TITLE OF THE INVENTION
YEAST STRAINS FOR PROTEIN PRODUCTION

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The present invention relates to the field of molecular biology, in particular, the invention is concerned with novel selection genes to be used for improved protein production from transformed expression systems.

(2) Description of Related Art

In recent years the budding yeast *Pichia pastoris* has become a popular organism for the expression of heterologous proteins of academic and commercial interest (Cereghino *et al.*, Curr. Opin. Biotechnol. 4: 329-332 (2002); Cereghino and Cregg, FEMS Microbiol. Rev. 24: 45-66 (2000). It was recently shown that it is possible to genetically modify the glycosylation machinery of *P. pastoris* and express heterologous glycoproteins decorated with complex type human glycans (Choi *et al.*, Proc. Natl. Acad. Sci. 100: 5022-5027 (2003); Hamilton *et al.*, Science 301: 1244-1246 (2003); Bobrowicz *et al.*, Glycobiology 14: 757-766 (2004); Hamilton, Science, 313: 1441-1443 (2006). However, a need remains for methods and materials to achieve higher cellular productivity in transformed cell lines, such as transformed *P. pastoris* cell lines.

Over the years, numerous auxotrophic and dominant selectable markers have been developed (Higgins *et al.*, Methods Mol. Biol. 103: 41-53 (1998); Lin Cereghino *et al.*, Gene 263: 159-169 (2001); Nett and Gerngross, Yeast 20: 1279-1290 (2003); Nett *et al.*, Yeast 22: 295-304 (2005) and used to construct protein expression vectors for various applications. Commonly, a gene of interest is integrated into the *P. pastoris* genome using a plasmid that is either linearized in the marker gene, another homologous region on the plasmid or in the *AOX1* promoter fragment and transformed into the appropriate auxotrophic mutant. Homologous recombination of the free DNA termini then results in single-crossover type integration into these loci. Most *P. pastoris* transformants will contain a single copy of the expression vector, but to obtain transformants that express a high level of the protein of interest it is often desirable to screen for multi copy integrants. Using expression vectors that contain drug resistance genes as selection markers like Kan^R or Zeo^R it is possible to increase the number of transformants harboring multiple copies of the expression vector by increasing the level of drug used for selection. One significant disadvantage of the single-crossover type integration lies in the fact that the multiple integrated copies can collapse back into a single copy by homologous recombination. This can be especially problematic during scale-up of the expression reaction during fermentation if the protein of interest is toxic to the cells or the eviction of several copies of expression plasmid possesses other growth benefit for the cells.

U.S. Patent No. 5,584,039 relates to a selectable marker gene *ADE2* isolated from *Pichia methanolica*. Piontek *et al.*, Appl Microbiol. Biotechnol. 50:331-338 (1998) relates to novel gene expression systems in *Schwanniomyces occidentalis* and *Pichia stipitis*, which systems utilize vectors containing an *ADE2* marker and a putative replication sequence. However, no corresponding gene has previously been isolated from *Pichia pastoris*, and the effects of transformation with *ADE2* in *P. pastoris* have not previously been identified.

Accordingly, a need exists for improved methods of transformation, selection and expression of heterogeneous genes using the *Pichia pastoris* yeast as the host expression system.

BRIEF SUMMARY OF THE INVENTION

The present invention provides methods and materials for the use of lower eukaryotic cells such as yeast or filamentous fungi as an expression system for expressing recombinant proteins.

In one aspect, the method is based on constructing slower growing *ade2* auxotrophic strains of the lower eukaryote cells and using integration vectors that are capable of integrating into the genome of the *ade2* auxotrophic strain and which comprises nucleic acids encoding an *ADE2* marker gene or open reading frame (ORF) operably linked to a promoter and a recombinant protein, wherein the integration vector integrates into the genome of the *ade2* auxotrophic strain, the *ADE2* renders the auxotrophic strain prototrophic for adenine, and the recombinant protein is expressed.

Thus, provided is an expression system comprising (a) a *Pichia pastoris* host cell in which the endogenous *ADE2* gene encoding Ade2p has been removed from the genome of the host cell; and (b) an integration vector comprising (1) a nucleic acid encoding the Ade2p; (2) a nucleic acid having an insertion site for the insertion of one or more expression cassettes comprising a nucleic acid encoding one or more heterologous peptides, proteins, and/or functional nucleic acids of interest, and (3) a targeting nucleic acid that directs insertion of the integration vector into a particular location of the genome of the host cell by homologous recombination.

Also, provided is a method for producing a recombinant *Pichia pastoris* host cell that expresses a heterologous protein or peptide comprising (a) providing the host cell in which the endogenous *ADE2* gene encoding an Ade2p has been removed from the genome of the host cell; and (a) transforming the host cell with an integration vector comprising (1) a nucleic acid encoding the Ade2p; (2) a nucleic acid having one or more expression cassettes comprising a nucleic acid encoding one or more heterologous peptides, proteins, and/or functional nucleic acids of interest, and (3) a targeting nucleic acid that directs insertion of the integration vector into a particular location of the genome of the host cell by homologous recombination, wherein the transformed host cell produces the recombinant protein.

Further provided is an isolated nucleic acid comprising the *ADE2* gene of *Pichia pastoris*. In particular aspects, the nucleic acid comprises the open reading frame that encodes the Ade2p protein or the nucleic acid has a nucleotide sequence with 95% identity to the nucleic acid sequence shown in SEQ ID NO:60 from nucleotide 127 to nucleotide 1,815. Further provided is an isolated polypeptide comprising an amino acid sequence with 95% identity to the amino acid sequence shown in SEQ ID NO:61.

The applicants further discovered that operably linking an auxotrophic marker gene or ORF to a minimal promoter in the integration vector, that is a promoter that has low transcriptional activity, enabled the production of recombinant host cells that contain a sufficient number of copies of the integration vector integrated into the genome of the auxotrophic host cell to render the cell prototrophic and which render the cells capable of producing amounts of the recombinant protein or functional nucleic acid of interest that are greater than the amounts that would be produced in a cell that contained only one copy of the integration vector integrated into the genome.

Therefore, provided is a method in which an auxotrophic strain of a lower eukaryote cell is obtained or constructed and an integration vector is provided that is capable of integrating into the genome of the auxotrophic strain and which comprises nucleic acids encoding a marker gene or ORF that compliments the auxotrophy and is operably linked to a weak promoter, an attenuated endogenous or heterologous promoter, a cryptic promoter, or a truncated endogenous or heterologous promoter and a recombinant protein. Host cells in which a number of the integration vectors have been integrated into the genome to compliment the auxotrophy of the host cell are selected in medium that lacks the metabolite that compliments the auxotrophy and maintained by propagating the host cells in medium that lacks the metabolite that compliments the auxotrophy or in medium that contains the metabolite because in that case, cells that evict the plasmids including the marker will grow more slowly.

In a further embodiment, provided is an expression system comprising (a) a host cell in which the endogenous gene encoding an auxotrophic selectable marker protein has been removed from the genome of the host cell; and (b) an integration vector comprising (1) a nucleic acid comprising an open reading frame (ORF) encoding a function that is complementary to the function of the endogenous gene encoding the auxotrophic selectable marker protein and which is operably linked to a weak promoter, an attenuated endogenous or heterologous promoter, a cryptic promoter, a truncated endogenous or heterologous promoter, or no promoter; (2) a nucleic acid having an insertion site for the insertion of one or more expression cassettes comprising a nucleic acid encoding one or more heterologous peptides, proteins, and/or functional nucleic acids of interest, and (3) a targeting nucleic acid that directs insertion of the integration vector into a particular location of the genome of the host cell by homologous recombination.

In a further still embodiment, provided is a method for expression of a recombinant protein in a host cell comprising (a) providing the host cell in which the endogenous gene encoding an auxotrophic selectable marker protein has been removed from the genome of the host cell; and (a) transforming the host cell with an integration vector comprising (1) a nucleic acid comprising an open reading frame (ORF) encoding a function that is complementary to the function of the endogenous gene encoding the auxotrophic selectable marker protein and which is operably linked to a weak promoter, an attenuated endogenous or heterologous promoter, a cryptic promoter, a truncated endogenous or heterologous promoter, or no promoter; (2) a nucleic acid having one or more expression cassettes comprising a nucleic acid encoding one or more heterologous peptides, proteins, and/or functional nucleic acids of interest, and (3) a targeting nucleic acid that directs insertion of the integration vector into a particular location of the genome of the host cell by homologous recombination, wherein the transformed host cell produces the recombinant protein.

In further aspects of the above embodiments, the auxotrophic selectable marker protein is encoded by a gene selected from the group consisting of *ADE, URA*, and *LYS*. In a further still aspect, the auxotrophic selectable marker protein is encoded by the *ADE1* gene or the *ADE2* gene.

In further still aspects, the integration vector comprises multiple insertion sites for the insertion of one or more expression cassettes encoding the one or more heterologous peptides, proteins and/or functional nucleic acids of interest. In further still aspects, the integration vector comprises more than one expression cassette. In further still aspects, the integration vector comprises little or no homologous DNA sequence between the expression cassettes. In further still aspects, the integration vector comprises a first expression cassette encoding a light chain of a monoclonal antibody and a second expression cassette encoding a heavy chain of a monoclonal antibody.

In further still aspects, the host cell is a lower eukaryote. In further still aspects, the host cell is from a species selected from the group consisting of *Pichia pastoris*, *Pichia finlandica*, *Pichia trehalophila*, *Pichia koclamae*, *Pichia membranaefaciens*, *Pichia minuta* (*Ogataea minuta*, *Pichia lindneri*), *Pichia opuntiae*, *Pichia thermotolerans*, *Pichia salictaria*, *Pichia guercuum*, *Pichia pijperi*, *Pichia stiptis*, *Pichia methanolica*, *Pichia* sp., *Saccharomyces cerevisiae*, *Saccharomyces* sp., *Hansenula polymorpha*, *Kluyveromyces* sp., *Kluyveromyces lactis*, *Candida albicans*, *Aspergillus nidulans*, *Aspergillus niger*, *Aspergillus oryzae*, *Trichoderma reesei*, *Chrysosporium lucknowense*, *Fusarium* sp., *Fusarium gramineum*, *Fusarium venenatum*, *Physcomitrella patens*, and *Neurospora crassa*. In further still aspects, the expression system of claim 1, wherein the host cell is *Pichia pastoris* or a *Pichia pastoris* cell that has been modified to be capable of producing glycoproteins having hybrid or complex *N*-glycans.

