety. In another aspect, the optionally substituted heterocycloalkyl moiety or optionally substituted heteroaryl moiety is an optionally

substituted 5-membered heterocycloalkyl or an optionally substituted 5-membered heteroaryl moiety. In another aspect, the optionally substituted heterocycloalkyl or optionally substituted heteroaryl moiety is an optionally substituted moiety selected from pyrazolyl, furanyl, imidazolyl, isoxazolyl, oxadiazolyl, oxazolyl, pyrrolyl, pyridyl, pyrimidyl, pyridazinyl, thiazolyl, triazolyl, thienyl, dihydrothieno-pyrazolyl, thianaphthenyl, carbazolyl, benzimidazolyl, benzothienyl, benzofuranyl, indolyl, quinolinyl, benzotriazolyl, benzothiazolyl, benzooxazolyl, benzimidazolyl, isoquinolinyl, isoindolyl, acridinyl, benzoisazolyl, dimethylhydantoin, pyrazinyl, tetrahydrofuranyl, pyrrolinyl, pyrrolidinyl, morpholinyl, indolyl, diazepinyl, azepinyl, thiepinyl, piperidinyl, and oxepinyl. In another aspect, the optionally substituted heterocycloalkyl moiety or optionally substituted heteroaryl moiety is an optionally substituted furanyl. Non-limiting examples of the heterocyclic compounds include (1,2-dihydroxyethyl)-3,4-dihydroxyfuran-2(5H)-one; 4-hydroxy-5-methyl-3-furanone; 5-hydroxy-2(5H)-furanone; [1,2-dihydroxyethyl]furan-2,3,4(5H)-trione; α -hydroxy- γ -butyrolactone; ribonic γ -lactone; aldohexuronicaldohexuronic acid γ -lactone; gluconic acid δ -lactone; 4-hydroxycoumarin; dihydrobenzofuran; 5-(hydroxymethyl)furfural; furoin; 2(5H)-furanone; 5,6-dihydro-2H-pyran-2-one; and 5,6-dihydro-4-hydroxy-6-methyl-2H-pyran-2-one; or a salt or solvate thereof.

The nitrogen-containing compound may be any suitable compound with one or more nitrogen atoms. In one aspect, the nitrogen-containing compound comprises an amine, imine, hydroxylamine, or nitroxide moiety. Non-limiting examples of the nitrogen-containing compounds include acetone oxime; violuric acid; pyridine-2-aldoxime; 2-aminophenol; 1,2-benzenediamine; 2,2,6,6-tetramethyl-1-piperidinyloxy; 5,6,7,8-tetrahydrobiopterin; 6,7-dimethyl-5,6,7,8-tetrahydropterine; and maleamic acid; or a salt or solvate thereof.

The quinone compound may be any suitable compound comprising a quinone moiety as described herein. Non-limiting examples of the quinone compounds include 1,4-benzoquinone; 1,4-naphthoquinone; 2-hydroxy-1,4-naphthoquinone; 2,3-dimethoxy-5-methyl-1,4-benzoquinone or coenzyme Q₀; 2,3,5,6-tetramethyl-1,4-benzoquinone or duroquinone; 1,4-dihydroxyanthraquinone; 3-hydroxy-1-methyl-5,6-indolinedione or adrenochrome; 4-tert-butyl-5-methoxy-1,2-benzoquinone; pyrroloquinoline quinone; or a salt or solvate thereof.

The sulfur-containing compound may be any suitable compound comprising one or more sulfur atoms. In one aspect, the sulfur-containing comprises a moiety selected from thionyl, thioether, sulfinyl, sulfonyl, sulfamide, sulfonamide, sulfonic acid, and sulfonic ester. Non-limiting examples of the sulfur-containing compounds include ethanethiol; 2-propanethiol; 2-propene-1-thiol; 2-mercaptoethanesulfonic acid; benzenethiol; benzene-1,2-dithiol; cysteine; methionine; glutathione; cystine; or a salt or solvate thereof.

In one aspect, an effective amount of such a compound described above to cellulosic material as a molar ratio to glucosyl units of cellulose is about 10^{-6} to about 10, e.g., about 10^{-6} to about 7.5, about 10^{-6} to about 5, about 10^{-6} to about 2.5, about 10^{-6} to about 1, about 10^{-5} to about 1, about 10^{-5} to about 10^{-1} , about 10^{-4} to about 10^{-1} , about 10^{-3} to about 10^{-1} , or about 10^{-3} to about 10^{-2} . In another aspect, an effective amount of such a compound described above is about 0.1 μM to about 1 M, e.g., about 0.5 μM to about 0.75 M, about 0.75 μM to about 0.5 M, about 1 μM to about 0.25 M, about 1 μM to about 0.1 M, about 5 μM to about 50 mM, about 10 μM to about 25 mM, about 50 μM to about 25 mM, about 10 μM to about 10 mM, about 5 μM to about 5 mM, or about 0.1 mM to about 1 mM.

The term "liquor" means the solution phase, either aqueous, organic, or a combination thereof, arising from treatment of a lignocellulose and/or hemicellulose material in a slurry, or monosaccharides thereof, e.g., xylose, arabinose, mannose, etc., under conditions as described herein, and the soluble contents thereof. A liquor for cellulolytic enhancement of a GH61 polypeptide can be produced by treating a lignocellulose or hemicellulose material (or feedstock) by applying heat and/or pressure, optionally in the presence of a catalyst, e.g., acid, optionally in the presence of an organic solvent, and optionally in combination with physical disruption of the material, and then separating the solution from the residual solids. Such conditions determine the degree of cellulolytic enhancement obtainable through the combination of liquor and a GH61 polypeptide during hydrolysis of a cellulosic substrate by a cellulase preparation. The liquor can be separated from the treated material using a method standard in the art, such as filtration, sedimentation, or centrifugation.

In one aspect, an effective amount of the liquor to cellulose is about 10^{-6} to about 10 g per g of cellulose, e.g., about 10^{-6} to about 7.5 g, about 10^{-6} to about 5, about 10^{-6} to about 2.5 g, about 10^{-6} to about 1 g, about 10^{-5} to about 1 g, about 10^{-5} to about 10^{-1} g, about 10^{-4} to about 10^{-1} g, about 10^{-3} to about 10^{-1} g, or about 10^{-3} to about 10^{-2} g per g of cellulose.

In one aspect, the one or more (e.g., several) hemicellulolytic enzymes comprise a commercial hemicellulolytic enzyme preparation. Examples of commercial hemicellulolytic enzyme preparations suitable for use in the present invention include, for example, SHEARZYME™ (Novozymes A/S), CELLIC® HTec (Novozymes A/S), CELLIC® HTec2 (Novozymes A/S), CELLIC® HTec3 (Novozymes A/S), VISCOZYME® (Novozymes A/S), ULTRAFLO® (Novozymes A/S), PULPZYME® HC (Novozymes A/S), MULTIFECT® Xylanase (Genencor), ACCELLERASE® XY (Genencor), ACCELLERASE® XC (Genencor), ECOPULP® TX-200A (AB Enzymes), HSP 6000 Xylanase (DSM), DEPOL™ 333P (Biocatalysts Limit, Wales,

UK), DEPOL™ 740L. (Biocatalysts Limit, Wales, UK), and DEPOL™ 762P (Biocatalysts Limit, Wales, UK).

Examples of xylanases useful in the processes of the present invention include, but are not limited to, xylanases from *Aspergillus aculeatus* (GeneSeqP:AAR63790; WO 94/21785),
5 *Aspergillus fumigatus* (WO 2006/078256), *Penicillium pinophilum* (WO 2011/041405), *Penicillium* sp. (WO 2010/126772), *Thielavia terrestris* NRRL 8126 (WO 2009/079210), and *Trichophaea saccata* GH10 (WO 2011/057083).

Examples of beta-xylosidases useful in the processes of the present invention include, but are not limited to, beta-xylosidases from *Neurospora crassa* (SwissProt accession number Q7SOW4),
10 *Trichoderma reesei* (UniProtKB/TrEMBL accession number Q92458), and *Talaromyces emersonii* (SwissProt accession number Q8X212).

Examples of acetylxyylan esterases useful in the processes of the present invention include, but are not limited to, acetylxyylan esterases from *Aspergillus aculeatus* (WO 2010/108918), *Chaetomium globosum* (Uniprot accession number Q2GWX4), *Chaetomium*
15 *gracile* (GeneSeqP accession number AAB82124), *Humicola insolens* DSM 1800 (WO 2009/073709), *Hypocrea jecorina* (WO 2005/001036), *Myceliophthora thermophila* (WO 2010/014880), *Neurospora crassa* (UniProt accession number q7s259), *Phaeosphaeria nodorum* (Uniprot accession number Q0UJH1), and *Thielavia terrestris* NRRL 8126 (WO 2009/042846).

Examples of feruloyl esterases (ferulic acid esterases) useful in the processes of the present invention include, but are not limited to, feruloyl esterases from *Humicola insolens* DSM 1800 (WO 2009/076122), *Neosartorya fischeri* (UniProt Accession number A1D9T4),
20 *Neurospora crassa* (UniProt accession number Q9HGR3), *Penicillium aurantiogriseum* (WO 2009/127729), and *Thielavia terrestris* (WO 2010/053838 and WO 2010/065448).

Examples of arabinofuranosidases useful in the processes of the present invention include, but are not limited to, arabinofuranosidases from *Aspergillus niger* (GeneSeqP accession number AAR94170), *Humicola insolens* DSM 1800 (WO 2006/114094 and WO 2009/073383), and *M. giganteus* (WO 2006/114094).
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Examples of alpha-glucuronidases useful in the processes of the present invention include, but are not limited to, alpha-glucuronidases from *Aspergillus clavatus* (UniProt accession number alcc12), *Aspergillus fumigatus* (SwissProt accession number Q4WW45),
30 *Aspergillus niger* (Uniprot accession number Q96WX9), *Aspergillus terreus* (SwissProt accession number Q0CJP9), *Humicola insolens* (WO 2010/014706), *Penicillium aurantiogriseum* (WO 2009/068565), *Talaromyces emersonii* (UniProt accession number

Q8X211), and *Trichoderma reesei* (Uniprot accession number Q99024).

The polypeptides having enzyme activity used in the processes of the present invention may be produced by fermentation of the above-noted microbial strains on a nutrient medium containing suitable carbon and nitrogen sources and inorganic salts, using procedures known in the art (see, e.g., Bennett, J.W. and LaSure, L. (eds.), *More Gene Manipulations in Fungi*, Academic Press, CA, 1991). Suitable media are available from commercial suppliers or may be prepared according to published compositions (e.g., in catalogues of the American Type Culture Collection). Temperature ranges and other conditions suitable for growth and enzyme production are known in the art (see, e.g., Bailey, J.E., and Ollis, D.F., *Biochemical Engineering Fundamentals*, McGraw-Hill Book Company, NY, 1986).

The fermentation can be any method of cultivation of a cell resulting in the expression or isolation of an enzyme or protein. Fermentation may, therefore, be understood as comprising shake flask cultivation, or small- or large-scale fermentation (including continuous, batch, fed-batch, or solid state fermentations) in laboratory or industrial fermentors performed in a suitable medium and under conditions allowing the enzyme to be expressed or isolated. The resulting enzymes produced by the methods described above may be recovered from the fermentation medium and purified by conventional procedures.

Fermentation. The fermentable sugars obtained from the hydrolyzed cellulosic material can be fermented by one or more (e.g., several) fermenting microorganisms capable of fermenting the sugars directly or indirectly into a desired fermentation product. "Fermentation" or "fermentation process" refers to any fermentation process or any process comprising a fermentation step. Fermentation processes also include fermentation processes used in the consumable alcohol industry (e.g., beer and wine), dairy industry (e.g., fermented dairy products), leather industry, and tobacco industry. The fermentation conditions depend on the desired fermentation product and fermenting organism and can easily be determined by one skilled in the art.