DEFINITIONS

Unless otherwise defined herein, scientific and technical terms and phrases used in connection with the present invention shall have the meanings that are commonly understood by those of ordinary skill in the art. Further, unless otherwise required by context, singular terms shall include the plural and plural terms shall include the singular. Generally, nomenclatures used in connection with, and techniques of biochemistry, enzymology, molecular and cellular biology, microbiology, genetics and protein and nucleic acid chemistry and hybridization described herein are those well known and commonly used in the art. The methods and techniques of the present invention are generally performed according to conventional methods well known in the art and as described in various general and more specific references that are cited and discussed throughout the present specification unless otherwise indicated. See, e.g., Sambrook *et al.* Molecular Cloning: A Laboratory Manual, 2d ed., Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y. (1989); Ausubel *et al.*, Current Protocols in Molecular Biology, Greene Publishing Associates (1992, and Supplements to 2002); Harlow and Lane, Antibodies: A Laboratory Manual, Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y. (1990); Taylor and Drickamer, Introduction to Glycobiology, Oxford Univ. Press (2003); Worthington Enzyme Manual, Worthington Biochemical Corp., Freehold, NJ; Handbook of Biochemistry: Section A Proteins, Vol I, CRC Press (1976); Handbook of Biochemistry: Section A Proteins, Vol II, CRC Press (1976); Essentials of Glycobiology, Cold Spring Harbor Laboratory Press (1999). All publications, patents and other references mentioned herein are hereby incorporated by reference in their entireties.

The genetic nomenclature for naming chromosomal genes of yeast is used herein. Each gene, allele, or locus is designated by three italicized letters. Dominant alleles are denoted by using uppercase letters for all letters of the gene symbol, for example, *ADE2* for the adenine 2 gene, whereas lowercase letters denote the recessive allele, for example, the auxotrophic marker for adenine 2, *ade2*. Wild-type genes are denoted by superscript "+" and mutants by a "-" superscript. The symbol Δ can denote partial or complete deletion. Insertion of genes follow the bacterial nomenclature by using the symbol "::", for example, *trp2::ARG2* denotes the insertion of the *ARG2* gene at the *TRP2* locus, in which *ARG2* is dominant (and functional) and *trp2* is recessive (and defective). Proteins encoded by a gene are referred to by the relevant gene symbol, non-italicized, with an initial uppercase letter and usually with the suffix 'p", for example, the adenine 2 protein encoded by *ADE2* is Ade2p. Phenotypes are designated by a non-italic, three letter abbreviation corresponding to the gene symbol, initial letter in uppercase. Wild-type strains are indicated by a "+" superscript and mutants are designated by a "-" superscript. For example, $Ade2^+$ is a wild-type phenotype whereas $Ade2^-$ is an auxotrophic phenotype (requires adenine).

The term "vector" as used herein is intended to refer to a nucleic acid molecule capable of transporting another nucleic acid to which it has been linked. One type of vector is a "plasmid", which refers to a circular double stranded DNA loop into which additional DNA segments may be ligated. Other vectors include cosmids, bacterial artificial chromosomes (BAC) and yeast artificial chromosomes (YAC). Another type of vector is a viral vector, wherein additional DNA segments may be ligated into the viral genome (discussed in more detail below). Certain vectors are capable of autonomous replication in a host cell into which they are introduced (e.g., vectors having an origin of replication which functions in the host cell). Other vectors can be integrated into the genome of a host cell upon introduction into the host cell, and are thereby replicated along with the host genome. Moreover, certain preferred vectors are capable of directing the expression of genes to which they are operatively linked. Such vectors are referred to herein as "recombinant expression vectors" (or simply, "expression vectors").

The term "integration vector" refers to a vector that can integrate into a host cell and which carries a selection marker gene or open reading frame (ORF), a targeting nucleic acid, one or more genes or nucleic acids of interest, and a nucleic acid sequence that functions as a microorganism autonomous DNA replication start site, herein after referred to as an origin of DNA replication, such as ORI for bacteria. The integration vector can only be replicated in the host cell if it has been integrated into the host cell genome by a process of DNA recombination such as homologous recombination that integrates a linear piece of DNA into a specific locus of the host cell genome. For example, the targeting nucleic acid targets the integration vector to the corresponding region in the genome where it then by homologous recombination integrates into the genome.

The term "selectable marker gene", "selection marker gene", "selectable marker sequence" or the like refers to a gene or nucleic acid sequence carried on a vector that confers to a transformed host a genetic advantage with respect to a host that does not contain the marker gene. For example, the *P. pastoris URA5* gene is a selectable marker gene because its presence can be selected for by the ability of cells containing the gene to grow in the absence of uracil. Its presence can also be selected against by the inability of cells containing the gene to grow in the presence of 5-FOA. Selectable marker genes or sequences do not necessarily need to display both positive and negative selectability. Non-limiting examples of marker sequences or genes from *P. pastoris* include *ADE1*, *ADE2 ARG4*, *HIS4*, *LYS2*, *URA5*, and *URA3*. In general, a selectable marker gene as used the expression systems disclosed herein encodes a gene product that complements an auxotrophic mutation in the host. An auxotrophic mutation or auxotrophy is the inability of an organism to synthesize a particular organic compound or metabolite required for its growth (as defined by IUPAC). An auxotroph is an organism that displays this characteristic; auxotrophic is the corresponding adjective. Auxotrophy is the opposite of prototrophy.

The term "a targeting nucleic acid" refers to a nucleic acid carried on the vector plasmid that directs the insertion by homologous recombination of the vector integration plasmid into a specific homologous locus in the host called the "target locus".

The term "sequence of interest" or "gene of interest" or "nucleic acid of Interest" refers to a nucleic acid sequence, typically encoding a protein or a functional RNA, that is not normally produced in the host cell. The methods disclosed herein allow efficient expression of one or more sequences of interest or genes of interest stably integrated into a host cell genome. Non-limiting examples of sequences of interest include sequences encoding one or more polypeptides having an enzymatic activity, e.g., an enzyme which affects N-glycan synthesis in a host such as mannosyltransferases, N-acetylglucosaminyltransferases, UDP-N-acetylglucosamine transporters, galactosyltransferases, UDP-N-acetylgalactosyltransferase, sialyltransferases, fucosyltransferases, erythropoietin, cytokines such as interferon-α, interferon-β, interferon-γ, interferon-ω, and granulocyte-CSF, coagulation factors such as factor VIII, factor IX, and human protein C, soluble IgE receptor α-chain, IgG, IgM, urokinase, chymase, urea trypsin inhibitor, IGF-binding protein, epidermal growth factor, growth hormone-releasing factor, annexin V fusion protein, angiostatin, vascular endothelial growth factor-2, myeloid progenitor inhibitory factor-1, and osteoprotegerin.

The term "operatively linked" refers to a linkage in which a expression control sequence is contiguous with the gene or sequence of interest or selectable marker gene or sequence to control expression of the gene or sequence, as well as expression control sequences that act in trans or at a distance to control the gene of interest.

The term "expression control sequence" as used herein refers to polynucleotide sequences which are necessary to affect the expression of coding sequences to which they are operatively linked. Expression control sequences are sequences which control the transcription, post-transcriptional events, and translation of nucleic acid sequences. Expression control sequences include appropriate transcription initiation, termination, promoter, and enhancer sequences; efficient RNA processing signals such as splicing and polyadenylation signals; sequences that stabilize cytoplasmic mRNA; sequences that enhance translation efficiency (e.g., ribosome binding sites); sequences that enhance protein stability; and when desired, sequences that enhance protein secretion. The nature of such control sequences differs depending upon the host organism; in prokaryotes, such control sequences generally include promoter, ribosomal binding site, and transcription termination sequence. The term "control sequences" is intended to include, at a minimum, all components whose presence is essential for expression, and can also include additional components whose presence is advantageous, for example, leader sequences and fusion partner sequences.

The term "recombinant host cell" ("expression host cell," "expression host system," "expression system" or simply "host cell"), as used herein, is intended to refer to a cell into

which a recombinant vector has been introduced. It should be understood that such terms are intended to refer not only to the particular subject cell but to the progeny of such a cell. Because certain modifications may occur in succeeding generations due to either mutation or environmental influences, such progeny may not, in fact, be identical to the parent cell, but are still included within the scope of the term "host cell" as used herein. A recombinant host cell may be an isolated cell or cell line grown in culture or may be a cell which resides in a living tissue or organism.

The term "eukaryotic" refers to a nucleated cell or organism, and includes insect cells, plant cells, mammalian cells, animal cells, and lower eukaryotic cells.

The term "lower eukaryotic cells" includes yeast, unicellular and multicellular or filamentous fungi. Yeast and fungi include, but are not limited to *Pichia pastoris*, *Pichia finlandica*, *Pichia trehalophila*, *Pichia koclamae*, *Pichia membranaefaciens*, *Pichia minuta* (*Ogataea minuta*, *Pichia lindneri*), *Pichia opuntiae*, *Pichia thermotolerans*, *Pichia salictaria*, *Pichia guercuum*, *Pichia pijperi*, *Pichia stiptis*, *Pichia methanolica*, *Pichia* sp., *Saccharomyces cerevisiae*, *Saccharomyces* sp., *Hansenula polymorpha*, *Kluyveromyces* sp., *Kluyveromyces lactis*, *Candida albicans*, *Aspergillus nidulans*, *Aspergillus niger*, *Aspergillus oryzae*, *Trichoderma reesei*, *Chrysosporium lucknowense*, *Fusarium* sp., *Fusarium gramineum*, *Fusarium venenatum*, *Physcomitrella patens*, and *Neurospora crassa*.

The term "peptide" as used herein refers to a short polypeptide, e.g., one that is typically less than about 50 amino acids long and more typically less than about 30 amino acids long. The term as used herein encompasses analogs, derivatives, and mimetics that mimic structural and thus, biological function of polypeptides and proteins.

The term "polypeptide" encompasses both naturally-occurring and non-naturally-occurring proteins, and fragments, mutants, derivatives and analogs thereof. A polypeptide may be monomeric or polymeric. Further, a polypeptide may comprise a number of different domains each of which has one or more distinct activities.

The term "fusion protein" refers to a polypeptide comprising a polypeptide or fragment coupled to heterologous amino acid sequences. Fusion proteins are useful because they can be constructed to contain two or more desired functional elements from two or more different proteins. A fusion protein comprises at least 10 contiguous amino acids from a polypeptide of interest, more preferably at least 20 or 30 amino acids, even more preferably at least 40, 50 or 60 amino acids, yet more preferably at least 75, 100 or 125 amino acids. Fusions that include the entirety of the proteins of the present invention have particular utility. The heterologous polypeptide included within the fusion protein of the present invention is at least 6 amino acids in length, often at least 8 amino acids in length, and usefully at least 15, 20, and 25 amino acids in length. Fusions also include larger polypeptides, or even entire proteins, such as the green fluorescent protein (GFP) chromophore-containing proteins having particular utility. Fusion

proteins can be produced recombinantly by constructing a nucleic acid sequence which encodes the polypeptide or a fragment thereof in frame with a nucleic acid sequence encoding a different protein or peptide and then expressing the fusion protein. Alternatively, a fusion protein can be produced chemically by crosslinking the polypeptide or a fragment thereof to another protein.

The term "functional nucleic acid" refers to a nucleic acid molecule that, upon introduction into a host cell or expression in a host cell, specifically interferes with expression of a protein. In general, functional nucleic acid molecules have the capacity to reduce expression of a protein by directly interacting with a transcript that encodes the protein. Ribozymes, antisense nucleic acids, and siRNA molecules, including shRNA molecules, short RNAs (typically less than 400 bases in length), and micro-RNAs (miRNAs) constitute exemplary functional nucleic acids.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention pertains. Exemplary methods and materials are described below, although methods and materials similar or equivalent to those described herein can also be used in the practice of the present invention and will be apparent to those of skill in the art. All publications and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including definitions, will control. The materials, methods, and examples are illustrative only and not intended to be limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows an alignment of the *P. pastoris* Ade2p amino acid sequence (SEQ ID NO:61) to the *S. cerevisiae* Ade2p amino acid sequence (SEQ ID NO:62).

Figure 2A shows a map of plasmid pGLY1065.

Figure 2B shows a map of plasmid pGLY2057.

Figure 2C shows a map of plasmid pGLY225.

Figure 2D shows a map of plasmid pGLY1083.

Figure 2E shows a map of plasmid pGLY2092.

Figure 2F shows a map of plasmid pGLY2094.

Figure 3 shows western blots and Coomassie gels of the protein produced in *ade1* auxotrophic yeast strains transformed with integration vectors expressing glucocerebrosidase, a single-chain anti-HER2 antibody, or human CD40 ectodomain. Panel A shows the single-chain anti-HER2 antibody produced in seven clones of YGLY563 *ade1*$^-$ cells transformed with pJ903 encoding a single-chain anti-HER2 antibody operably linked to the GAPDH promoter and *ADE1* ORF operably linked to its native promoter and the single chain anti-HER2 antibody produced in seven clones of YGLY563 *ade1*$^-$ cells transformed with pJ904 encoding single-chain anti-HER2 antibody operably linked to the GAPDH promoter and *ADE1* ORF not operably linked to a

promoter. Panel B shows the glucocerebrosidase (GBA) produced in produced in seven clones of YGLY564 *ade1*- cells transformed with pGly1084 encoding GBA operably linked to the GAPDH promoter and *ADE1* ORF operably linked to its native promoter and the GBA produced in seven clones of YGLY564 *ade1*- cells transformed with pGLY1085 encoding GBA operably linked to the GAPDH promoter and *ADE1* ORF not operably linked to a promoter. Panel C shows Coomassie gels of the human CD40 ectodomain produced in six clones of YGLY563 *ade1*- cells transformed with pGLY1073 encoding human CD40 ectodomain operably linked to the AOX1 promoter and *ADE1* ORF operably linked to its native promoter and the human CD40 ectodomain produced in six clones of YGLY563 *ade1*- cells transformed with pGLY1074 encoding human CD40 ectodomain operably linked to the GAPDH promoter and *ADE1* ORF not operably linked to a promoter. Panel D shows the human CD40 ectodomain produced in six clones of YGLY564 *ade-1* cells transformed with pGLY1073 encoding human CD40 ectodomain operably linked to the AOX1 promoter and *ADE1* ORF operably linked to its native promoter and the human CD40 ectodomain produced in six clones of YGLY564 *ade*- cells transformed with pGLY1074 encoding human CD40 ectodomain operably linked to the AOX1 promoter and *ADE1* ORF not operably linked to a promoter.

Figure 4 shows western blots of the protein produced in *ade2* auxotrophic yeast strains transformed with integration vectors encoding erythropoietin (EPO). Panel A shows the EPO produced in six clones of YGLY1215 *ade2*- cells transformed with pGly2663 encoding EPO operably linked to the AOX1 promoter and *ADE1* ORF operably linked to its native promoter and the EPO produced in six clones of YGLY1215 *ade2*- cells transformed with pGly2664 encoding EPO operably linked to the AOX1 promoter and *ADE2* ORF not operably linked to a promoter. Panel B shows the EPO produced in six clones of YGLY1216 *ade2*- cells transformed with pGly2663 encoding EPO operably linked to the AOX1 promoter and *ADE1* ORF operably linked to its native promoter and the EPO produced in six clones of YGLY1216 *ade2*- cells transformed with pGly2664 encoding EPO operably linked to the AOX1 promoter and *ADE2* ORF not operably linked to a promoter.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides methods and materials for the use of lower eukaryotic cells such as yeast or filamentous fungi as an expression system for expressing recombinant peptides, proteins, or functional nucleic acids. In one aspect, the method provides a method for expressing a recombinant protein comprising obtaining or constructing slower growing *ade2* auxotrophic strains of the lower eukaryote cells and introducing into the cells integration vectors that are capable of integrating into the genome of the *ade2* auxotrophic strain and which comprises a nucleic acid encoding an *ADE2* marker gene or open reading frame (ORF) operably linked to a promoter and a nucleic acid expressing a recombinant protein or functional nucleic

acid of interest, wherein the integration vector integrates into the genome of the *ade2* auxotrophic strain, the *ADE2* renders the auxotrophic strain prototrophic for adenine and the recombinant peptide, protein, or functional nucleic acid is expressed. The recombinant host cells are selected for in medium that lacks the metabolite adenine but can be maintained in medium that lacks the metabolite adenine or in medium that includes the metabolite adenine. In general, those recombinant host cells that might lose the *ADE2* marker (revertants) will grow more slowly and will be lost over time as the recombinant cells are grown. The loss of revertants over time will occur whether the recombinant host cells are grown in medium that includes the metabolite adenine or in medium that either lacks the metabolite adenine.

In developing the above invention, the applicants discovered that when the integration vector for introducing a recombinant protein into a lower eukaryote host cell that is auxotrophic for a particular marker gene includes in the integration vector a nucleic acid encoding the complimentary marker gene or ORF but wherein the marker gene or ORF is operably linked to a weak, attenuated, cryptic, truncated promoter that reduces the native activity of the promoter to level less than the native promoter, or no promoter, the auxotrophy of the host cell can be complimented provided that more than one copy of the integration vector is integrated into the genome of the host cell. Because the recombinant host cell contains more than one copy of the integration vector and each copy of the integration vector is transcriptionally active, the recombinant host cell is capable of producing a sufficient quantity of the marker gene or ORF to render the host cell prototrophic for the auxotrophic marker and thus capable of growing in medium that lacks the metabolite that can compliment the auxotrophy. The weaker the promoter linked to the complimentary marker gene or ORF, the more copies of the integration vector integrated into the genome of the host cell that are needed to render the host cell prototrophic for the auxotrophic marker. Host cells that lose copies of the integration vector integrated into the host genome during cell growth or passage in medium that lack the metabolite that can compliment the auxotrophy are rendered auxotrophic again for the marker gene. These newly auxotrophic host cells are at a selective disadvantage in the culture medium and in general, are lost as the remaining prototrophic host cells continue to grow and replicate. Importantly, because the integration vector contains an expression cassette that expresses one or more recombinant proteins or functional nucleic acids of interest, host cells containing one or more copies of the integration vector will produce more of the recombinant protein than would be produced in host cells that contained only one copy of the integration vector.

Therefore, methods, materials, and systems that are particularly useful for producing recombinant host cells that are capable of producing large quantities of recombinant proteins (including peptides), or functional nucleic acids are provided. Thus, the present invention provides a method in which an auxotrophic strain of a lower eukaryote cell is obtained or constructed and an integration vector is provided that is capable of integrating into the genome of

the auxotrophic strain and which comprises nucleic acids encoding a marker gene or ORF that compliments the auxotrophy and is either operably linked to a weak, cryptic, attenuated, or truncated promoter or no promoter and a recombinant protein. Host cells in which a number of the integration vectors have been integrated into the genome to compliment the auxotrophy of the host cell are selected in medium that lacks the metabolite that compliments the auxotrophy and maintained by propagating the host cells in medium that either lacks the metabolite that compliments the auxotrophy or includes the metabolite that compliments the auxotrophy. In general, those recombinant host cells that might lose the auxotrophic marker (revertants) will grow more slowly and will be lost over time as the recombinant cells are grown. The loss of revertants over time will occur whether the recombinant host cells are grown in medium that includes the metabolite or in medium that either lacks the metabolite. This phenomenon has been observed at least for the auxotrophic markers *ADE*, *URA*, or *LYS* and is currently believed to be due at least in part to poor transport of the metabolite from the medium into the recombinant host cell.

In a general aspect, recombinant host cells are rendered auxotrophic for a particular organic compound by removing or deleting the gene or locus encoding the gene product necessary for producing the organic compound or an intermediate for producing the organic compound or metabolite. The auxotrophic host cells are then transformed with an integration vector that comprises (1) a nucleic acid comprising an open reading frame (ORF) encoding a selectable marker gene or other nucleic acid that complements the auxotrophy; (2) a nucleic acid encoding one or more ORFs encoding a heterologous or recombinant protein or peptide or expressing a functional nucleic acid of interest; and (3) nucleic acid comprising a targeting sequence that directs insertion of the integration vector into a particular target location or locus of the genome of the host cell by homologous recombination.