In the fermentation step, sugars, released from the cellulosic material as a result of the pretreatment and enzymatic hydrolysis steps, are fermented to a product, e.g., ethanol, by a fermenting organism, such as yeast. Hydrolysis (saccharification) and fermentation can be separate or simultaneous, as described herein.

Any suitable hydrolyzed cellulosic material can be used in the fermentation step in practicing the present invention. The material is generally selected based on the desired fermentation product, i.e., the substance to be obtained from the fermentation, and the process employed, as is well known in the art.

The term "fermentation medium" is understood herein to refer to a medium before the fermenting microorganism(s) is(are) added, such as, a medium resulting from a saccharification process, as well as a medium used in a simultaneous saccharification and fermentation process (SSF).

5 "Fermenting microorganism" refers to any microorganism, including bacterial and fungal organisms, suitable for use in a desired fermentation process to produce a fermentation product. The fermenting organism can be hexose and/or pentose fermenting organisms, or a combination thereof. Both hexose and pentose fermenting organisms are well known in the art. Suitable fermenting microorganisms are able to ferment, *i.e.*, convert, sugars, such as glucose, xylose, 10 xylulose, arabinose, maltose, mannose, galactose, and/or oligosaccharides, directly or indirectly into the desired fermentation product. Examples of bacterial and fungal fermenting organisms producing ethanol are described by Lin *et al.*, 2006, *Appl. Microbiol. Biotechnol.* 69: 627-642.

Examples of fermenting microorganisms that can ferment hexose sugars include bacterial and fungal organisms, such as yeast. Preferred yeast includes strains of *Candida*, 15 *Kluyveromyces*, and *Saccharomyces*, *e.g.*, *Candida sonorensis*, *Kluyveromyces marxianus*, and *Saccharomyces cerevisiae*.

Examples of fermenting organisms that can ferment pentose sugars in their native state include bacterial and fungal organisms, such as some yeast. Preferred xylose fermenting yeast include strains of *Candida*, preferably *C. sheatae* or *C. sonorensis*; and strains of *Pichia*, preferably 20 *P. stipitis*, such as *P. stipitis* CBS 5773. Preferred pentose fermenting yeast include strains of *Pachysolen*, preferably *P. tannophilus*. Organisms not capable of fermenting pentose sugars, such as xylose and arabinose, may be genetically modified to do so by methods known in the art.

Examples of bacteria that can efficiently ferment hexose and pentose to ethanol include, for example, *Bacillus coagulans*, *Clostridium acetobutylicum*, *Clostridium thermocellum*, 25 *Clostridium phytofermentans*, *Geobacillus* sp., *Thermoanaerobacter saccharolyticum*, and *Zymomonas mobilis* (Philippidis, 1996, *supra*).

Other fermenting organisms include strains of *Bacillus*, such as *Bacillus coagulans*; *Candida*, such as *C. sonorensis*, *C. methanosorbosa*, *C. diddensiae*, *C. parapsilosis*, *C. naedodendra*, *C. blankii*, *C. entomophila*, *C. brassicae*, *C. pseudotropicalis*, *C. boidinii*, *C. utilis*, 30 and *C. scheidtiae*; *Clostridium*, such as *C. acetobutylicum*, *C. thermocellum*, and *C. phytofermentans*; *E. coli*, especially *E. coli* strains that have been genetically modified to improve the yield of ethanol; *Geobacillus* sp.; *Hansenula*, such as *Hansenula anomala*; *Klebsiella*, such as *K. oxytoca*; *Kluyveromyces*, such as *K. marxianus*, *K. lactis*, *K. thermotolerans*, and *K. fragilis*; *Schizosaccharomyces*, such as *S. pombe*; *Thermoanaerobacter*, such as *Thermoanaerobacter*

saccharolyticum; and *Zymomonas*, such as *Zymomonas mobilis*.

In a preferred aspect, the yeast is a *Bretannomyces*. In a more preferred aspect, the yeast is *Bretannomyces clausenii*. In another preferred aspect, the yeast is a *Candida*. In another more preferred aspect, the yeast is *Candida sonorensis*. In another more preferred aspect, the yeast is *Candida boidinii*. In another more preferred aspect, the yeast is *Candida blankii*. In another more preferred aspect, the yeast is *Candida brassicae*. In another more preferred aspect, the yeast is *Candida diddensii*. In another more preferred aspect, the yeast is *Candida entomophiliia*. In another more preferred aspect, the yeast is *Candida pseudotropicalis*. In another more preferred aspect, the yeast is *Candida scephatae*. In another more preferred aspect, the yeast is *Candida utilis*. In another preferred aspect, the yeast is a *Clavispora*. In another more preferred aspect, the yeast is *Clavispora lusitaniae*. In another more preferred aspect, the yeast is *Clavispora opuntiae*. In another preferred aspect, the yeast is a *Kluyveromyces*. In another more preferred aspect, the yeast is *Kluyveromyces fragilis*. In another more preferred aspect, the yeast is *Kluyveromyces marxianus*. In another more preferred aspect, the yeast is *Kluyveromyces thermotolerans*. In another preferred aspect, the yeast is a *Pachysolen*. In another more preferred aspect, the yeast is *Pachysolen tannophilus*. In another preferred aspect, the yeast is a *Pichia*. In another more preferred aspect, the yeast is a *Pichia stipitis*. In another preferred aspect, the yeast is a *Saccharomyces* spp. In another more preferred aspect, the yeast is *Saccharomyces cerevisiae*. In another more preferred aspect, the yeast is *Saccharomyces distaticus*. In another more preferred aspect, the yeast is *Saccharomyces uvarum*.

In a preferred aspect, the bacterium is a *Bacillus*. In a more preferred aspect, the bacterium is *Bacillus coagulans*. In another preferred aspect, the bacterium is a *Clostridium*. In another more preferred aspect, the bacterium is *Clostridium acetobutylicum*. In another more preferred aspect, the bacterium is *Clostridium phytofermentans*. In another more preferred aspect, the bacterium is *Clostridium thermocellum*. In another more preferred aspect, the bacterium is *Geobacillus* sp. In another more preferred aspect, the bacterium is a *Thermoanaerobacter*. In another more preferred aspect, the bacterium is *Thermoanaerobacter saccharolyticum*. In another preferred aspect, the bacterium is a *Zymomonas*. In another more preferred aspect, the bacterium is *Zymomonas mobilis*.

Commercially available yeast suitable for ethanol production include, e.g., BIOFERM™ AFT and XR (NABC - North American Bioproducts Corporation, GA, USA), ETHANOL RED™ yeast (Fermentis/Lesaffre, USA), FALI™ (Fleischmann's Yeast, USA), FERMIOL™ (DSM Specialties), GERT STRAND™ (Gert Strand AB, Sweden), and SUPERSTART™ and

THERMOSACC™ fresh yeast (Ethanol Technology, WI, USA).

In a preferred aspect, the fermenting microorganism has been genetically modified to provide the ability to ferment pentose sugars, such as xylose utilizing, arabinose utilizing, and xylose and arabinose co-utilizing microorganisms.

5 The cloning of heterologous genes into various fermenting microorganisms has led to the construction of organisms capable of converting hexoses and pentoses to ethanol (co-fermentation) (Chen and Ho, 1993, Cloning and improving the expression of *Pichia stipitis* xylose reductase gene in *Saccharomyces cerevisiae*, *Appl. Biochem. Biotechnol.* 39-40: 135-147; Ho *et al.*, 1998, Genetically engineered *Saccharomyces* yeast capable of effectively
10 cof fermenting glucose and xylose, *Appl. Environ. Microbiol.* 64: 1852-1859; Kotter and Ciriacy, 1993, Xylose fermentation by *Saccharomyces cerevisiae*, *Appl. Microbiol. Biotechnol.* 38: 776-783; Walfridsson *et al.*, 1995, Xylose-metabolizing *Saccharomyces cerevisiae* strains overexpressing the TKL1 and TAL1 genes encoding the pentose phosphate pathway enzymes transketolase and transaldolase, *Appl. Environ. Microbiol.* 61: 4184-4190; Kuyper *et al.*, 2004,
15 Minimal metabolic engineering of *Saccharomyces cerevisiae* for efficient anaerobic xylose fermentation: a proof of principle, *FEMS Yeast Research* 4: 655-664; Beall *et al.*, 1991, Parametric studies of ethanol production from xylose and other sugars by recombinant *Escherichia coli*, *Biotech. Bioeng.* 38: 296-303; Ingram *et al.*, 1998, Metabolic engineering of bacteria for ethanol production, *Biotechnol. Bioeng.* 58: 204-214; Zhang *et al.*, 1995, Metabolic
20 engineering of a pentose metabolism pathway in ethanologenic *Zymomonas mobilis*, *Science* 267: 240-243; Deanda *et al.*, 1996, Development of an arabinose-fermenting *Zymomonas mobilis* strain by metabolic pathway engineering, *Appl. Environ. Microbiol.* 62: 4465-4470; WO 2003/062430, xylose isomerase).

 In a preferred aspect, the genetically modified fermenting microorganism is *Candida*
25 *sonorensis*. In another preferred aspect, the genetically modified fermenting microorganism is *Escherichia coli*. In another preferred aspect, the genetically modified fermenting microorganism is *Klebsiella oxytoca*. In another preferred aspect, the genetically modified fermenting microorganism is *Kluyveromyces marxianus*. In another preferred aspect, the genetically modified fermenting microorganism is *Saccharomyces cerevisiae*. In another preferred aspect,
30 the genetically modified fermenting microorganism is *Zymomonas mobilis*.

 It is well known in the art that the organisms described above can also be used to produce other substances, as described herein.

 The fermenting microorganism is typically added to the degraded cellulosic material or hydrolysate and the fermentation is performed for about 8 to about 96 hours, e.g., about 24 to

about 60 hours. The temperature is typically between about 26°C to about 60°C, e.g., about 32°C or 50°C, and about pH 3 to about pH 8, e.g., pH 4-5, 6, or 7.

In one aspect, the yeast and/or another microorganism are applied to the degraded cellulosic material and the fermentation is performed for about 12 to about 96 hours, such as typically 24-60 hours. In another aspect, the temperature is preferably between about 20°C to about 60°C, e.g., about 25°C to about 50°C, about 32°C to about 50°C, or about 32°C to about 50°C, and the pH is generally from about pH 3 to about pH 7, e.g., about pH 4 to about pH 7. However, some fermenting organisms, e.g., bacteria, have higher fermentation temperature optima. Yeast or another microorganism is preferably applied in amounts of approximately 10^5 to 10^{12} , preferably from approximately 10^7 to 10^{10} , especially approximately 2×10^8 viable cell count per ml of fermentation broth. Further guidance in respect of using yeast for fermentation can be found in, e.g., "The Alcohol Textbook" (Editors K. Jacques, T.P. Lyons and D.R. Kelsall, Nottingham University Press, United Kingdom 1999), which is hereby incorporated by reference.

For ethanol production, following the fermentation the fermented slurry is distilled to extract the ethanol. The ethanol obtained according to the processes of the invention can be used as, e.g., fuel ethanol, drinking ethanol, i.e., potable neutral spirits, or industrial ethanol.

A fermentation stimulator can be used in combination with any of the processes described herein to further improve the fermentation process, and in particular, the performance of the fermenting microorganism, such as, rate enhancement and ethanol yield. A "fermentation stimulator" refers to stimulators for growth of the fermenting microorganisms, in particular, yeast. Preferred fermentation stimulators for growth include vitamins and minerals. Examples of vitamins include multivitamins, biotin, pantothenate, nicotinic acid, meso-inositol, thiamine, pyridoxine, para-aminobenzoic acid, folic acid, riboflavin, and Vitamins A, B, C, D, and E. See, for example, Alfenore *et al.*, Improving ethanol production and viability of *Saccharomyces cerevisiae* by a vitamin feeding strategy during fed-batch process, Springer-Verlag (2002), which is hereby incorporated by reference. Examples of minerals include minerals and mineral salts that can supply nutrients comprising P, K, Mg, S, Ca, Fe, Zn, Mn, and Cu.