The targeting sequence in the plasmid can comprise any sequence within the host cell genome such as a host cell gene, a host cell promoter or terminator sequence, or a sequence of unknown function. For integrating into a host cell promoter or termination sequence, the promoter and/or the terminator sequence in the expression cassette used for regulating expression of the one or more ORFs encoding a heterologous or recombinant protein or peptide or expressing a functional nucleic acid of interest can also function as the targeting sequence for targeting the integration vector to the target location. For example, the nucleic acid of (1) or (2) above can be operably linked to a host cell promoter for a host cell gene adjacent to the promoter to which the integration vector is targeted. Integration of the vector into the promoter via roll-in single crossover homologous recombination results in a duplication of the promoter sequences. Thus, after integration, the expression cassette is still operably linked to the promoter comprising the targeting sequence and the host cell gene adjacent to the promoter that was the targeting sequence is still operable. Thus, in the recombinant host cell, expression of a heterologous

protein, peptide, or functional nucleic is effected without disrupting expression of the host cell gene adjacent to the targeting site.

To integrate the integration vector into the genome of a host cell by roll-in single crossover homologous recombination, the vector is linearized by cleaving the integration vector at a site within the targeting sequence so as to produce a linear nucleic acid molecule in which the targeting sequences are at the ends of the molecule. Single cross-over events lead to a duplication of the genomic locus and generates direct repeats. While these direct repeats display a high recombination rate and can result in the loss of the marker and expression cassette during propagation of the recombinant host cell, the method disclosed herein where the marker is operably linked to a weak, cryptic, attenuated, or truncated promoter or no promoter ensures that only host cells that maintain the copy number of integration vectors sufficient to render the host cell prototrophic for the marker during propagation. In a preferred aspect, the integration vector is linearized at a restriction enzyme site that occurs only once in the targeting sequence. The vector then integrates into the target site by roll-in single crossover homologous recombination. Roll-in single crossover homologous recombination enables integration of the integration vector into the genome without disrupting expression of the gene at the target site. Roll-in single crossover homologous recombination has been described in Nett *et al.*, Yeast 22: 295-304 (2005).

An important feature of the integration vector is that the ORF encoding the selectable marker gene or other nucleic acid is not operably linked to its endogenous full-strength promoter or to a heterologous full-strength promoter but to a weak promoter, an attenuated endogenous or heterologous promoter, a cryptic promoter, or a truncated endogenous or heterologous promoter in which the truncation renders the promoter with a transcription activity that is less than the native promoter. In particular embodiments, the attenuated or truncated promoter has a transcription activity that is no more than 50% of the activity of the full-strength promoter. In further embodiments, the attenuated or truncated promoter has a transcription activity that is no more than 10% of the activity of the full-strength promoter. In further embodiments, the attenuated or truncated promoter has a transcription activity that is no more than 1% of the activity of the full-strength promoter. While not wishing to be bound by any theory, it is believed that in general, the nucleic acid sequence adjacent to the ORF encoding the selectable marker gene will contain a so-called cryptic promoter that enables a low level of expression of the selectable marker gene. A cryptic promoter will allow a sufficient amount of spurious transcription initiation adjacent to the ORF sufficient to produce a low amount of the selectable marker. Since expression of the selectable marker gene is below the level needed to fully complement the auxotrophy, multiple integrations of the integration vector into the target sequence in the host cell is necessary for full complementation of the auxotrophy. Because multiple copies of the integration vector must be integrated into the genome of the host cell to

complement the auxotrophy, there are multiple copies of the ORF encoding the protein or peptide or functional nucleic acid of interest, all of which are expressed. Thus, the host cell is capable of encoding more of the protein or peptide or functional nucleic acid of interest than a host cell that includes only one copy of the integration vector integrated into its genome.

In practicing the method, it is preferable that there not be any of the selectable marker gene sequence in the auxotrophic host cell that could compete with the targeting sequence for integration. Thus, in further embodiments, either the entire gene encoding the marker (including upstream and downstream regions) is deleted or removed from the genome or at least the open reading frame encoding the marker gene is deleted or removed from the genome. Stable recombinant host cells in which the integration vector is integrated into the target locus are selected by cultivating the transformed host cells in a culture medium that lacks the particular organic compound (metabolite). Because the selectable marker gene or ORF is not operably linked to an endogenous or heterologous full-strength promoter but is operably linked to a weak, attenuated, cryptic promoter, or truncated promoter (or in particular aspects, no promoter), the recombinant, transformed host cells containing only one copy of the integration vector inserted into the target locus are not rendered prototrophic for the organic compound or metabolite. For the transformed host cells to be rendered prototrophic for the organic compound or metabolite, multiple copies of the integration vector must be integrated into the target locus for the host cell. In addition, because multiple copies of the integration vector must be integrated into the target locus, significant quantities of the protein or peptide encoded by the gene or sequence of interest are also produced.

Lower eukaryotes such as yeast are preferred for expression of proteins because they can be economically cultured, give high yields, and when appropriately modified are capable of suitable glycosylation. Yeast particularly offers established genetics allowing for rapid transformations, tested protein localization strategies and facile gene knock-out techniques. Suitable vectors have expression control sequences, such as promoters, including 3-phosphoglycerate kinase or other glycolytic enzymes, and an origin of replication, termination sequences and the like as desired.

Various yeasts, such as *K. lactis*, *Pichia pastoris*, *Pichia methanolica*, and *Hansenula polymorpha* are generally preferred for cell culture because they are able to grow to high cell densities and secrete large quantities of recombinant protein. Likewise, filamentous fungi, such as *Aspergillus niger*, *Fusarium* sp, *Neurospora crassa* and others can be used to produce glycoproteins of the invention at an industrial scale. Other cells useful as host cells in the present invention include prokaryotic cells, such as *E. coli*, and eukaryotic host cells in cell culture, including lower eukaryotic cells, plant cells, and mammalian cells, such as Chinese Hamster Ovary (CHO).

Lower eukaryotes, particularly yeast, can be genetically modified so that they express glycoproteins in which the glycosylation pattern is human-like or humanized. Such can be achieved by eliminating selected endogenous glycosylation enzymes and/or supplying exogenous enzymes as described by Gerngross *et al.*, US 2004/0018590, the disclosure of which is hereby incorporated herein by reference. For example, a host cell can be selected or engineered to be depleted in 1,6-mannosyl transferase activities, which would otherwise add mannose residues onto the N-glycan on a glycoprotein.

U.S. Published application No. 20070072262 discloses *ARG1*, *ARG2*, *ARG3*, *HIS1*, *HIS2*, *HIS5*, and *HIS6* genes and methods of using the genes for stable genetic integration into yeast and U.S. published application No. 20040229306 discloses the *Pichia pastoris URA5* gene and its use for genetic stable integration in yeast. Selectable marker genes that are particularly useful in practicing the methods and systems herein include, but are not limited to, *URA3*, *URA5*, *HIS3*, *LEU2*, *TRP1*, *LYS2*, *ADE1*, and *ADE2* loci. Useful are auxotrophic host cells and selectable marker genes in which the particular auxotrophy renders the cell less able to compete with or grow more slowly than the corresponding prototroph. Thus, particularly useful selectable marker genes are the selectable marker genes *ADE1*, *ADE2*. *LYS2*, *URA3*, and *URA5*.

The *ADE1* gene has been cloned from various species of yeast and fungi, including *Saccharomyces cerevisiae* (Myasnikov *et al.*, Gene,109:143-147 (1991); *Kluyveromyces lactis* (Zonneveld and van der Zanden, *et al.*, Yeast, 11:823-827 (1995), *Pichia pastoris* (Cereghino et al., Gene 263: 159-169 (2001)). *ADE1* gene encodes N-succinyl-5-aminoimidazole-4-carboxamide ribotide (SAICAR) synthetase, which is required for *de novo* purine nucleotide biosynthesis. Red pigment accumulates in mutant cells deprived of adenine.

The *ADE2* gene has been cloned from various species of yeast and fungi, including *Saccharomyces cerevisiae* (Jones and Fink, "Regulation of amino acid and nucleotide biosynthesis in yeast" pp.181-299 in The Molecular Biology of the Yeast *Saccharomyces*: Metabolism and Gene Expression, Strathern *et al.* (Eds.) Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press); *Candida albicans* (Kurtz *et al.*, Mol. Cell. Biol., 6:142-149 (1986)); *Aspergillus oryzae*, (Jin *et al.*, Biosci Biotechnol Biochem. 68:656-62(2004), and *Pichia pastoris* (herein). The *ADE2* gene encodes phosphoribosyl-aminoimidazole carboxylase, which catalyzes a step in the *de novo* purine nucleotide biosynthetic pathway. Red pigment accumulates in mutant cells deprived of adenine.

In further embodiments, a cell line can be transformed with a vector that will displace or knock out the function of one or more auxotrophic genes, for example, knocking out or displacing the *ADE1* or *ADE2* genes to render the cells auxotrophic for adenine, for example, cells with an Ade1$^-$ or Ade2$^-$ phenotype. Thus, the present invention includes methods for genetically engineering cell lines such that they contain auxotrophic mutations which impede the growth of the cells. These cell lines containing auxotrophic mutations can then serve as the host

cells for selection as taught herein, in which the host cells are transformed with integration vectors encoding one or more desired glycoproteins and genes which complement the auxotrophic mutations such that the cells expressing the desired protein(s) will also carry the gene(s) which complement the auxotrophic mutations and provide a phenotype which is readily identifiable and selectable.

The method disclosed herein using the *ADE1* or *ADE2* markers and *ade1* or *ade2* auxotrophic host cells is particularly useful for making recombinant *Pichia pastoris* host cells because it addresses the scarcity of suitable markers for *Pichia pastoris* that can be used for multicopy selection. To date, primarily dominant markers, like Zeocin, are used for this purpose. However, dominant markers possess significant disadvantages. For example, during fermentation, it is frequently not feasible to add the antibiotic, in order to make sure all integrated copies of the heterologous gene stay integrated. However, if the constructs disclosed herein are evicted, the cells will become unable to produce adenine and will exhibit the selectable phenotype of slower growth and pinkish color. Therefore, heterologous constructs which are evicted during fermentation are easily selected against by virtue of this slower growth.

The advantages of the disclosed system are the ability to select transformants with multiple copies of the marker and desired gene for expression in the host cell integrated in the genome by color, and the stable retention of the transformants with one or more copies integrated into the genome because of the slow growth of *ade1* or *ade2* cells. In one aspect, the system utilizes the differential phenotypes of pink/white color selection of *ade/ADE* strains coupled with the slow growth of strains having an Ade1$^-$ or Ade2$^-$ phenotype and the integration of a plasmid comprising a copy of the *ADE1* or *ADE2* open reading frame (ORF) operably linked to a promoter and a desired gene for expression in the host cell in order to in order to provide a system that is an improvement over the current system for making recombinant host cells that relies upon dominant Zeocin selection. In another aspect, the system utilizes the differential phenotypes of pink/white color selection of *ade/ADE* strains coupled with the slow growth of strains having an Ade1$^-$ or Ade2$^-$ phenotype and the forced multiple integration of a plasmid comprising a copy of the *ADE1* or *ADE2* ORF operably linked to a weak, attenuated, or cryptic promoter and a desired gene for expression in the host cell in order to provide a system that is an improvement over the current system for making recombinant host cells that relies upon dominant Zeocin selection. Thus, the methods and materials are useful for stable high level expression of heterologous proteins.

Thus, in particular embodiments, the method and system comprises recombinant host cells, non-human eukaryotic host cells, in particular lower eukaryotic host cells such as yeast and filamentous fungal host cells, with improved productivity for the production of recombinant proteins, including glycoproteins when using host cells capable of making glycoproteins having hybrid or complex *N*-glycans. The recombinant host cells are modified by the reduction or

elimination of the function of at least one endogenous gene encoding an auxotrophic marker gene, such as *ADE1* or *ADE2*. Cells with a mutation leading to adenine deficiency grow quite slowly, and accumulate a reddish pigment, which results in production of pink colonies (that is, cells with an Ade1$^-$ or Ade2$^-$ phenotype). When these cells with an Ade1$^-$ or Ade2$^-$ phenotype are transformed with a plasmid comprising an *ADE1* or *ADE2* ORF, respectively, operably linked to a promoter for expressing the *ADE1* or *ADE2* ORF, the *Ade1* or *Ade2* mutation is complemented and the cell is rendered prototrophic for adenine, that is, the cells are rendered to have an Ade1$^+$ or Ade2$^+$ phenotype. These complemented recombinant cells exhibit a white color and large colony size, which facilitates identification and selection of the recombinant cells. Alternatively, when these cells with an Ade1$^-$ or Ade2$^-$ phenotype are transformed with a plasmid comprising the *ADE1* or *ADE2* ORF, respectively, not operably linked to a promoter for expressing the *ADE1* or *ADE2* ORF, the *Ade1* or *Ade2* mutation is complemented only in recombinant cells that contain more than one copy of the *ADE1* or *ADE2* gene integrated into the genome.

In other embodiments, the integration vectors are provided for the selectable expression of heterologous genes in an expression system employing host cells, which exhibit an Ade1$^-$ or Ade2$^-$ phenotype, such as the host cells described above. The integration vectors comprise a nucleic acid comprising a promoter sequence and a transcription termination sequence separated by and operably linked to a cloning site. A nucleic acid sequence encoding one or more desired heterologous proteins or peptides or functional nucleic acid of interest is inserted into the cloning site using standard ligation techniques in the proper orientation to be expressed via the promoter. The integration vector preferably comprises at least one promoter, which is functional in the host cell, followed by at least one restriction site, preferably a multiple cloning site, followed by a transcription terminator sequence which is functional in the host cell. Using appropriate known techniques, a nucleotide fragment encoding the desired protein or polypeptide can be ligated into the restriction sites of cloning site of the integration vector. The integration vectors also comprises at least one copy of a selectable marker ORF selected from the group consisting of *ADE1* and *ADE2*, which may be under the control of appropriate transcription termination terminator sequences, which are functional in the host cell. In some embodiments, the ORF is operably linked to a full-strength homologous or heterologous promoter and in other embodiments, the ORF is operably linked to a cryptic promoter, weak promoter, attenuated promoter, or a truncated homologous or heterologous promoter with reduced transcriptional activity compared to the full-strength promoter.

In a further embodiment, provided are methods, materials, and systems for the construction of recombinant host cells for expressing heterologous or recombinant proteins and peptides wherein the *ADE1* gene has been removed or deleted to render the host cells auxotrophic for adenine, for example, render the cells *ade1*. The *ade1* host cells are then

transformed with an integration vector comprising (1) a nucleic acid encoding the Ade1p or Ade1p activity operably linked to a weak promoter, an attenuated endogenous or heterologous promoter, a cryptic promoter, a truncated endogenous or heterologous promoter, or no promoter; (2) one or more nucleic acids encoding a gene or functional nucleic acid of interest to produce a heterologous or recombinant protein or peptide or functional nucleic acid ectopically; and (3) a targeting nucleic acid sequence that directs insertion of the integration vector into a particular target location or locus of the genome of the host cell by homologous recombination. Stable recombinant host cells in which the integration vector is integrated into the target locus are selected by cultivating the transformed host cells in a culture medium that lacks adenine. Because the nucleic acid encoding the Ade1p activity is operably linked to a weak, attenuated, cryptic promoter, or truncated promoter, the recombinant, transformed host cells containing only one copy of the integration vector inserted into the target locus are not rendered prototrophic for adenine. For the transformed host cells to be rendered prototrophic, multiple copies of the integration vector must be integrated into the target locus for the host cell. In addition, because multiple copies of the integration vector must be integrated into the target locus, significant quantities of the protein or peptide encoded by the gene or sequence of interest are produced.

In another embodiment, provided are methods, materials, and systems for the construction of recombinant host cells for expressing heterologous or recombinant proteins and peptides wherein the *ADE2* gene has been removed or deleted to render the host cells auxotrophic for adenine. The *ade2* host cells are then transformed with an integration vector comprising (1) a nucleic acid encoding the Ade2p or Ade2p activity operably linked to a weak promoter, an attenuated endogenous or heterologous promoter, a cryptic promoter, a truncated endogenous or heterologous promoter, or no promoter; (2) one or more nucleic acids encoding a gene or functional nucleic acid of interest to produce a heterologous or recombinant protein or peptide or functional nucleic acid ectopically; and (3) a targeting nucleic acid sequence that directs insertion of the integration vector into a particular target location or locus of the genome of the host cell by homologous recombination. Stable recombinant host cells in which the integration vector is integrated into the target locus are selected by cultivating the transformed host cells in a culture medium that lacks adenine. Because the nucleic acid encoding the Ade2p activity is operably linked to a weak, attenuated, or cryptic promoter, the recombinant, transformed host cells containing only one copy of the integration vector inserted into the target locus are not rendered prototrophic for adenine. For the transformed host cells to be rendered prototrophic for adenine, more than one copy of the integration vector must be integrated into the target locus for the host cell. In addition, because multiple copies of the integration vector must be integrated into the target locus, significant quantities of the protein or peptide encoded by the gene or sequence of interest are produced.

In both of the above embodiments, *ade1* or *ade2* auxotrophs grow more slowly than prototrophs (e.g., *ADE1* or *ADE2*, respectively) or cells rendered prototrophic by integration of multiple copies of the integration vector into the genome. In culture, revertants and transformed cells that lose multiple copies of the integration vector inserted into the target locus will grow more slowly and be out-competed by those cells that maintain the multiple copies of the integration vector integrated into the target locus. In addition, in particular organisms such as yeast, *ade1* or *ade2* auxotrophs are red or pink in color whereas prototrophs or cells rendered prototrophic by integration of more than one copy of the integration vector into the genome are white. Thus, selection of recombinant cells containing multiple copies of the integration vector inserted into the target sequence can be based upon selecting white colonies.

The methods and systems herein can be practiced in any organism in which auxotrophic mutations can be made such as the *ade1* or *ade2* and complementation thereof results in the selectable phenotype described herein. The methods involve transforming host cells which exhibit *ade1* or ade2 minus phenotype with integration vectors which include nucleotide sequences encoding the complementary Ade1p or Ade2p proteins, such that when the host cells are transformed with the integration vector encoding a desired secreted glycoprotein, the complementation of the Ade1$^-$ and/or Ade2$^-$ phenotype leads to stable integration of the genes encoding the desired glycoprotein, and contributes to improved quality of the transformed recombinant host cells, particularly, increased yield of the desired recombinant glycoprotein.

In further embodiments, the host cells of the present invention carry other genetic manipulations in their genome, such that the host cells, and/or the proteins or peptides produced therefrom, exhibit desired properties. For example, the host cell may be manipulated in accordance with the methods described in for example, U.S. Patent No. 7,029,872, U.S. Published Application No. 2004/0018590, and Hamilton *et al.*, *Science*, 313: 1441-1443 (2006); such that the host cells are capable of producing recombinant glycoproteins with highly homogeneous levels of one or more desired glycoforms. In other embodiments, the host cells may be modified by deleting one or more endogenous genes encoding molecular chaperone proteins and/or transforming the host cell with one or more heterologous genes encoding molecular chaperone genes originating from the species of the heterologous protein or polypeptide to be produced. For example, a host cell of the species *Pichia* may be modified by elimination of the endogenous protein PDI and/or BiP, and transformed with one or ore plasmids encoding mammalian PDI, BiP and/or GRP94 genes. *See*, Choi *et al. supra*, the disclosure of which is hereby incorporated herein by reference.

In further still embodiments, methods are provided for increasing the productivity of recombinant human or mammalian glycoproteins in a non-human eukaryotic host cell, lower eukaryotic host cell, or a yeast or filamentous fungal host cell. The methods comprise the step of transforming a host cell, which is *ade1* or *ade2* and capable of producing glycoproteins having

hybrid or complex N-glycans, with a vector comprising a nucleic acid encoding *ADE1* or *ADE2* ORF and a nucleic acid encoding a glycoprotein of interest.

The following examples are intended to promote a further understanding of the present invention.

EXAMPLE 1

Cloning of *Pichia pastoris ADE1* and *ADE2* genes was performed as follows.

The cloning of the *P. pastoris ADE1* gene has been published before (Cereghino *et al.*, *supra*). Additional 5'- and 3'- sequence was obtained using a partial *P. pastoris* genomic sequence obtained from Integrated Genomics, Chicago, IL. The nucleotide sequence of the *P. pastoris ADE1* open reading frame (ORF), including promoter and transcription termination sequences, is shown in SEQ ID NO: 56. The amino acid sequence of the *P. pastoris ADE1* is shown in SEQ ID NO:57. Querying the same genomic sequence with the *S. cerevisiae ADE2* ORF, the *P. pastoris ADE2* homologue (563 amino acids with 69% identity) was identified using the program BLAST (Altschul *et al.*, J. Mol. Biol. 215: 403-410 (1990)). The nucleotide sequence encoding the *P. pastoris ADE2* ORF, including promoter and transcription termination sequences, is shown in SEQ ID NO:60. The *ADE2* ORF is encoded by nucleotides 127 to 1,815 of the nucleotide sequence shown in SEQ ID NO:60 and has the amino acid sequence shown in SEQ ID NO:61. Alignment of the *P. pastoris ADE2* amino acid sequence (SEQ ID NO:61) to the *S. cerevisiae ADE2* amino acid sequence (SEQ ID NO:62) is shown in Figure 1.