Fermentation products: A fermentation product can be any substance derived from the fermentation. The fermentation product can be, without limitation, an alcohol (e.g., arabinitol, n-butanol, isobutanol, ethanol, glycerol, methanol, ethylene glycol, 1,3-propanediol [propylene glycol], butanediol, glycerin, sorbitol, and xylitol); an alkane (e.g., pentane, hexane, heptane, octane, nonane, decane, undecane, and dodecane), a cycloalkane (e.g., cyclopentane, cyclohexane, cycloheptane, and cyclooctane), an alkene (e.g. pentene, hexene, heptene, and octene); an amino acid (e.g., aspartic acid, glutamic acid, glycine, lysine, serine, and threonine);

a gas (e.g., methane, hydrogen (H₂), carbon dioxide (CO₂), and carbon monoxide (CO)); isoprene; a ketone (e.g., acetone); an organic acid (e.g., acetic acid, acetonc acid, adipic acid, ascorbic acid, citric acid, 2,5-diketo-D-gluconic acid, formic acid, fumaric acid, glucaric acid, gluconic acid, glucuronic acid, glutaric acid, 3-hydroxypropionic acid, itaconic acid, lactic acid, malic acid, malonic acid, oxalic acid, oxaloacetic acid, propionic acid, succinic acid, and xylonic acid); and polyketide. The fermentation product can also be protein as a high value product.

In a preferred aspect, the fermentation product is an alcohol. It will be understood that the term "alcohol" encompasses a substance that contains one or more hydroxyl moieties. In a more preferred aspect, the alcohol is n-butanol. In another more preferred aspect, the alcohol is isobutanol. In another more preferred aspect, the alcohol is ethanol. In another more preferred aspect, the alcohol is methanol. In another more preferred aspect, the alcohol is arabinitol. In another more preferred aspect, the alcohol is butanediol. In another more preferred aspect, the alcohol is ethylene glycol. In another more preferred aspect, the alcohol is glycerin. In another more preferred aspect, the alcohol is glycerol. In another more preferred aspect, the alcohol is 1,3-propanediol. In another more preferred aspect, the alcohol is sorbitol. In another more preferred aspect, the alcohol is xylitol. See, for example, Gong, C. S., Cao, N. J., Du, J., and Tsao, G. T., 1999, Ethanol production from renewable resources, in *Advances in Biochemical Engineering/Biotechnology*, Scheper, T., ed., Springer-Verlag Berlin Heidelberg, Germany, 65: 207-241; Silveira, M. M., and Jonas, R., 2002, The biotechnological production of sorbitol, *Appl. Microbiol. Biotechnol.* 59: 400-408; Nigam, P., and Singh, D., 1995, Processes for fermentative production of xylitol – a sugar substitute, *Process Biochemistry* 30 (2): 117-124; Ezeji, T. C., Qureshi, N. and Blaschek, H. P., 2003, Production of acetone, butanol and ethanol by *Clostridium beijerinckii* BA101 and *in situ* recovery by gas stripping, *World Journal of Microbiology and Biotechnology* 19 (6): 595-603.

In another preferred aspect, the fermentation product is an alkane. The alkane can be an unbranched or a branched alkane. In another more preferred aspect, the alkane is pentane. In another more preferred aspect, the alkane is hexane. In another more preferred aspect, the alkane is heptane. In another more preferred aspect, the alkane is octane. In another more preferred aspect, the alkane is nonane. In another more preferred aspect, the alkane is decane. In another more preferred aspect, the alkane is undecane. In another more preferred aspect, the alkane is dodecane.

In another preferred aspect, the fermentation product is a cycloalkane. In another more preferred aspect, the cycloalkane is cyclopentane. In another more preferred aspect, the cycloalkane is cyclohexane. In another more preferred aspect, the cycloalkane is cycloheptane.

In another more preferred aspect, the cycloalkane is cyclooctane.

In another preferred aspect, the fermentation product is an alkene. The alkene can be an unbranched or a branched alkene. In another more preferred aspect, the alkene is pentene. In another more preferred aspect, the alkene is hexene. In another more preferred aspect, the alkene is heptene. In another more preferred aspect, the alkene is octene.

In another preferred aspect, the fermentation product is an amino acid. In another more preferred aspect, the organic acid is aspartic acid. In another more preferred aspect, the amino acid is glutamic acid. In another more preferred aspect, the amino acid is glycine. In another more preferred aspect, the amino acid is lysine. In another more preferred aspect, the amino acid is serine. In another more preferred aspect, the amino acid is threonine. See, for example, Richard, A., and Margaritis, A., 2004, Empirical modeling of batch fermentation kinetics for poly(glutamic acid) production and other microbial biopolymers, *Biotechnology and Bioengineering* 87 (4): 501-515.

In another preferred aspect, the fermentation product is a gas. In another more preferred aspect, the gas is methane. In another more preferred aspect, the gas is H₂. In another more preferred aspect, the gas is CO₂. In another more preferred aspect, the gas is CO. See, for example, Kataoka, N., A. Miya, and K. Kiriya, 1997, Studies on hydrogen production by continuous culture system of hydrogen-producing anaerobic bacteria, *Water Science and Technology* 36 (6-7): 41-47; and Gunaseelan V.N. in *Biomass and Bioenergy*, Vol. 13 (1-2), pp. 83-114, 1997, Anaerobic digestion of biomass for methane production: A review.

In another preferred aspect, the fermentation product is isoprene.

In another preferred aspect, the fermentation product is a ketone. It will be understood that the term "ketone" encompasses a substance that contains one or more ketone moieties. In another more preferred aspect, the ketone is acetone. See, for example, Qureshi and Blaschek, 2003, *supra*.

In another preferred aspect, the fermentation product is an organic acid. In another more preferred aspect, the organic acid is acetic acid. In another more preferred aspect, the organic acid is acetonetic acid. In another more preferred aspect, the organic acid is adipic acid. In another more preferred aspect, the organic acid is ascorbic acid. In another more preferred aspect, the organic acid is citric acid. In another more preferred aspect, the organic acid is 2,5-diketo-D-gluconic acid. In another more preferred aspect, the organic acid is formic acid. In another more preferred aspect, the organic acid is fumaric acid. In another more preferred aspect, the organic acid is glucaric acid. In another more preferred aspect, the organic acid is gluconic acid. In another more preferred aspect, the organic acid is glucuronic acid. In another

more preferred aspect, the organic acid is glutaric acid. In another preferred aspect, the organic acid is 3-hydroxypropionic acid. In another more preferred aspect, the organic acid is itaconic acid. In another more preferred aspect, the organic acid is lactic acid. In another more preferred aspect, the organic acid is malic acid. In another more preferred aspect, the organic acid is malonic acid. In another more preferred aspect, the organic acid is oxalic acid. In another more preferred aspect, the organic acid is propionic acid. In another more preferred aspect, the organic acid is succinic acid. In another more preferred aspect, the organic acid is xylonic acid. See, for example, Chen, R., and Lee, Y. Y., 1997, Membrane-mediated extractive fermentation for lactic acid production from cellulosic biomass, *Appl. Biochem. Biotechnol.* 63-65: 435-448.

In another preferred aspect, the fermentation product is polyketide.

Recovery. The fermentation product(s) can be optionally recovered from the fermentation medium using any method known in the art including, but not limited to, chromatography, electrophoretic procedures, differential solubility, distillation, or extraction. For example, alcohol is separated from the fermented cellulosic material and purified by conventional methods of distillation. Ethanol with a purity of up to about 96 vol.% can be obtained, which can be used as, for example, fuel ethanol, drinking ethanol, *i.e.*, potable neutral spirits, or industrial ethanol.

Signal Peptides

The present invention also relates to an isolated polynucleotide encoding a signal peptide comprising or consisting of amino acids 1 to 17 of SEQ ID NO: 4 or amino acids 1 to 17 of SEQ ID NO: 2. The polynucleotide may further comprise a gene encoding a protein, which is operably linked to the signal peptide. The protein is preferably foreign to the signal peptide. In one aspect, the polynucleotide encoding the signal peptide is nucleotides 1 to 51 of SEQ ID NO: 3. In another aspect, the polynucleotide encoding the signal peptide is nucleotides 1 to 51 of SEQ ID NO: 1.

The present invention also relates to nucleic acid constructs, expression vectors and recombinant host cells comprising such polynucleotides.

The present invention also relates to methods of producing a protein, comprising (a) cultivating a recombinant host cell comprising such a polynucleotide operably linked to a gene encoding the protein; and optionally (b) recovering the protein.

The protein may be native or heterologous to a host cell. The term "protein" is not meant herein to refer to a specific length of the encoded product and, therefore, encompasses peptides, oligopeptides, and polypeptides. The term "protein" also encompasses two or more

polypeptides combined to form the encoded product. The proteins also include hybrid polypeptides and fused polypeptides.

Preferably, the protein is a hormone, enzyme, receptor or portion thereof, antibody or portion thereof, or reporter. For example, the protein may be a hydrolase, isomerase, ligase, lyase, oxidoreductase, or transferase, e.g., an alpha-galactosidase, alpha-glucosidase, aminopeptidase, amylase, beta-galactosidase, beta-glucosidase, beta-xylosidase, carbohydrase, carboxypeptidase, catalase, cellobiohydrolase, cellulase, chitinase, cutinase, cyclodextrin glycosyltransferase, deoxyribonuclease, endoglucanase, esterase, glucoamylase, invertase, laccase, lipase, mannosidase, mutanase, oxidase, pectinolytic enzyme, peroxidase, phytase, polyphenoloxidase, proteolytic enzyme, ribonuclease, transglutaminase, or xylanase.

The gene may be obtained from any prokaryotic, eukaryotic, or other source.

The present invention is further described by the following examples that should not be construed as limiting the scope of the invention.

Examples

Strain

The fungal strain NN000308 was purchased from Centraalbureau voor Schimmelcultures named as CBS174.70. The strain NN000308 was identified as *Corynascus thermophilus* (previously identified as *Thielavia thermophila*, - syn. *Myceliophthora fergusii*), based on both morphological characteristics and ITS rDNA sequence.

Media

PDA medium was composed of 39 grams of potato dextrose agar and deionized water to 1 liter.

YG agar plates were composed of 5.0 g of yeast extract, 10.0 g of glucose, 20.0 g of agar, and deionized water to 1 liter.

YPG medium was composed of 0.4% of yeast extract, 0.1% of KH_2PO_4 , 0.05% of $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, and 1.5% glucose in deionized water.

Minimal medium plates were composed of 342 g of sucrose, 20 ml of salt solution, 20 g of agar, and deionized water to 1 liter. The salt solution was composed of 2.6% KCl, 2.6% $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, 7.6% KH_2PO_4 , 2 ppm $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$, 20 ppm $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, 40 ppm $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$, 40 ppm $\text{MnSO}_4 \cdot 2\text{H}_2\text{O}$, 40 ppm $\text{Na}_2\text{MoO}_4 \cdot 2\text{H}_2\text{O}$, and 400 ppm $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$.

Example 1: *Corynascus thermophilus* genomic DNA extraction

Corynascus thermophilus strain NN000308 was inoculated onto a PDA plate and incubated for 3 days at 45°C in the darkness. Several mycelia-PDA plugs were inoculated into 500 ml shake flasks containing 100 ml of YPG medium. The flasks were incubated for 4 days at 45°C with shaking at 160 rpm. The mycelia were collected by filtration through MIRACLOTH® (Calbiochem, La Jolla, CA, USA) and frozen in liquid nitrogen. Frozen mycelia were ground, by a mortar and a pestle, to a fine powder, and genomic DNA was isolated using using a DNeasy® Plant Maxi Kit (QIAGEN GmbH, Hilden, Germany).