EXAMPLE 2

Construction of *ADE1* and *ADE2* Knock-out vectors and strains was as follows.

In the first step of plasmid construction, we created a universal knock-out plasmid containing DNA regions of: (a) the *ARG3* gene of *P. pastoris* (Nett *et al.* 2005, *supra*) as space holders for the 5' and 3' regions of the gene to be knocked out; (b) the *P. pastoris URA5*-blaster(Nett and Gerngross, Yeast 20: 1279-1290 (2003) as auxotrophic marker; and (c) an expression cassette with a multiple cloning site for insertion of a foreign gene.

To create a *URA5*-blaster cassette compatible with the architecture of the universal knock-out plasmid the *Sac*I-*Pvu*II fragment of *lacZ* was cloned into the *Sac*I-*Sma*I sites of pUC19. The resulting plasmid was digested with *Hinc*II and the *Sac*I-*Pvu*II fragment of *lacZ* that had been blunt-ended using T4DNA polymerase was inserted into this plasmid in a head to tail orientation to yield pGLY8. A 1.0 kb DNA fragment of the *P. pastoris URA5* gene was amplified using primers Ura5comp5 (SEQ ID NO:1) and Ura5comp3 (SEQ ID NO: 2) and yeast strain NRRL Y-11430 genomic DNA as template and cloned into the *Bam*HI-*Xba*I sites of pGLY8 to generate pGLY10. In order to remove the internal *Sac*I and *Xho*I sites three overlapping fragments of *URA5* were amplified using pGLY10 as template and primer pairs

URA5MUT1 (SEQ ID NO:3) and URA5MUT2 (SEQ ID NO:4), URA5MUT3 (SEQ ID NO:5,) and URA5MUT4 (SEQ ID NO:6), and URA5MUT5 (SEQ ID NO:7) and URA5MUT6 (SEQ ID NO:8) respectively. The resulting PCR products were gel purified, mixed and served as template in a fusion PCR using URA5MUT1 (SEQ ID NO:3) and URA5MUT6 (SEQ ID NO:8) as primers. The resulting PCR product was then cloned into vector pCR2.1 TOPO®, removed again using *Cla*I and *Bss*HII and cloned into pGLY10 that also had been digested with *Cla*I and *Bss*HII to yield pGLY12. To remove the *Sac*I and *Bam*HI sites, pGLY12 was first cut with *Sac*I, blunt-ended using T4DNA polymerase and religated creating pGLY13a and then cut with *Bam*HI, blunt-ended and religated to yield pGLY13b. In both cases, the *lacZ-URA5* cassette can be released by digestion with *Eco*RI and *Sph*I.

A 1.1 kb DNA fragment of the ARG3-5' region was amplified by PCR using primers ARG355DIS (SEQ ID NO:9) and ARG353-2 (SEQ ID NO:10) with *P. pastoris* genomic DNA as a template and cloned into the *Sac*I–*Sal*I sites of pUC19. The resulting plasmid was cut with *Bam*HI and *Sal*I and a 0.7 kb DNA fragment of the *ARG3*-3' region that had been amplified using primers ARG335-2 (SEQ ID NO:11) and ARG333 (SEQ ID NO:12) was cloned into the open sites creating pGLY21. The plasmid was cut with *Bam*HI blunt-ended with T4DNA polymerase and the *Eco*RI and *Sph*I cut and blunted *lacZ*-URA5 cassette from pGLY 13a or pGLY13b were inserted resulting in plasmids pGLY22b and pGLY23 respectively. Plasmid pGLY22b constitutes the universal knock-out plasmid without additional expression cassette, whereas pGLY23 was further modified to also contain a cassette for the additional expression of a heterologous gene.

To create an expression cassette with *Not*I and *Pac*I as cloning sites, a 0.5 kb DNA fragment containing the GAPDH promoter of *P. pastoris* was amplified using primers GAP5CLEAN (SEQ ID NO:13) and GAP3CLEAN (SEQ ID NO:14) and *P. pastoris* genomic DNA as template and cloned into the *Bam*HI – *Sph*I sites of pUC19. The resulting plasmid was cut with *Spe*I and *Sph*I and a 0.3 kb fragment containing the *S. cerevisiae* CYC1transcriptional terminator region that had been amplified using primers CYC5CLEAN (SEQ ID NO:15) and CYC3CLEAN (SEQ ID NO:16) and *S. cerevisiae* genomic DNA as template and had been cut with *Nhe*I and *Sph*I was cloned into the open sites creating pGLY17. The expression cassette was released by *Bam*HI digestion and cloned into pGLY23 to yield pGLY24.

The *ADE1* knock-out plasmid was constructed from pGLY22b in the following way. A 1.8 kb fragment of the *ADE1*-5' region that had been amplified using primers ADE155L (SEQ ID NO:17) and ADE153L (SEQ ID NO:18) was cut with *Sac*I and *Pme*I and cloned into pGLY22b to yield pGLY1064. Then a 1.5 kb fragment of the *ADE1*-3' region that had been amplified using primers ADE1KO35 (SEQ ID NO:19) and ADE133L (SEQ ID NO:20) was cut with *Swa*I and *Sph*I and cloned into pGLY1064 creating the *ADE1* knock-out plasmid pGLY1065. (Figure 1A)

The *ADE2* knock-out plasmid was constructed from pGLY24 in the following way. The *P. pastoris* ALG3 transcriptional terminator was PCR amplified using primers RCD534 (SEQ ID NO:21) and RCD535 (SEQ ID NO:22) and *P. pastoris* genomic DNA as template, cut with *Eco*RV and *Afl*II and cloned into the *Pme*I–*Afl*II sites of pGLY24 to create pGLY566. This modification is irrelevant for the following ADE2 knock out plasmid, but served to construct a plasmid used for a different project. A 1.7 kb fragment of the *ADE2*-3' region that had been amplified using primers ADE235 (SEQ ID NO:25) and ADE233 (SEQ ID NO:26) was cut with *Swa*I and *Sal*I and cloned into pGLY566 to yield pGLY1079. Then a 1.0 kb fragment of the ADE2-5' region that had been amplified using primers ADE255KO (SEQ ID NO:23) and ADE253KO (SEQ ID NO:24) was cut with *Sac*I and *Fse*I and cloned into pGLY1079 to yield the *ADE2* knock-out plasmid pGLY2057. (Figure 1B)

ADE1 and *ADE2* knock-out strains were constructed the following way. The strain YGLY24-3 [*ura5*Δ::*MET16*, *och1*Δ::*lacZ*, *bmt2*Δ::*lacZ*/KlMNN2-2, *mnn4*L1Δ::*lacZ*/MmSLC35A3, *pno1*Δ*mnn4*Δ::*lacZ*, *met16*Δ::*lacZ*], that had been constructed using methods described earlier (Nett and Gerngross, Yeast 20: 1279-1290 (2003); Choi *et al.*, Proc. Natl. Acad. Sci. 100: 5022-5027 (2003); Hamilton *et al.*, Science 301: 1244-1246 (2003) was transformed with pGLY1065 and two pink transformants were designated YGLY563 and YGLY564. Their Ade1 phenotype was confirmed by their inability to grow on media lacking Adenine. These strains are capable of producing glycoproteins having predominantly $Man_5GlcNAc_2$ N-glycans.

Strains YGLY227 and YGLY228 (direct descendants of YGLY24-3 that had been transformed with a *URA5* marked *Trichoderma reesei* 1,2 mannosidase expressing plasmid and counterselected on 5-FOA in an unrelated experiment) were transformed with pGLY2057 and for each strain one pink transformant was isolated generating strains YGLY1215 and YGLY1216 respectively. Their ade2 phenotype was also confirmed by their inability to grow on media lacking Adenine (results not shown). As expected (Cereghino *et al.*, supra), both the *ade1* and *ade2* strains exhibited a slow growth phenotype even on media supplemented with Adenine. These strains are capable of producing glycoproteins having predominantly $Man_5GlcNAc_2$ N-glycans.

EXAMPLE 3

Construction of *ADE1* and *ADE2* Marked Integration Vectors was as follows.

A vector with a more suitable multiple cloning site containing sites for *Bgl*II, *Eco*RI, *Kpn*I, *Swa*I, *Bam*HI, *Not*I, *Pac*I, *Asc*I and *Sfi*I was constructed by cutting pUC19 with *Eco*RI and *Hind*III and inserting annealed oligos EXMCS1 (SEQ ID NO:27) and EXMCS2 (SEQ ID NO:28), creating pGLY192. A 0.3 kb DNA fragment containing the *S. cerevisiae* CYC1 transcriptional terminator region that had been amplified using primers CYCTT5 (SEQ ID

NO:29) and CYCTT3 (SEQ ID NO:30) and *S. cerevisiae* genomic DNA as template was cut with *Bam*HI and *Swa*I and cloned into pGLY192 yielding pGLY213. Then the *P. pastoris* AOX1 promoter was amplified from genomic DNA using oligos AOX1P-5 (SEQ ID NO:31) and AOX1P-3 (SEQ ID NO:32), cut with *Bgl*II and *Eco*RI and ligated into pGLY213 to create pGLY214. Since both *ade* knock-out plasmids had been designed to remove the complete ORF, a region for integration of the plasmid as an alternative to the promoter region was added. To this end a 1.8 kb fragment containing the *P. pastoris* TRP2 gene was amplified from genomic DNA using oligos TRP2-5 (SEQ ID NO:33) and TRP2-3revised (SEQ ID NO:34), cut with *Sfi*I and cloned into pGLY214 to yield pGLY215. This plasmid contains an *Eco*RI, *Kpn*I, *Swa*I site for addition of the gene of interest and a *Bam*HI, *Not*I, *Pac*I, *Asc*I, site for addition of the truncated ADE markers.

ADE1 marker cassettes containing the *ADE1* ORF operably linked to its native promoter or to various truncations of the native promoter were constructed as follows. The *ADE1* markers with full-length or truncated promoters were PCR amplified using oligo *ADE1*-3 (SEQ ID NO:35) as 3'-oligo and ADE1-5C-BAM (SEQ ID NO:36), ADE1-5-100 (SEQ ID NO:37), ADE1-5-186 (SEQ ID NO:38), ADE1-5-295 (SEQ ID NO:39), ADE1-5-325 (SEQ ID NO:40), and ADE1-5ORF (SEQ ID NO:41) as 5'-oligos, yielding fragments with 370, 276, 191, 82, 50, and 0 nucleotides of promoter region respectively. The first five fragments were cut with *Not*I and *Asc*I and the last fragment was cut with *Pac*I and *Asc*I and all fragments were cloned into pGLY215 to generate the *ADE1* marked integration plasmids pGLY220 to pGLY225 respectively (*See* Figure 1C for a plasmid map of pGLY225). To create plasmids for constitutive protein expression, the AOX1 promoter in pGLY220 and pGLY225 was removed and replaced by a GAPDH promoter that had been amplified using primers GAPDHP-5 (SEQ ID NO:42) and GAPDHP-3 (SEQ ID NO:43), yielding plasmids pGLY1082 and pGLY1083 respectively (*See* Figure 1D for a plasmid map of pGLY1083).

ADE2 marker cassettes containing the *ADE2* ORF operably linked to its native promoter or to various truncations of the native promoter were constructed as follows. An unmarked integration plasmid equivalent to pGLY215 for the *ADE2* marker cassettes was constructed essentially the same way as above. The main difference between this plasmid, called pGFI4, and pGLY215 was that it contained the GAPDH promoter that had been amplified as above and the multiple cloning site for addition of the gene of interest had been expanded using oligos 5oligoERSSKFS (SEQ ID NO:44) and 3oligoSFSSRF (SEQ ID NO:45) to contain the restriction sites *Eco*RI, *Rsr*II, *Sph*I, *Stu*I, *Kpn*I, *Fse*I and *Swa*I. The truncated *ADE2* markers were amplified using oligo ADE23 (SEQ ID NO:46) as 3'-oligo and oligos ADE25NotI-1 (SEQ ID NO:47), ADE25NotI-2 (SEQ ID NO:48), ADE25NotI-3 (SEQ ID NO:49), ADE25NotI-4 (SEQ ID NO:50), and ADE25'PacInew (SEQ ID NO:51) as 5'-oligos, yielding fragments with 126, 82, 51, 13, and 0 nucleotides of promoter region respectively. The first four DNA fragments were cut

with *Not*I and *Asc*I and the last DNA fragment was cut with *Pac*I and *Asc*I and all fragments were cloned into pGFI4 to generate the ADE2 marked integration plasmids pGLY2077 to pGLY2081 respectively. In addition to the *Eco*RI site in the multiple cloning site these plasmids also contain an *Eco*RI site in the *ADE2* ORF.

In pGLY2077 and pGLY2081 the *Eco*RI site in the ORF was therefore removed by site directed mutagenesis creating pGLY2091 and pGLY2092 respectively. (*See* Figure 1E for a plasmid map of pGLY2092). To create plasmids for inducible protein expression, the GAPDH promoter in these two last constructs was removed and replaced by an AOX1 promoter that had been amplified using primers AOX1P-5 (SEQ ID NO:52) and AOX1P-3 (SEQ ID NO:53) as above, yielding plasmids pGLY2093 and pGLY2094 respectively (*See* Figure 1F for a plasmid map of pGLY2094).

In order to test the effect of the truncated markers on protein expression, several vectors expressing various proteins of interest were constructed.

Human glucocerebrosidase (GBA) was fused to the human serum albumin (HSA) signal sequence and cloned into the *Eco*RI / *Kpn*I sites of pGLY1082 and pGLY1083 to create GAPDH driven and *ADE1* marked integration vectors pGLY1084 and pGLY1085 respectively. A single-chain version of the anti-HER2 monoclonal antibody Herceptin® (U.S. Patent Application No. 20060252096) fused to the *S. cerevisiae* alpha mating factor pre-sequence and cloned into the *Eco*RI/*Swa*I sites of pGLY1082 and pGLY1083 to yield GAPDH driven and *ADE1* marked integration vectors pJN904 and pJN905 respectively. The human CD40 ectodomain (amino acids 20 to 192, a gift of R.J. Noelle; Lu, L. *et al.*, J. Biol. Chem. 278: 45414-45418 (2003) was fused to the *S. cerevisiae* alpha mating factor prepro-sequence and cloned into the *Eco*RI/*Kpn*I sites of pGLY 220 and pGLY225 to create AOX1 driven and *ADE1* marked integration vectors pGLY1073 and pGLY1074 respectively. Human EPO was fused to the *S. cerevisiae* alpha mating factor pre-sequence and cloned into the *Eco*RI/*Kpn*I sites of pGLY2093 and pGLY2094 to yield AOX1 driven and *ADE2* marked integration vectors pGLY2663 and pGLY2664 respectively.

EXAMPLE 4

Effect of *ADE* marker promoter length on copy number and protein expression was determined.

To test the effect of the various *ADE* marker promoter truncations on copy number and protein expression, we considered the following assumptions: 1) Since all integration plasmids are integrated into the same genomic locus (*TRP2*), it is not expected that a reduction of marker promoter strength will lead to an increased copy number of plasmid integrants per se; 2) If the marker promoter strength drops below a certain threshold it is expected that clones integrating only a single copy of the plasmid will grow at a slower rate than clones integrating multiple

copies of the plasmid due to the slow growth phenotype of the *ade* minus phenotype. This should also be concomitant with the appearance of pink color in the low copy clones; 3) A gradual drop in marker promoter strength should therefore lead to decreasing numbers of fast growing white clones and on a relative basis increasing numbers of slow growing pink clones; and, 4) In order to eliminate any effect that the expression of a heterologous protein might exert on the growth of transformants, the empty expression plasmids should be tested initially.

Auxotrophic *ade1* strains YGLY563 and YGLY564 were therefore transformed with equal amounts (0.2 μg) of integration plasmids pGLY220 to pGLY225 that had been linearized in the *TRP2* integration region using *Bsp*EI and spread on minimal media plates. After five days of incubation at 23°C the transformation plates were assessed for colony number. Surprisingly, integration plasmids pGLY220 to pGLY224 all yielded approximately the same number of colonies. Both yeast strains that had been transformed with pGLY225 however yielded less than 10% of the number of white transformants with a significant number of barely visible, pink transformants in the background (*See* Table 1). It had been anticipated that the plasmids with the promoter truncations would give rise to smaller number of colonies as the length of the promoter decreased, with the shortest one, only containing the ORF, yielding none. The results however suggest that the *CYC1* terminator region and the multiple cloning site in front of the marker contain a cryptic promoter activity that allows for a background level of transcription, thereby resulting in levels of *ADE1* gene product that in some cases are enough to complement the ade1 auxotrophic phenotype.

When *ade2* auxotrophic strains YGLY1215 and YGLY1216 were transformed with integration plasmids pGLY2077 to pGLY2081, a somewhat similar picture was obtained. In the case of the truncated *ADE2* markers however, a gradual reduction in colony number concomitant with a shorter promoter was observed. As was the case for *ADE1*, the vector only containing the *ADE2* ORF with no native promoter sequence at all yielded less than 10% of the number of white transformants than the construct with the full promoter sequence (*See* Table 1).

Table 1.
Approximate number of white colonies after transformation of yeast strains with plasmids.

	YGLY563	YGLY564
pGLY220	300	170
pGLY221	300	170
pGLY222	300	170
pGLY223	300	170
pGLY224	300	170
pGLY225	20	3

	YGLY1215	YGLY1216
pGLY2077	600	600
pGLY2078	600	500
pGLY2079	120	80
pGLY2080	35	40
pGLY2081	35	25

In order to test how this anticipated multicopy integration affected protein expression levels, plasmids expressing GBA, single-chain anti-HER2 antibody, human CD40 ectodomain or human EPO were transformed into *ade1* or *ade2* auxotrophic yeast strains (*See* Table 2). Transformants were grown in 96 well deep well plates, expression was induced using the appropriate carbon source and protein levels were assessed by Western Blot or Coomassie gel (*See* Figures 3 and 4). For most transformations using the promoterless *ADE2* ORF as marker, as expected, a very low number of white transformants (5 to 20) were observed. However the expression level of those clones was generally significantly higher than clones obtained from transformations using the complete *ADE2* gene as marker, which usually gave rise to hundreds of transformants (*See* Figures 3 and 4). Especially striking is the amount of protein produced from the clone shown in the lane marked in Figure 3D with an asterisk.

Table 2.
Transformation of yeast strains with plasmids expressing heterologous proteins.

Yeast Strain	Plasmid	Auxotrophic Marker	Protein Expressed	Promoter	Figure
YGLY563	pJN903	ADE1 + promoter	single chain anti-HER2 antibody	GAPDH	3A
YGLY563	pJN904	ADE1 - promoter	single chain anti-HER2 antibody	GAPDH	3A
YGLY564	pGLY1084	ADE1 + promoter	Glucocerebrosidase	GAPDH	3B
YGLY564	pGLY1085	ADE1 - promoter	Glucocerebrosidase	GAPDH	3B
YGLY563	pGLY1073	ADE1 + promoter	Human CD40 Ectodomain	AOX1	3C
YGLY563	pGLY1074	ADE1 - promoter	Human CD40 Ectodomain	AOX1	3C
YGLY564	pGLY1073	ADE1 + promoter	Human CD40 Ectodomain	AOX1	3D

YGLY564	pGLY1074	ADE1-promoter	Human CD40 Ectodomain	AOX1	3D
YGLY1215	pGLY2663	ADE2+promoter	Human EPO	AOX1	4A
YGLY1215	pGLY2664	ADE2-promoter	Human EPO	AOX1	4A
YGLY1216	pGLY2663	ADE2+promoter	Human EPO	AOX1	4B
YGLY1216	pGLY2664	ADE2-promoter	Human EPO	AOX1	4B

Materials and Methods

Escherichia coli strain DH5α was used for recombinant DNA work. Wild type P. pastoris strain NRRL-Y 11430 was used for construction of yeast strains (ATCC #76273). PCR reactions were performed according to supplier recommendations using EXTAQ (TaKaRa), Taq Poly (Promega) or Pfu Turbo® (Stratagene, La Jolla, CA). Restriction and modification enzymes were from New England Biolabs (Beverly, MA). Yeast strains were grown in YPD (1% yeast extract, 2% peptone, 2% dextrose and 1.5% agar) or synthetic defined medium (1.4% yeast nitrogen base, 2% dextrose, $4x10^{-5}$% biotin and 1.5% agar) supplemented as appropriate. Yeast transformations were performed by electroporation as described in (Nett *et al.*, 2005). Coomassie gels and Western Blots were performed using 4-20% precast TRIS-SDS gels and the Mini PROTEAN 3 cell from Biorad according to the manufacturer's instructions. Primary antibodies for detection were: Goat Anti-Human IgG (Fc) #31413 from Pierce at 1:10000 dilution for Herceptin; Anti human EPO #sc7956 from Santa Cruz Biotechnology at 1:500 dilution; Anti-GBA rabbit polyclonal (custom made) from Rockland Immunochemicals, Inc. at 1:500 dilution.