Example 2: Genome sequencing, assembly and annotation

The extracted genomic DNA samples were delivered to Beijing Genome Institute (BGI, Shenzhen, China) for genome sequencing using using an ILLUMINA® GA2 System (Illumina, Inc., San Diego, CA, USA). The raw reads were assembled at BGI using program SOAPdenovo (Li *et al.*, 2010, *Genome Research* 20(2): 265-72). The assembled sequences were analyzed using standard bioinformatics methods for gene identification and functional prediction. Briefly, geneID (Parra *et al.*, 2000, *Genome Research* 10(4):511-515) was used for gene prediction. Blastall version 2.2.10 (Altschul *et al.*, 1990, *J. Mol. Biol.* 215 (3): 403–410, National Center for Biotechnology Information (NCBI), Bethesda, MD, USA) and HMMER version 2.1.1 (National Center for Biotechnology Information (NCBI), Bethesda, MD, USA) were used to predict function based on structural homology. The family GH6 cellobiohydrolase polypeptides were identified directly by analysis of the Blast results. The Agene program (Munch and Krogh, 2006, *BMC Bioinformatics* 7:263) and SignalP program (Nielsen *et al.*, 1997, *Protein Engineering* 10: 1-6) were used to identify starting codons. The SignalP program was further used to predict the signal peptides. Pepstats (Rice *et al.*, 2000, *Trends Genet.* 16(6): 276-277) was used to predict isoelectric points and molecular weights of the deduced amino acid sequences.

Example 3: Characterization of a *Corynascus thermophilus* genomic sequence encoding a polypeptide having cellobiohydrolase activity

The genomic DNA sequence (SEQ ID NO: 1) and deduced amino acid sequence (SEQ ID NO: 2) of the *Corynascus thermophilus* polypeptide coding sequence is shown in Figure 1. The coding sequence is 1382 bp including the stop codon and is interrupted by 2 introns of 106 bp (nucleotides 440 to 545) and 91 bp (nucleotides 871 to 961). The G+C content of the mature polypeptide coding sequence without introns and stop condon is 65.69%. The encoded predicted protein is 394 amino acids. Using the SignalP program (Nielsen *et al.*, 1997, *Protein Engineering* 10: 1-6), a signal peptide of 17 residues was predicted. The predicted mature

protein contains 377 amino acids with a predicted molecular weight of 41092.45 dalton and predicted isoelectric point of 4.67. The cellobiohydrolase catalytic domain was predicted to be amino acids 44 to 393, by aligning the amino acid sequence using BLAST to all CAZY-defined subfamily modules (Cantarel *et al.*, 2009, *Nucleic Acids Res.* 37: D233-238), where the single most significant alignment within a subfamily was used to predict the GH6 domain.

A comparative pairwise global alignment of amino acid sequences was determined using the Needleman and Wunsch algorithm (Needleman and Wunsch, 1970, *J. Mol. Biol.* 48: 443-453) with gap open penalty of 10, gap extension penalty of 0.5, and the EBLOSUM62 matrix. The alignment showed that the mature part of amino acid sequence of the *Corynascus thermophilus* coding sequence encoding the cellobiohydrolase polypeptide shared 88.59% identity to the amino acid sequence of a cellobiohydrolase II protein from *Chrysosporium lucknowense* (accession number GENESEQP:AZG10703 and SEQ ID NO: 8 in US2011045546-A1).

The genomic DNA sequence (SEQ ID NO: 3) and deduced amino acid sequence (SEQ ID NO: 4) of the *Corynascus thermophilus* polypeptide coding sequence is shown in Figure 2. The coding sequence is 1662 bp including the stop codon and is interrupted by 3 introns of 84 bp (nucleotides 93 to 176), 113 bp (nucleotides 647 to 759) and 55 bp (nucleotides 1345 to 1399). The G+C content of the mature polypeptide coding sequence without introns and stop codon is 65.49%. The encoded predicted protein is 469 amino acids. Using the SignalP program (Nielsen *et al.*, 1997, *Protein Engineering* 10: 1-6), a signal peptide of 17 residues was predicted. The predicted mature protein contains 452 amino acids with a predicted molecular weight of 48165.43 Dalton and predicted isoelectric point of 5.01. The cellobiohydrolase catalytic domain and CBD domain were predicted to be amino acids 106 to 469 and amino acids 24 to 63, respectively, by aligning the amino acid sequence using BLAST to all CAZY-defined subfamily modules (Cantarel *et al.*, 2009, *Nucleic Acids Res.* 37: D233-238), where the single most significant alignment within a subfamily was used to predict the GH6 domain and CBD domain.

A comparative pairwise global alignment of amino acid sequences was determined using the Needleman and Wunsch algorithm (Needleman and Wunsch, 1970, *J. Mol. Biol.* 48: 443-453) with gap open penalty of 10, gap extension penalty of 0.5, and the EBLOSUM62 matrix. The alignment showed that the mature part of amino acid sequence of the *Corynascus thermophilus* coding sequence encoding the cellobiohydrolase polypeptide shared 79.46% identity to the amino acid sequence of cellobiohydrolase II from *Chaetomium thermophilum* (accession number GENESEQP:AYE06216 and SEQ ID NO: 56 in US2010159494-A1).

Example 4: Cloning of the *Corynascus thermophilus* GH6 cellobiohydrolase (CBH) genes from genomic DNA

Two cellobiohydrolase genes (shown in Table 1) were selected for expression cloning.

Table 1: cellobiohydrolase genes

Gene name	DNA sequence	Protein sequence	Protein name
GH6_Mf1789	SEQ ID NO: 1	SEQ ID NO: 2	P24FVQ
GH6_Mf4799	SEQ ID NO: 3	SEQ ID NO: 4	P24FVR

Based on the DNA information obtained from genome sequencing, oligonucleotide primers, shown below in Table 2, were designed to amplify all GH6 cellobiohydrolase genes from genomic DNA of *Corynascus thermophilus* NN000308. Primers fabricated by Invitrogen (Invitrogen, Beijing, China).

Table 2: primers

1_forward	ACACAAC TGGGGATCC ACC atgaagctcgcgcaatctg	SEQ ID NO: 5
1_reverse	GTCACCCTCTAGATCT catcagagcgagtgacagcaacag	SEQ ID NO: 6
2_forward	ACACAAC TGGGGATCC ACC atggccaagaagctcttcatcaac	SEQ ID NO: 7
2_reverse	GTCACCCTCTAGATCT acactctcccttcgcttgcttg	SEQ ID NO: 8

Lowercase characters represent the coding regions of the genes in forward primers and the flanking region of the gene in reverse primers, while capitalized parts were homologous to the insertion sites of pPFJO355 vector which has been described in WO2011005867.

For each gene, 20 picomoles of each forward and reverse primer pair were used in a PCR reaction composed of 2 µl of *Corynascus thermophilus* NN000308 genomic DNA, 10 µl of 5X GC Buffer (Finnzymes Oy, Espoo, Finland), 1.5 µl of dimethyl sulfoxide (DMSO), 2.5 mM each of dATP, dTTP, dGTP, and dCTP, and 0.6 unit of PHUSION™ High-Fidelity DNA Polymerase (Finnzymes Oy, Espoo, Finland) in a final volume of 50 µl. The amplification was performed using a Peltier Thermal Cycler (MJ Research Inc., South San Francisco, CA, USA) programmed for denaturing at 98°C for 1 minutes; 6 cycles of denaturing at 98°C for 15 seconds, annealing at 67°C for 30 seconds, with a 1°C decrease per cycle and elongation at 72°C for 3 minutes; and another 24 cycles each at 94°C for 15 seconds, 63°C for 30 seconds and 72°C for 3 minutes; and a final extension at 72°C for 5 minutes. The heat block then went to a 4°C soak cycle.

The PCR products were isolated by 1.0% agarose gel electrophoresis using 90 mM Tris-borate and 1 mM EDTA (TBE) buffer where a single product band from each reaction (1.4 kb

and 1.7 kb respectively) was visualized under UV light. PCR products were then purified from solution using an ILLUSTRA® GFX® PCR DNA and Gel Band Purification Kit (GE Healthcare, Buckinghamshire, UK) according to the manufacturer's instructions.

Plasmid pPFJO355 was digested with *Bam* HI and *Bgl* II, isolated by 1.0% agarose gel electrophoresis using TBE buffer, and purified using an ILLUSTRA® GFX® PCR DNA and Gel Band Purification Kit according to the manufacturer's instructions.

An IN-FUSION® CF Dry-down PCR Cloning Kit (Clontech Laboratories, Inc., Mountain View, CA, USA) was used to clone several of the PCR fragments directly into the expression vector pPFJO355, without the need for restriction digestion and ligation.

Table 3: plasmids

Gene name	Plasmid	DNA map
GH6_Mf1789	pGH6_Mf1789	Figure 3
GH6_Mf4799	pGH6_Mf4799	Figure 4

The PCR products and the digested vector were ligated together using an IN-FUSION® CF Dry-down PCR Cloning resulting in plasmids (Table 3): pGH6_Mf1789 (Figure 3) and pGH6_Mf4799 (Figure 4) respectively in which transcription of the *Corynascus thermophilus* GH6 cellobiohydrolase genes was under the control of a promoter from the gene for an *Aspergillus oryzae* alpha-amylase. In brief, for each ligation reaction 30 ng of pPFJO355, digested with *Bam* HI and *Bgl* II, and 60 ng of each *Corynascus thermophilus* GH6 cellobiohydrolase purified PCR products were added to reaction vials and resuspended in a final volume of 10µl with addition of deionized water. The reactions were incubated at 37°C for 15 minutes and then 50°C for 15 minutes. Three microlitres of the reaction products were used to transform *E. coli* TOP10 competent cells (TIANGEN Biotech (Beijing) Co. Ltd., Beijing, China). *E. coli* transformants containing an expression construct were detected by colony PCR. Colony PCR is a method for quick screening of plasmid inserts directly from *E. coli* colonies. Briefly, in the premixed PCR solution aliquot in each PCR tube, including PCR buffer, MgCl₂, dNTPs and primer pairs from which the PCR fragment was generated, a single colony was added by picking with a sterile tip and twirling the tip in the reaction solution. Normally 7-10 colonies were screened. After the PCR, reactions were analyzed by 1.0% agarose gel electrophoresis using TBE buffer. Plasmid DNA was prepared from colonies showing an insert with the expected size using a QIAPREP® Spin Miniprep Kit (QIAGEN). The *Corynascus thermophilus* GH6 cellobiohydrolase genes inserted in pGH6_Mf1789 and pGH6_Mf4799 were confirmed by DNA sequencing using a 3730XL DNA Analyzer (Applied Biosystems Inc, Foster City, CA, USA).

Example 5: Expression of the *Corynascus thermophilus* GH6 cellobiohydrolase (CBH) genes in *Aspergillus oryzae*

Aspergillus oryzae HowB101 (WO 95/035385 Example 1) protoplasts were prepared according to the method of Christensen *et al.*, 1988, *Bio/Technology* 6: 1419-1422 and transformed with 3 µg of pGH6_Mf1789 and pGH6_Mf4799. Each transformation yielded approximately 50 transformants. Eight transformants from each transformation were isolated to individual Minimal medium plates.

Four transformants for each transformation were inoculated separately into 3 ml of YPM medium in a 24-well plate and incubated at 30°C with mixing at 150 rpm. After 3 days incubation, 20 µl of supernatant from each culture were analyzed by SDS-PAGE using a NUPAGE® NOVEX® 4-12% Bis-Tris Gel with MES (Invitrogen Corporation, Carlsbad, CA, USA) according to the manufacturer's instructions. The resulting gel was stained with INSTANTBLUE™ (Expedeon Ltd., Babraham Cambridge, UK). The SDS-PAGE profiles of the cultures showed that both genes were expressed. The sizes for each major band(s) of each gene are shown below in Table 4. The expression strains were designated as shown in the second column.

Table 4: Expression

plasmid	Expression strain	Size of recombinant protein (kDa)
pGH6_Mf1789	O7J2F	42
pGH6_Mf4799	O7R3K	60

Example 6: Fermentation of expression *Aspergillus oryzae* strains O7J2F and O7R3K

A slant of each transformant was used to inoculate 4-6 two-liter shaking flasks containing 400 ml of YPM medium. The total culture volume of each expression strain is shown in Table 5. The shaking flasks were then incubated at 30°C for 3 days at 80 rpm. The cultures were harvested on day 3 and filtered using a 0.45 µm DURAPORE® Membrane (Millipore, Bedford, MA, USA).

Table 5: Fermentation

Expression strain	Culture volume (ml)
O7J2F	1600
O7R3K	4000

Example 7: Purification of recombinant *Corynascus thermophilus* GH6 cellobiohydrolase (CBH) from *Aspergillus oryzae* strains O7J2F and O7R3K

A 1600 ml supernatant of the broth from *Aspergillus oryzae* O7J2F was precipitated with ammonium sulfate (80% saturation), re-dissolved in 50 ml of 20 mM Bis-Tris buffer, pH 6.0, dialyzed against the same buffer, and filtered through a 0.45 µm filter. The final volume was 80 ml. The solution was applied to a 40 ml Q SEPHAROSE® Fast Flow column (GE Healthcare Life Sciences, Piscataway, NJ, USA) equilibrated in 20 mM Bis-Tris buffer, pH6.0, and the proteins were eluted using a linear NaCl gradient (0–0.5M). Fractions eluted with 0.2-0.3 M NaCl were collected. The sample was further purified on a 40 ml Phenyl SEPHAROSE® 6 Fast Flow column (GE 17-0965-05) with a linear (NH₄)₂SO₄ gradient (1.2 - 0 M). Fractions were evaluated by SDS-PAGE using a NUPAGE® NOVEX® 4-12% Bis-Tris Gel with MES. Fractions containing a band at approximately 40 kDa were pooled and concentrated by ultrafiltration.

A 4000 ml supernatant of the broth from *Aspergillus oryzae* strain O7R3K was precipitated with ammonium sulfate (80% saturation), re-dissolved in 50 ml of 20 mM Tris-HCl buffer, pH6.5, dialyzed against the same buffer and filtered through a 0.45 µm filter. The final volume was 120 ml. The solution was applied to a 40 ml SEPHAROSE® Fast Flow column (GE Healthcare Life Sciences, Piscataway, NJ, USA) equilibrated in 20 mM Tris-HCl buffer, pH 6.5, and the proteins were eluted using a linear NaCl gradient (0–0.25 M). Fractions didn't bind to the column were collected. The sample was further purified on a 40ml Phenyl SEPHAROSE® 6 Fast Flow column (GE 17-0965-05) with a linear (NH₄)₂SO₄ gradient (1.2 - 0 M). Fractions were evaluated by SDS-PAGE using a NUPAGE® NOVEX® 4-12% Bis-Tris Gel with MES. Fractions containing a band at approximately 60 kDa were pooled and concentrated by ultrafiltration.

Example 8: GH6 cellobiohydrolase (CBH) activity assay on phosphoric acid-swollen cellulose (PASC)

A PASC stock slurry solution was prepared by moistening 5 g of microcrystalline cellulose (AVICEL®; JRS Pharma, Holzmühle 1, Rosenberg, Germany) with water, followed by the addition of 150 ml of ice cold 85% o-phosphoric acid. The suspension was slowly stirred in an ice-bath for 1 hour. Then 500 ml of ice cold acetone were added while stirring. The slurry was filtered using Calbiochem® MIRACLOTH® (EMD Millipore Bioscience, Billerica, MA, USA) and then washed three times with 100 ml of ice cold acetone (drained as dry as possible after each wash). Finally, the filtered slurry was washed twice with 500 ml of water, and again drained as dry as possible after each wash. The PASC was mixed with deionized water to a total volume of 500 ml with a concentration of 10 g/liter, blended to homogeneity (using an ULTRA-TURRAX® Homogenizer, Cole-Parmer, Vernon Hills, IL, USA), and stored in a refrigerator for up to one month.

The PASC stock solution was diluted with 50 mM sodium acetate pH 5.0 buffer to a concentration of 2 g/liter, and used as the substrate. To 150 µl of PASC stock solution, 20 µl of enzyme sample were added and the reaction mixture was incubated for 60 minutes with shaking at 850 rpm. At the end of the incubation, 50 µl of 2% NaOH were added to stop the reaction. The reaction mixture was centrifuged at 1,000 x g. The released sugars were measured by first mixing 10 µl of the reaction mixture with 90 µl of 0.4% NaOH, followed by 50 µl of 1.5% *p*-hydroxybenzoic acid hydrazide in 2% NaOH (PHBAH, Sigma Chemical Co., St. Louis, MO, USA). The mixture was boiled at 100°C for 5 minutes, and then 100 µl were transferred to a microtiter plate for an absorbance reading at 410 nm (Spectra Max M2, Molecular devices Sunnyvale, CA, USA). Blanks were made by omitting PASC in the hydrolysis step, and by replacing the hydrolysate with buffer in the sugar determination step. The cellobiohydrolase activity was calculated based on the difference between the absorbance of the sample and the absorbance of the blanks.

As a result, O7J2F showed some cellobiohydrolase activity, and O7R3K showed good cellobiohydrolase activity with an absorbance at 410 nm of 0.7188.

The present invention is further described by the following numbered paragraphs:

[1] An isolated polypeptide having cellobiohydrolase activity, selected from the group consisting of:

(a) a polypeptide having at least 80%, e.g., at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to the mature polypeptide of SEQ ID NO: 4; or a polypeptide having at least 89%, e.g., at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to the mature polypeptide of SEQ ID NO: 2;

(b) a polypeptide encoded by a polynucleotide that hybridizes under at least medium stringency conditions with (i) the mature polypeptide coding sequence of SEQ ID NO: 3 or the mature polypeptide coding sequence of SEQ ID NO: 1, (ii) the cDNA sequence of SEQ ID NO: 3 or the cDNA sequence of SEQ ID NO: 1, or (iii) the full-length complement of (i) or (ii);

(c) a polypeptide encoded by a polynucleotide having at least 80%, e.g., at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to the

mature polypeptide coding sequence of SEQ ID NO: 3 or the cDNA sequence thereof; or a polypeptide encoded by a polynucleotide having at least 89%, e.g., at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to the mature polypeptide coding sequence of SEQ ID NO: 1 or the cDNA sequence thereof;

(d) a variant of the mature polypeptide of SEQ ID NO: 4 or the mature polypeptide of SEQ ID NO: 2 comprising a substitution, deletion, and/or insertion at one or more (e.g., several) positions; and

(e) a fragment of the polypeptide of (a), (b), (c), or (d) that has cellobiohydrolase activity.

[2] The polypeptide of paragraph 1, having at least 80%, at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99% or 100% sequence identity to the mature polypeptide of SEQ ID NO: 4; or having at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99% or 100% sequence identity to the mature polypeptide of SEQ ID NO: 2.

[3] The polypeptide of paragraph 1, which is encoded by a polynucleotide that hybridizes under medium, medium-high, high, or very high stringency conditions or very high stringency conditions with (i) the mature polypeptide coding sequence of SEQ ID NO: 3 or the mature polypeptide coding sequence of SEQ ID NO: 1, (ii) the cDNA sequence of SEQ ID NO: 3 or the cDNA sequence of SEQ ID NO: 1, or (iii) the full-length complement of (i) or (ii).

[4] The polypeptide of paragraph 1, comprising or consisting of SEQ ID NO: 4 or SEQ ID NO: 2, or comprising or consisting of the mature polypeptide of SEQ ID NO: 4 or the mature polypeptide of SEQ ID NO: 2.

[5] The polypeptide of paragraph 4, wherein the mature polypeptide is amino acids 18 to 469 of SEQ ID NO: 4, or amino acids 18 to 394 of SEQ ID NO: 2.

[6] The polypeptide of paragraph 1, which is encoded by a polynucleotide having at least 80%, at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99% or 100% sequence identity to the mature polypeptide coding sequence of SEQ ID NO: 3, or the cDNA sequence thereof; or which is encoded by a polynucleotide having at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least

98%, at least 99% or 100% sequence identity to the mature polypeptide coding sequence of SEQ ID NO: 1, or the cDNA sequence thereof.

[7] The polypeptide of paragraph 1, which is a variant of the mature polypeptide of SEQ ID NO: 4 or the mature polypeptide of SEQ ID NO: 2 comprising a substitution, deletion, and/or insertion at one or more (e.g., several) positions, wherein the variant has cellobiohydrolase activity.

[8] The polypeptide of paragraph 1, which is a fragment of SEQ ID NO: 4 or SEQ ID NO: 2, wherein the fragment has cellobiohydrolase activity.

[9] An isolated polypeptide comprising a catalytic domain selected from the group consisting of:

(a) a catalytic domain having at least 80% sequence identity to the catalytic domain of SEQ ID NO: 4 or at least 89% sequence identity to the catalytic domain of SEQ ID NO: 2;

(b) a catalytic domain encoded by a polynucleotide that hybridizes under medium, medium-high, high, or very high stringency conditions with (i) nucleotides 400 to 1659 of SEQ ID NO: 3 or nucleotides 130 to 1376 of SEQ ID NO: 1, (ii) the cDNA sequence thereof, or (iii) the full-length complement of (i) or (ii);

(c) a catalytic domain encoded by a polynucleotide having at least 80% sequence identity to the catalytic domain coding sequence of SEQ ID NO: 3 or the cDNA sequence thereof; or a catalytic domain encoded by a polynucleotide having at least 89% sequence identity to the catalytic domain coding sequence of SEQ ID NO: 1 or the cDNA sequence thereof;

(d) a variant of amino acids 106 to 469 of SEQ ID NO: 4 or amino acids 44 to 393 of SEQ ID NO: 2 comprising a substitution, deletion, and/or insertion at one or more (e.g., several) positions; and

(e) a fragment of the catalytic domain of (a), (b), (c), or (d) that has cellobiohydrolyase activity.

[10] The polypeptide of paragraph 9, having at least 80%, at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to amino acids 106 to 469 of SEQ ID NO: 4, or at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to amino acids 44 to 393 of SEQ ID NO: 2.

[11] The polypeptide of paragraph 9, comprising or consisting of the catalytic domain of SEQ ID NO: 4 or the catalytic domain of SEQ ID NO: 2.

[12] The polypeptide of paragraph 11, wherein the catalytic domain is amino acids 106 to 469 of SEQ ID NO: 4 or amino acids 44 to 393 of SEQ ID NO: 2.

5 [13] The polypeptide of paragraph 9, which is encoded by a polynucleotide having at least 80%, at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to nucleotides 400 to 1659 of SEQ ID NO: 3 or the cDNA sequence thereof,
10 or which is encoded by a polynucleotide having at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to nucleotides 130 to 1376 of SEQ ID NO: 1 or the cDNA sequence thereof.

15 [14] The polypeptide of paragraph 9, which is a variant of amino acids 106 to 469 of SEQ ID NO: 4 or amino acids 44 to 393 of SEQ ID NO: 2 comprising a substitution, deletion, and/or insertion at one or more (e.g., several) positions, wherein the variant has cellobiohydrolase activity.

20 [15] The polypeptide of paragraph 9, which is a fragment of amino acids 106 to 469 of SEQ ID NO: 4 or amino acids 44 to 393 of SEQ ID NO: 2, wherein the fragment has cellobiohydrolase activity.

[16] The polypeptide of any of paragraphs 9-15, further comprising a carbohydrate binding domain.

[17] An isolated polypeptide comprising a carbohydrate binding domain selected from the group consisting of:

25 (a) a carbohydrate binding domain having at least 80% sequence identity to amino acids 24 to 63 of SEQ ID NO: 4;

(b) a carbohydrate binding domain encoded by a polynucleotide that hybridizes under medium, medium-high, high, or very high stringency conditions with (i) nucleotides 70 to 273 of SEQ ID NO: 3, (ii) the cDNA sequence thereof, or (iii) the full-length complement of (i) or
30 (ii);

(c) a carbohydrate binding domain encoded by a polynucleotide having at least 80% sequence identity to nucleotides 70 to 273 of SEQ ID NO: 3 or the cDNA sequence thereof;

(d) a variant of amino acids 24 to 63 of SEQ ID NO: 4 comprising a substitution, deletion, and/or insertion at one or more (e.g., several) positions; and

(e) a fragment of (a), (b), (c), (d) or (e) that has cellulose binding activity.

[18] The polypeptide of paragraph 17, having at least 80%, at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to amino acids 24 to 63 of SEQ ID NO: 4.

[19] The polypeptide of paragraph 17, comprising or consisting of the carbohydrate binding domain of SEQ ID NO: 4.

[20] The polypeptide of paragraph 19, wherein the carbohydrate binding domain is amino acids 24 to 63 of SEQ ID NO: 4.

[21] The polypeptide of paragraph 17, which is encoded by a polynucleotide having at least 80%, at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to nucleotides 70 to 273 of SEQ ID NO: 3.

[22] The polypeptide of paragraph 17, which is a variant of amino acids 24 to 63 of SEQ ID NO: 4 comprising a substitution, deletion, and/or insertion at one or more (e.g., several) positions of the carbohydrate binding domain of SEQ ID NO: 4, wherein the variant has cellulose binding activity.

[23] The polypeptide of paragraph 17, which is a fragment of the carbohydrate binding domain of SEQ ID NO: 4, wherein the fragment has cellulose binding activity.

[24] The polypeptide of any of paragraphs 17-23, wherein the carbohydrate binding domain is operably linked to a catalytic domain, preferably a catalytic domain obtained from a hydrolase, isomerase, ligase, lyase, oxidoreductase, or transferase, e.g., an aminopeptidase, amylase, carbohydrase, carboxypeptidase, catalase, cellobiohydrolase, cellulase, chitinase, cutinase, cyclodextrin glycosyltransferase, deoxyribonuclease, endoglucanase, esterase, alpha-galactosidase, beta-galactosidase, glucoamylase, alpha-glucosidase, beta-glucosidase, invertase, laccase, lipase, mannosidase, mutanase, oxidase, pectinolytic enzyme, peroxidase, phytase, polyphenoloxidase, proteolytic enzyme, ribonuclease, transglutaminase, xylanase, or beta-xylosidase.

[25] A composition comprising the polypeptide of any of paragraphs 1-24.

[26] An isolated polynucleotide encoding the polypeptide of any of paragraphs 1-24.

[27] A nucleic acid construct or expression vector comprising the polynucleotide of paragraph 26 operably linked to one or more control sequences that direct the production of the polypeptide in an expression host.

5 [28] A recombinant host cell comprising the polynucleotide of paragraph 26 operably linked to one or more control sequences that direct the production of the polypeptide.

[29] A method of producing the polypeptide of any of paragraphs 1-24, comprising: (a) cultivating a cell, which in its wild-type form produces the polypeptide, under conditions conducive for production of the polypeptide; and optionally (b) recovering the polypeptide.

10 [30] A method of producing a polypeptide having cellobiohydrolase activity, comprising: (a) cultivating the recombinant host cell of paragraph 28 under conditions conducive for production of the polypeptide; and optionally (b) recovering the polypeptide.

[31] A transgenic plant, plant part or plant cell transformed with a polynucleotide encoding the polypeptide of any of paragraphs 1-24.

15 [32] A method of producing a polypeptide having cellobiohydrolase activity, comprising: (a) cultivating the transgenic plant or plant cell of paragraph 31 under conditions conducive for production of the polypeptide; and optionally (b) recovering the polypeptide.

[33] A method of producing a mutant of a parent cell, comprising inactivating a polynucleotide encoding the polypeptide of any of paragraphs 1-24, which results in the mutant producing less of the polypeptide than the parent cell.

20 [34] A mutant cell produced by the method of paragraph 33.

[35] The mutant cell of paragraph 34, further comprising a gene encoding a native or heterologous protein.

25 [36] A method of producing a protein, comprising: (a) cultivating the mutant cell of paragraph 34 or 35 under conditions conducive for production of the protein; and optionally (b) recovering the protein.

[37] A double-stranded inhibitory RNA (dsRNA) molecule comprising a subsequence of the polynucleotide of paragraph 26, wherein optionally the dsRNA is an siRNA or an miRNA molecule.

30 [38] The double-stranded inhibitory RNA (dsRNA) molecule of paragraph 37, which is about 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25 or more duplex nucleotides in length.

[39] A method of inhibiting the expression of a polypeptide having cellobiohydrolase activity in a cell, comprising administering to the cell or expressing in the cell the double-stranded inhibitory RNA (dsRNA) molecule of paragraph 37 or 38.

[40] A cell produced by the method of paragraph 39.

[41] The cell of paragraph 40, further comprising a gene encoding a native or heterologous protein.

[42] A method of producing a protein, comprising: (a) cultivating the cell of paragraph 40 or 41 under conditions conducive for production of the protein; and optionally (b) recovering the protein.

[43] An isolated polynucleotide encoding a signal peptide comprising or consisting of amino acids 1 to 17 of SEQ ID NO: 4 or amino acids 1 to 17 of SEQ ID NO: 2.

[44] A nucleic acid construct or expression vector comprising a gene encoding a protein operably linked to the polynucleotide of paragraph 43, wherein the gene is foreign to the polynucleotide encoding the signal peptide.

[45] A recombinant host cell comprising a gene encoding a protein operably linked to the polynucleotide of paragraph 43, wherein the gene is foreign to the polynucleotide encoding the signal peptide.

[46] A method of producing a protein, comprising: (a) cultivating a recombinant host cell comprising a gene encoding a protein operably linked to the polynucleotide of paragraph 46, wherein the gene is foreign to the polynucleotide encoding the signal peptide, under conditions conducive for production of the protein; and optionally (b) recovering the protein.

[47] A method for degrading or converting a cellulosic material, comprising: treating the cellulosic material with an enzyme composition in the presence of the polypeptide having cellobiohydrolase activity of any of paragraphs 1-24.

[48] The method of paragraph 47, wherein the cellulosic material is pretreated.

[49] The method of of paragraph 47 or 48, further comprising recovering the degraded cellulosic material.

[50] The method of any of paragraphs 47-49, wherein the enzyme composition comprises one or more (e.g., several) enzymes selected from the group consisting of a cellulase, a GH61 polypeptide having cellulolytic enhancing activity, a hemicellulase, an esterase, an expansin, a laccase, a ligninolytic enzyme, a pectinase, a peroxidase, a protease, and a swollenin.

[51] The method of paragraph 50, wherein the cellulase one or more enzymes selected from the group consisting of an endoglucanase, a cellobiohydrolase, and a beta-glucosidase.

[52] The method of paragraph 50, wherein the hemicellulase is one or more enzymes selected from the group consisting of a xylanase, an acetyxylan esterase, a feruloyl esterase, an arabinofuranosidase, a xylosidase, and a glucuronidase.

[53] The method of any of paragraphs 47-52, wherein the degraded cellulosic material is a sugar.

[54] The method of paragraph 53, wherein the sugar is selected from the group consisting of glucose, xylose, mannose, galactose, and arabinose.

5 [55] A method for producing a fermentation product, comprising: (a) saccharifying a cellulosic material with an enzyme composition in the presence of the polypeptide having cellobiohydrolase activity of any of paragraphs 1-24; (b) fermenting the saccharified cellulosic material with one or more (e.g., several) fermenting microorganisms to produce the fermentation product; and (c) recovering the fermentation product from the fermentation.

10 [56] The method of paragraph 55, wherein the cellulosic material is pretreated.

[57] The method of paragraph 55 or 56, wherein the enzyme composition comprises one or more enzymes selected from the group consisting of a cellulase, a GH61 polypeptide having cellulolytic enhancing activity, a hemicellulase, an esterase, an expansin, a laccase, a ligninolytic enzyme, a pectinase, a peroxidase, a protease, and a swollenin.

15 [58] The method of paragraph 57, wherein the cellulase is one or more enzymes selected from the group consisting of an endoglucanase, a cellobiohydrolase, and a beta-glucosidase.

[59] The method of paragraph 57, wherein the hemicellulase is one or more enzymes selected from the group consisting of a xylanase, an acetyxylan esterase, a feruloyl esterase, an arabinofuranosidase, a xylosidase, and a glucuronidase.

20 [60] The method of any of paragraphs 55-59, wherein steps (a) and optionally (b) are performed simultaneously in a simultaneous saccharification and fermentation.

[61] The method of any of paragraphs 55-60, wherein the fermentation product is an alcohol, an alkane, a cycloalkane, an alkene, an amino acid, a gas, isoprene, a ketone, an organic acid, or polyketide.

25 [62] A method of fermenting a cellulosic material, comprising: fermenting the cellulosic material with one or more fermenting microorganisms, wherein the cellulosic material is saccharified with an enzyme composition in the presence of the polypeptide having cellobiohydrolase activity of any of paragraphs 1-24.

30 [63] The method of paragraph 62, wherein the cellulosic material is pretreated before saccharification.

[64] The method of paragraph 62 or 63, wherein the enzyme composition comprises one or more (e.g., several) enzymes selected from the group consisting of a cellulase, a GH61

polypeptide having cellulolytic enhancing activity, a hemicellulase, an esterase, an expansin, a laccase, a ligninolytic enzyme, a pectinase, a peroxidase, a protease, and a swollenin.

[65] The method of paragraph 64, wherein the cellulase is one or more enzymes selected from the group consisting of an endoglucanase, a cellobiohydrolase, and a beta-glucosidase.

[66] The method of paragraph 64, wherein the hemicellulase is one or more enzymes selected from the group consisting of a xylanase, an acetyxylan esterase, a feruloyl esterase, an arabinofuranosidase, a xylosidase, and a glucuronidase.

[67] The method of any of paragraphs 62-66, wherein the fermenting of the cellulosic material produces a fermentation product.

[68] The method of paragraph 67, further comprising recovering the fermentation product from the fermentation.

[69] The method of paragraph 67 or 68, wherein the fermentation product is an alcohol, an alkane, a cycloalkane, an alkene, an amino acid, a gas, isoprene, a ketone, an organic acid, or polyketide.

[70] A whole broth formulation or cell culture composition comprising a polypeptide of any of paragraphs 1-24.

The invention described and claimed herein is not to be limited in scope by the specific aspects herein disclosed, since these aspects are intended as illustrations of several aspects of the invention. Any equivalent aspects are intended to be within the scope of this invention. Indeed, various modifications of the invention in addition to those shown and described herein will become apparent to those skilled in the art from the foregoing description. Such modifications are also intended to fall within the scope of the appended claims. In the case of conflict, the present disclosure including definitions will control.

CLAIMS

What is claimed is:

5 1. An isolated polypeptide having cellobiohydrolase activity, selected from the group consisting of:

(a) a polypeptide having at least 80%, *e.g.*, at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%,
10 at least 99%, or 100% sequence identity to the mature polypeptide of SEQ ID NO: 4; or at least 89%, *e.g.*, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to the mature polypeptide of SEQ ID NO: 2;

(b) a polypeptide encoded by a polynucleotide that hybridizes under at least medium stringency conditions, at least medium-high stringency conditions, at least high stringency conditions, or at least very high stringency conditions with (i) the mature polypeptide coding sequence of SEQ ID NO: 3 or the mature polypeptide coding sequence of SEQ ID NO: 1, (ii) the cDNA sequence of SEQ ID NO: 3 or the cDNA sequence of SEQ ID NO: 1, or (iii) the full-length complement of (i) or (ii);
15

(c) a polypeptide encoded by a polynucleotide having at least 80%, *e.g.*, at least 81%, at least 82%, at least 83%, at least 84%, at least 85%, at least 86%, at least 87%, at least 88%, at least 89%, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to the mature polypeptide coding sequence of SEQ ID NO: 3 or the cDNA sequence thereof; or at
20 least 89%, *e.g.*, at least 90%, at least 91%, at least 92%, at least 93%, at least 94%, at least 95%, at least 96%, at least 97%, at least 98%, at least 99%, or 100% sequence identity to the mature polypeptide coding sequence of SEQ ID NO: 1 or the cDNA sequence thereof;

(d) a variant of the mature polypeptide of SEQ ID NO: 4 or the mature polypeptide of SEQ ID NO: 2 comprising a substitution, deletion, and/or insertion at one or more (*e.g.*,
25 several) positions; and

(e) a fragment of the polypeptide of (a), (b), (c), or (d) that has cellobiohydrolase activity.
30

2. The polypeptide of claim 1, comprising or consisting of SEQ ID NO: 4 or SEQ ID NO: 2, or the mature polypeptide of SEQ ID NO: 4 or the mature polypeptide of SEQ ID NO: 2.

3. The polypeptide of claim 1 or 2, wherein the mature polypeptide is amino acids 18 to 469 of SEQ ID NO: 4, or amino acids 18 to 394 of SEQ ID NO: 2.

4. An isolated polypeptide comprising a catalytic domain selected from the group consisting of:

(a) a catalytic domain having at least 80% sequence identity to amino acids 106 to 469 of SEQ ID NO: 4 or at least 89% sequence identity to amino acids 44 to 393 of SEQ ID NO: 2;

(b) a catalytic domain encoded by a polynucleotide that hybridizes under medium, medium-high, high, or very high stringency conditions with (i) nucleotides 400 to 1659 of SEQ ID NO: 3 or nucleotides 130 to 1376 of SEQ ID NO: 1, (ii) the cDNA sequence thereof, or (iii) the full-length complement of (i) or (ii);

(c) a catalytic domain encoded by a polynucleotide having at least 80% sequence identity to the catalytic domain of SEQ ID NO: 3 or the cDNA sequence thereof; or a catalytic domain encoded by a polynucleotide having at least 89% sequence identity to the catalytic domain of SEQ ID NO: 1 or the cDNA sequence thereof;

(d) a variant of amino acids 106 to 469 of SEQ ID NO: 4 or amino acids 44 to 393 of SEQ ID NO: 2 comprising a substitution, deletion, and/or insertion at one or more (e.g., several) positions; and

(e) a fragment of the catalytic domain of (a), (b), (c), or (d) that has cellobiohydrolyase activity.

5. An isolated polypeptide comprising a carbohydrate binding domain, which is selected from the group consisting of:

(a) a carbohydrate binding domain having at least 80% sequence identity to amino acids 24 to 63 of SEQ ID NO: 4;

(b) a carbohydrate binding domain encoded by a polynucleotide that hybridizes under medium, medium-high, high, or very high stringency conditions with (i) nucleotides 70 to 273 of SEQ ID NO: 3, (ii) the cDNA sequence thereof, or (iii) the full-length complement of (i) or (ii);

(c) a carbohydrate binding domain encoded by a polynucleotide having at least 80% sequence identity to nucleotides 70 to 273 of SEQ ID NO: 3 or the cDNA sequence thereof;

(d) a variant of amino acids 24 to 63 of SEQ ID NO: 4 comprising a substitution, deletion, and/or insertion at one or more (e.g., several) positions; and

5 (e) a fragment of (a), (b), (c), (d) or (e) that has cellulose binding activity.

6. The polypeptide of claim 5, wherein the carbohydrate binding domain is operably linked to a catalytic domain, preferably a catalytic domain obtained from a hydrolase, isomerase, ligase, lyase, oxidoreductase, or transferase, e.g., an aminopeptidase, amylase, carbohydrase, 10 carboxypeptidase, catalase, cellobiohydrolase, cellulase, chitinase, cutinase, cyclodextrin glycosyltransferase, deoxyribonuclease, endoglucanase, esterase, alpha-galactosidase, beta-galactosidase, glucoamylase, alpha-glucosidase, beta-glucosidase, invertase, laccase, lipase, mannosidase, mutanase, oxidase, pectinolytic enzyme, peroxidase, phytase, polyphenoloxidase, proteolytic enzyme, ribonuclease, transglutaminase, xylanase, or beta- 15 xylosidase.

7. A composition comprising the polypeptide of any of claims 1-6.

8. An isolated polynucleotide encoding the polypeptide of any of claims 1-6.

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9. A nucleic acid construct or expression vector comprising the polynucleotide of claim 8 operably linked to one or more control sequences that direct the production of the polypeptide in an expression host.

25 10. A recombinant host cell comprising the polynucleotide of claim 8 operably linked to one or more control sequences that direct the production of the polypeptide.

11. A method of producing the polypeptide of any of claims 1-6, comprising:

30 (a) cultivating a cell, which in its wild-type form produces the polypeptide, under conditions conducive for production of the polypeptide; and

(b) recovering the polypeptide.

12. A method of producing a polypeptide having cellobiohydrolase activity, comprising:

(a) cultivating the host cell of claim 10 under conditions conducive for production of

the polypeptide; and

(b) recovering the polypeptide.

13. An isolated polynucleotide encoding a signal peptide comprising or consisting of amino acids 1 to 17 of SEQ ID NO: 4 or amino acids 1 to 17 of SEQ ID NO: 2.

14. A method of producing a protein, comprising:

(a) cultivating a recombinant host cell comprising a gene encoding a protein operably linked to the polynucleotide of claim 13, wherein the gene is foreign to the polynucleotide encoding the signal peptide, under conditions conducive for production of the protein; and

(b) recovering the protein.

15. A whole broth formulation or cell culture composition comprising the polypeptide of any of claims 1-6.

16. A process for degrading a cellulosic material, comprising: treating the cellulosic material with an enzyme composition in the presence of the polypeptide having cellobiohydrolase activity of any of claims 1-6.

17. A process for producing a fermentation product, comprising:

(a) saccharifying a cellulosic material with an enzyme composition in the presence of the polypeptide having cellobiohydrolase activity of any of claims 1-6;

(b) fermenting the saccharified cellulosic material with one or more fermenting microorganisms to produce the fermentation product; and

(c) recovering the fermentation product from the fermentation.

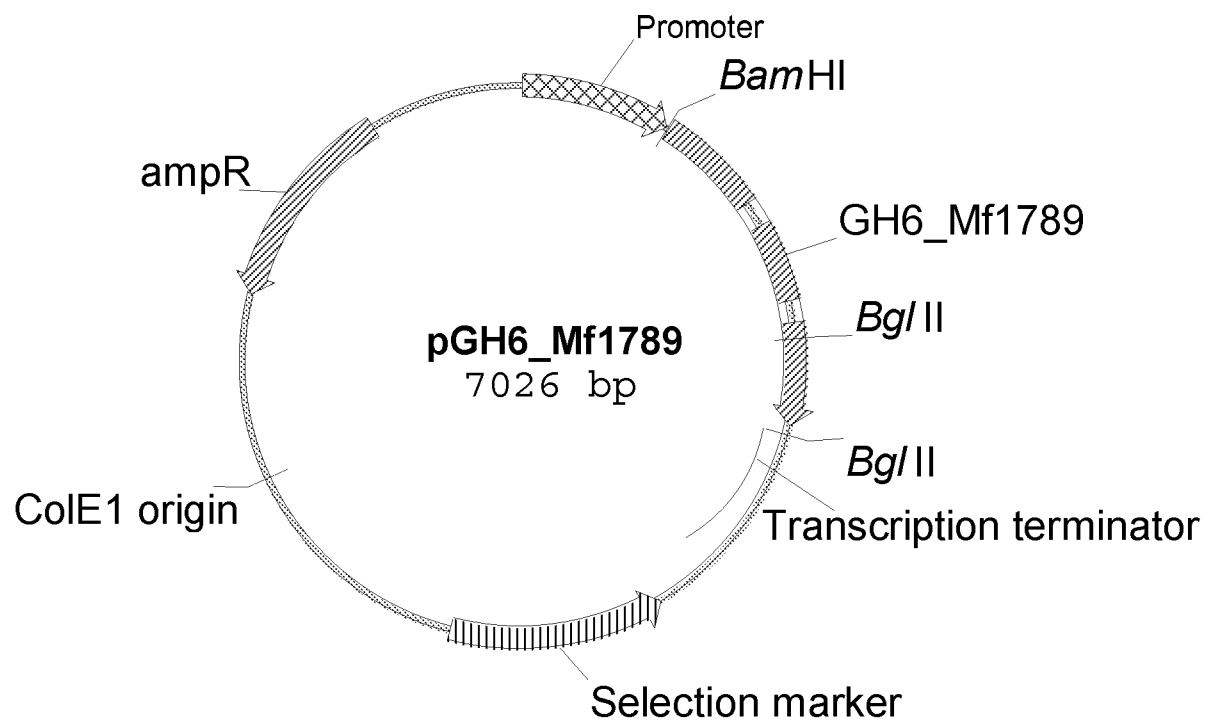
18. A process of fermenting a cellulosic material, comprising: fermenting the cellulosic material with one or more fermenting microorganisms, wherein the cellulosic material is saccharified with an enzyme composition in the presence of the polypeptide having cellobiohydrolase activity of any of claims 1-6.

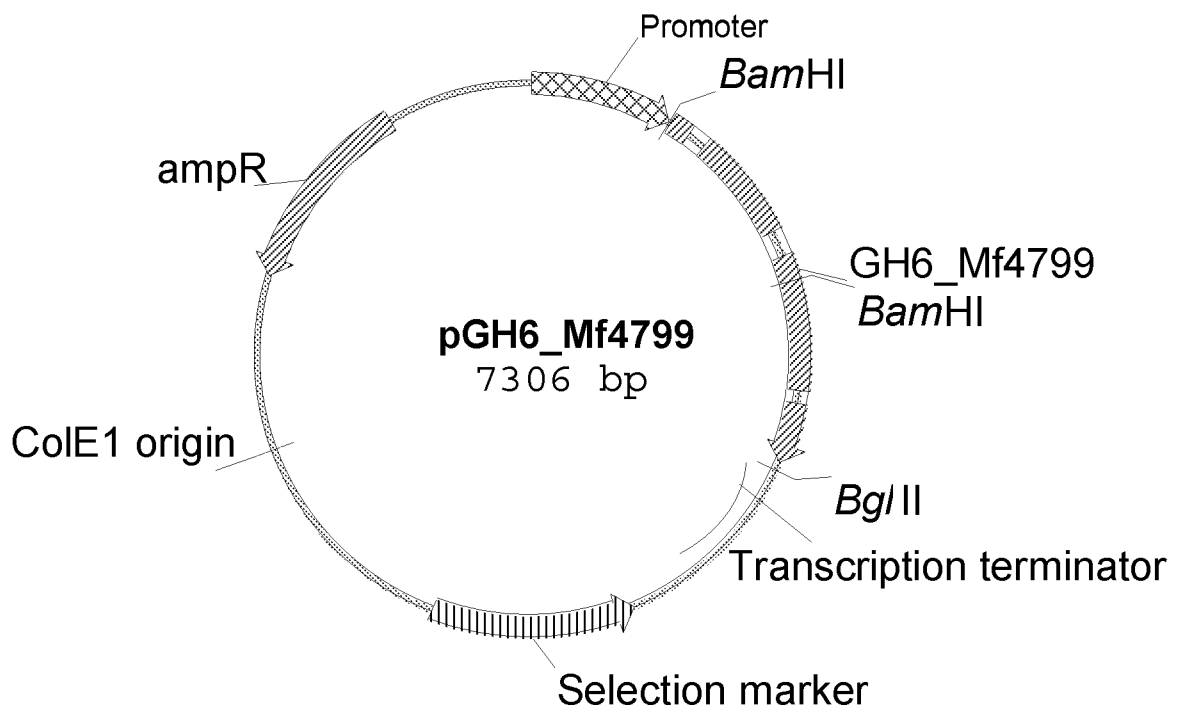
M K L A Q S A A V A F A A T A L A A P S
 1. ATGAAGCTCG CGCAATCTGC CGCCGTGGCG TTCGCGCCA CGGCTCTCGC TGCCCCCTCG
 R T T P E K P R Q A A G C A S A V T L D
 61. CGCACCCTC CCGAAAAGCC CCGTCAGGCG GCGGGTTGCG CGTCGGCCGT GACACTGGAC
 A S T N V W K Q Y K L H P N N F Y R A E
 121. GCCAGCACC ACGTGTGGAA GCAGTACAAG CTGCACCCA ACAACTTCTA CCGTGCCGAG
 V E A A A D A I S D S T L A E K A R K V
 181. GTCGAGGCTG CCGCCGACGC CATCTCCGAC TCCACGCTGG CCGAGAAGGC CCGCAAGGTT
 A D I G T F L W L D T I E N I N R L E P
 241. GCCGACATCG GTACCTTCCT CTGGCTCGAC ACCATCGAGA ACATCAACCG GCTGGAGCCC
 A L E D V P C E N I L G L V I Y D L P G
 301. GCGCTCGAG ACGTGCCGTG CGAGAACATC CTGGGTCTCG TCATCTACGA CCTCCCGGGC
 R D C A A K A S N G E L K V G E I D R Y
 361. CGTGAATGCG CGGCCAAGGC CTCCAACGGC GAGCTCAAGG TCGGCGAGAT CGACAGGTAC
 K T E Y I D
 421. AAGACCGAGT ACATCGACAG TAAGTAAACC CTTTGTGGCC GTTCCCCCTT CCACCTCACC
 481. CACTCCTCCG AGACGTCTG GGGAGAGAGA GAGAGAGAGA GAGAGACTGA CGCGCTGGT
 K I A S I L K A H P N T A F A L V I E .
 541. CGCAGAGATC GCCTCGATCC TCAAGGCCCA CCCCAACACC GCCTTCGCCC TCGTCATCGA
 . P D S L P N L V T N I D Q Q A C Q Q S A .
 601. GCCCGACTCG CTCCCCAACC TGGTCAACAA CATCGATCAG CAGGCGTGCC AGCAGAGCGC
 . S G Y R E G V A Y A L Q Q L N L P N V V .
 661. CTCGCGCTAC CGCGAGGCG TCGCCTATGC CCTTCAGCAG CTCAACCTCC CCAACGTCGT
 . M Y I D A G H G G W L G W D D N L R P G .
 721. CATGTACATC GATGCCGCGC ACGGTGGCTG GCTCGGCTGG GACGACAACC TCAGGCCCCG
 . A Q E L A N V Y K A A G S P S Q V R G I .
 781. CGCCAGGAG CTCGCCAACG TCTACAAGGC CGCAGGCTCG CCCTCGCAAG TCGTGGTAT
 . S T N V A G W N S W
 841. CTCGACCAAC GTGGCTGGCT GGAACCTCTG GTAAGACACT CCATTCTCTC CGCCCCCTTT
 901. TTTTTCCTTC CCGTGAATG CAGGAAGCTG ACGTTTCCTT TTTTTCCTC CACTGCAACA
 D Q E P G E F A N D P D A Q W N K C Q N .
 961. GGGACCAAGA GCGCGGTGAG TTCGCGAACG ACCCGGATGC TCAGTGGAAT AAGTGCCAGA
 . E K I Y V N T F G A E L R N A G M P Y H .
 1021. ACGAGAAGAT CTACGTCAAC ACCTTCGGCG CCGAGCTCCG GAATGCCGCG ATGCCCTACC
 . A I I D T G R N G V T G L R Q E W G N W .
 1081. ACGCCATCAT CGACACCGGC CGCAACGGCG TCACCGGTCT CCGTCAGGAG TGGGGCAACT
 . C N V N G A G F G L R P S A D T G D D F .
 1141. GGTGCAACGT CAACGGTGCC GGCTTCGGTC TCGCCCCGAG TGCCGACACC GGCGACGACT
 . A D A F V W V K P G G E S D G T S D S S .
 1201. TCGCCGACGC CTTCTGTGTG GTCAAGCCCG GCGGCGAGTC CGACGGCACC AGCGACTCGT
 . A T R Y D E F C G K P D A F K P S P E A .
 1261. CGGCCACGCG CTACGACGAG TTCTGCGGCA AGCCCGACGC CTTCAAGCCC AGCCCTGAGG
 . G T W H Q E Y F E M L V K N A N P S L * .
 1321. CCGGTACCTG GCACCAGGAA TACTTCGAGA TGCTCGTCAA GAACGCCAAC CCCTCCCTCT
 . *
 1381. AAGCTCCTCG GCAGCCTGTT GCTGTCACTC GCTCTGATG

Fig. 1

M A K K L F I N A A L A A V V L A A P V
 1 ATGGCCAAGA AGCTCTTCAT CAACGCCGCG CTTGCGGCCG TCGTGCTGGC TGCTCCCGTT
 V E E R Q N C A G L W
 61 GTCGAGGAGC GCCAGAACTG CGCCGGTCTT TGGTAAGAGA GAAAGCCTCG CGCTGAGCAT
 G
 121 CCCAGAACTG CCTGGTCCAA GAACGGGACA CTGACCGTGG AAATTGACGA ACCTAGGGGC
 Q C G G N G W Q G P T C C V A G S T C V
 181 CAATGCGGCG GTAACGGGTG GCAGGGCCCG ACATGCTGCG TCGCGGGCTC GACCTGCGTC
 A Q N E W Y S Q C L P G G A S S S S S T
 241 GCACAGAACG AGTGGTACTC TCAGTGTCTG CCCGGCGGCG CCTCCTCGTC GTCGTCGACC
 T S Q G I P S T T V S S T S T T P P P I
 301 ACCTCGCAGG GCATCCCCAG CACCACCGTC TCCTCCACCT CCACTACCCC CCCGCCAATC
 S T S W S S I P G G A T S T A S Y A G N
 361 TCGACTTCCT GGAGCAGCAT CCCCGGCGGT GCGACCTCGA CGGCGAGCTA CGCCGGTAAC
 P F S G V R L W A N D Y Y R S E V H N I
 421 CCCTTCTCGG GCGTCCGGCT CTGGGCCAAC GACTATTACC GGTCCGAGGT CCACAACATC
 A I P S L T G S L V A K A S A V A E V P
 481 GCGATTCCCA GCCTGACCGG TAGTCTGGTC GCCAAGGCTT CCGCCGTCGC CGAAGTCCCG
 S F Q W L D R N V T V D T L M V D T L S
 541 AGCTTCCAGT GGCTCGACCG CAACGTTACC GTCGACACCC TGATGGTCGA CACTCTGTCA
 K I R A A N E A G A N P P Y A
 601 AAGATCCGGG CTGCCAACGA GGCCGGTGCC AACCTCCTT ATGCTGGTGA GTCAACGACG
 661 GAATGTCAAC GCGAACTCGT CATATCCACC TTCCTCTATC GCGTGACAGG GAACTCTGCT
 A Q L V V Y D L
 721 GATTACATTG CCTAACCCGG GAAACCAAAA AATAAACAGC CCAACTTGTC GTCTACGACC
 P D R D C A A A A S N G E W S I A N G G
 781 TCCCCGACCG TGAATGTGCC GCGGCCGCGT CCAATGGCGA GTGGTCGATT GCGAACGGCG
 A A N Y R G Y I D R I R Q L L I Q F S D
 841 GCGCGGCCAA CTACAGGGGC TACATCGACA GGATCCGCCA GCTCCTCATC CAATTCTCGG
 I R T I L V I E P D S M A N M V T N L N
 901 ACATCCGGAC CATCCTGGTC ATCGAGCCCG ACTCGATGGC CAACATGGTG ACAAACCTGA
 V A K C S N A R S T Y H E L T V Y A L K
 961 ACGTTGCCAA ATGCAGCAAC GCCCCGTCGA CGTACCATGA GTTGACCGTG TACGCCCTCA
 Q L N L P H V A M Y L D A G H A G W L G
 1021 AGCAACTCAA CCTGCCCCAT GTCGCCATGT ATCTCGACGC CGGCCACGCC GGCTGGCTCG
 W P A N V Q P A A D L F A G L Y K D A G
 1081 GTTGGCCCCG CAACGTCCAA CCGGCCGCGC ACCTGTTTGC CGGCCTCTAC AAAGACGCGG
 S P A A V R G L A T N V A N Y N A W S L
 1141 GTAGCCCGGC TGCCGTCCGC GGCCTTGCCA CAAATGTTGC CAACTACAAC GCCTGGAGCC
 S S A P S Y T S P N P N Y D E K H Y I E
 1201 TCTCCTCGGC CCCGTCGTAC ACGTCGCCGA ACCCAACTA CGACGAGAAG CACTACATCG
 A F S P L L N A A G F P A R F I V D T G
 1261 AGGCCTTCAG CCCGTCCTG AACGCGGCCG GCTTCCCGGC ACGCTTCATC GTCGACACCG
 R N G K Q P T
 1321 GCCGCAACGG CAAGCAACCT ACCGGTATGT TCACACAATG TTTCTCTCTC TCACGCACAA
 G Q L E W G D W C N V R D T
 1381 ACGACTAACA ATTCTACAGG CCAACTGGAG TGGGGCGACT GGTGCAACGT GAGGGACACC
 G F G V R P T A N T G H E L V D A F V W
 1441 GGCTTTGGCG TCCGCCCCGAC GGCCAACACA GGCCACGAGC TGGTCGATGC CTTCTGTCTGG
 I K P G G E S D G T S D T S A A R Y D Y
 1501 ATCAAGCCCG GCGGCGAGTC GGACGGCACG AGCGACACCA GCGCCGCTCG CTACGACTAC
 H C G L S D A L K P A P E A G Q W F Q A
 1561 CACTGCGGCC TGAGCGATGC CCTGAAGCCT GCCCCGAGG CCGGTCAGTG GTTCCAGGCC
 Y F E Q L L I N A N P P F *
 1621 TACTTCGAGC AGCTGCTCAT CAACGCCAAC CCGCGTTTTT AAGTACACCT CGTCGTCAAG
 1681 ACAAGCGAAG GGAGAGTGT

Fig. 2

**Fig. 3**

**Fig. 4**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2012/083990

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

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: C12N9/-, C11D3/-, C12N15/-, C12N5/-,

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)

CNPAT, WPI, EPODOC, CNKI, EBI, NCBI: polypeptide, cellobiohydrolase, polynucleotide, nucleic acid, amino acid, construct, vector, host cell, sequence listing

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO2009042871A1 (NOVOZYMES A/S ET-AL), 02 Apr. 2009 (02.04.2009) Claims 1-21, examples 1-7, sequence listing	1-18
A	WO2004056981A2 (NOVOZYMES A/S ET-AL), 08 Jul. 2004 (08.07.2004) Claims 1-22, examples 1-8, sequence listing	1-18

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:	“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
“A” document defining the general state of the art which is not considered to be of particular relevance	“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
“E” earlier application or patent but published on or after the international filing date	“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
“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)	“&” document member of the same patent family
“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	

Date of the actual completion of the international search 21 Jan. 2013 (21.01.2013)	Date of mailing of the international search report 07 Feb. 2013 (07.02.2013)
Name and mailing address of the ISA/CN The State Intellectual Property Office, the P.R.China 6 Xitucheng Rd., Jimen Bridge, Haidian District, Beijing, China 100088 Facsimile No. 86-10-62019451	Authorized officer LI, Zhe Telephone No. (86-10)82246716

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2012/083990

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		US2011081696A1	07.04.2011
		WO2004056981A3	11.11.2004

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2012/083990

Continuation of: A. CLASSIFICATION OF SUBJECT MATTER

C12N9/42 (2006.01) i

C11D3/386 (2006.01) i

C12N15/56 (2006.01) i

C12N5/10 (2006.01) i