While the present invention is described herein with reference to illustrated embodiments, it should be understood that the invention is not limited hereto. Those having ordinary skill in the art and access to the teachings herein will recognize additional modifications and embodiments within the scope thereof. Therefore, the present invention is limited only by the claims attached herein.

BRIEF DESCRIPTION OF THE SEQUENCES

SEQ ID NO:	Name	Sequence (5' to 3')
1	Ura5comp5	GCTCTAGAGGGACTTATCTGGGTCCAGACGATGTG
2	Ura5comp3	CGGGATCCGCCGCCGTGCCCAAAGCTCCGAAACAG
3	URA5MUT1	GCAGTCATCACATCATCGATAATCAGTACTC
4	URA5MUT2	CCGTGTTGAAGTTGTACGAGCTGGGCGGC
5	URA5MUT3	GCCGCCCAGCTCGTACAACTTCAACACGG
6	URA5MUT4	CACATTGAAGATGTCACTGGAGGGGTACC
7	URA5MUT5	GGTACCCCTCCAGTGACATCTTCAATGTG
8	URA5MUT6	GCTGGCTCGCGCGCAGTGTTTTTCGTGCTC
9	ARG355DIS	GAGCTCGGCCAGCTTGGCCGCTAACAGTAACAAAA ACTACCGCCAG
10	ARG353-2	GTCGACGGATCCGTTTAAACGACAGCCTTCTTTGG GTCATGAGTAACTTCCAAAC
11	ARG335-2	GGATCCACTAGTATTTAAATCACGGATTTATGCTTG ATCACATGACCAATCATAAC
12	ARG333	GTCGACGGCCGATGGGGCCCGCATTCTTCTTGCTTA ATAAACC
13	GAP5CLEAN	GGATCCCTCGAGAGATCTTTTTTGTAGAAATGTCTT GGTGTCCTCGTC
14	GAP3CLEAN	GCATGCACTAGTGCGGCCGCTGTGTTTTGATAGTTG TTCAATTGATTGAAATAG
15	CYC5CLEAN	GCTAGCTTAATTAAACAGGCCCCTTTTCCTTTGTCG ATATCATG
16	CYC3CLEAN	GCATGCGGATCCCTTAAGAGCCGGCAGCTTGCAAA TTAAAGCCTTCGAGCGTCC
17	ADE155L	CCACCGAGCTCGGCCAACTCGGCCTTTTTCAAGTTG ATGCTATCTTTTATGGATATTAAGCCAG
18	ADE153L	CCACCGTTTAAACCTCCATGCCACCCATCTAATGTT GATCAACG
19	ADE1KO35	ATTTAAATATGATTAGTACCCTCCTCGCCTTTTTCA GAC
20	ADE133L	CCACCGCATGCGGCCATGTTGGCCCCTCTTTTAAGC AACTCTCTTGGTCCTTGG
21	RCD534	GATATCGGCCGGCCATTTACAATTAGTAATATTAA GGTGG
22	RCD535	CTTAAGCGGACCGGTTTAAACCTACTAAGCGACGA AAACGGGAGC
23	ADE255KO	GGATGAGCTCGGCCAGTTGGGCCCTTAAAATCATC TGCCTCACCCCACCGACC
24	ADE253KO	GGATGGCCGGCCGACTTGCTAACCTGGCTCTGCCA TAGTTGAAAATACGTCG
25	ADE235	GGACGATTTAAATATTTAGTATTGTTTTTTAATAGA TGTATATATAATAGTACACG
26	ADE233	GGACGGTCGACGGCCATACTGGCCTGAGATGGATT TGAAATGCTC
27	EXMCS1	AATTGAGATCTGAATTCGGTACCATTTAAATGGAT CCGCGGCCGCTTAATTAAGGCGCGCCAGGCCATAA TGGCCT
28	EXMCS2	AGCTAGGCCATTATGGCCTGGCGCGCCTTAATTAA GCGGCCGCGGATCCATTTAAATGGTACCGAATTCA

		GATCTC
29	CYCTT5	GCAAGGATTTAAATACAGGCCCCTTTTCCTTTGTCG ATATCATG
30	CYCTT3	GGATCCAGCTTGCAAATTAAAGCCTTCGAGCGTCC
31	AOX1P-5	AGATCTAACATCCAAAGACGAAAGGTTGAATGAAA CC
32	AOX1P-3	GAATTCCGTTTCGAATAATTAGTTGTTTTTTGATCT TC
33	TRP2-5	GGCCATAATGGCCAAACGGTTTCTCAATTACTATA TACTACTAAC
34	TRP2-3revised	GGCCATTATGGCCAAACCATAAATTCCTACTTACG TCCTCCG
35	ADE1-3	GGCGCGCCCTGAGCCAAAAGACCCCCTGCCAATGA GC
36	ADE1-5C-BAM	GCGGCCGCGGGTGCTATCGTTTTGTGCAATTTGGTT TGC
37	ADE1-5-100	GCGGCCGCACTTTTACCAATAATCGTTTATGAATAC GG
38	ADE1-5-186	GCGGCCGCTCCACTTGAACGATTCATTATTCAGA
39	ADE1-5-295	GCGGCCGCCCAATATACTACTCTAGGAAACTCGAA AAAC
40	ADE1-5-325	GCGGCCGCCCTTTCCATGTGTCATCGCTTCCAACAC AC
41	ADE1-5-ORF	TTAATTAAATGTCCATTGTGAACACTGATCTGGAC GGAA
42	GAPDHP-5	AGATCTTTTTTGTAGAAATGTCTTGGTGTCCTCGTC C
43	GAPDHP-3	GAATTCTGTGTTTTGATAGTTGTTCAATTGATTG
44	5oligoERSSKF S	AATTCCGGACCGGCATGCAGGCCTGGTACCGGCCG GCCATTT
45	3oligoSFSSRF	AAATGGCCGGCCGGTACCAGGCCTGCATGCCGGTC CGG
46	ADE23AscI	GGATGGCGCGCCGCACATGAGGCTCTTTGCAAAGT TCCTCCAGG
47	ADE25NotI-1	GGATGCGGCCGCGTCAAAGCCGTATACTCGGTAGT GTGCTCGCC
48	ADE25NotI-2	GGATGCGGCCGCGACTTGACTCTTCACTAGCCTAT GCAAATAAGG
49	ADE25NotI-3	GGATGCGGCCGCGGTTACCTTTTCCAAGAATCGTA GAAACGATT
50	ADE25NotI-4	GGATGCGGCCGCCTTCCAAACTCTCATGGATTCTC AGGTAATAG
51	ADE2-5'PacInew	GGCCTTAATTAAATGGATTCTCAGGTAATAGGTAT TCTAGGAGGAGGCCAGCTAGGCCG
52	AOX1P-5	AGATCTAACATCCAAAGACGAAAGGTTGAATGAAA CC
53	AOX1P-3	GAATTCCGTTTCGAATAATTAGTTGTTTTTTGATCT TC
54	ADE 1 5' seq for KO	TTTTTCAAGTTGATGCTATCTTTTATGGATATTAAG CCAGTGAAACTTAGAGTTAGCAGTATCTTATCAAG AGTGAAAAAGTTGTGTTTCTTTTCATTTGAATTGTG CTTGGTCATTGATGAAATCAGAGTCATTCTCAAGA TGTATAACCATATCGATCTATAAGTCGCAGTTGCTT

		CCAAGTTTGACTCTTGCTCAATATCCAGATCTATGG AATCTTGAGCAGGTCTTTTGGAATAAAATGCGACT AAAAACCCAGAAAGTAGCCCAATTATATGCAGTCT GAACATGAGTGGTACTTTGGTGAGTGACCTCCATA TCCATGACATGGATGGATTTCGCCCTTTTCTTGTGT AATATGACATCAACAACGACGTGGATGACACAGTA ACAACAGTCAAGGAGAGTTTGAGACTTTCTTTTAC GCTTTTTATGACTATCTGTTTGTAATACTTCCATTT GCTAGCCGCTTTCAGCTGTTCCAATTCTTCCGTGCT AAGTCTCAAGTTCATAAAGAAGAAAAATGGAAAG AGGTATTCAAGGACTACCGTGTATTTTCTTGGCAA ATATCGCAACAGAAAGTTTCTCAGATCAAATGCAA ATCGATTTTTCATGCTATTCTTACCAATTATGCTTT CCAGTTCATAGAAAGATTTGACCATATCACCAGAT GAAACCATGCGAGAAGTTCCTCTTTTGACTAATAG GCCTTCACCCATAAAGTTTAAGATGTTCCTGAAAT ATACTGGACAGTTCTCGTAATCCATGATAAACGAC TTGAAAATCTGCGAGTAACATAATGGGAATAGATA CCATGAACGTAAGAGTTTGTCTCTCTTTGGAACACT TTTTAGCGCTTTGAGCCTACGAATGAAACAACTATT TTCTGGTTGATCTTCGAATTCAGCGTTGTCTGTGTC TTTCATATCAGAATCCTTGATAACGTATATAGAGG ATGTCTCTTTGGAAAATTGGTCGGGGTAAACCTGT TCCAAGAACTTATAGCCATACTCTACCATTAATACC GTAAAATATATTGATGCATAATTCTTTTGGTAATAT ATTTTACTGGGATACAGGGCAAATGACACCACTGA TGTGAATAGACTGGAAACGACTGAATTGAAAAGAA ACTTTTGCTTCTCAGTGACTTTTAAATAGCTCTCTG CGAAAATGTCAAGAATCTTGTTGAACAATGGTTTA ACTGAAAATAAGAGACCCAGTGATGTAGAAAATTT TAGCAAATTCACCCGATCATTGAACATTAAATTTCT TCTAGAATTTGCAATATTCAACTTTCTTAAGATCTT AAATATTACGCCCAACGATCCAAACAACAATAGAA ACCATCTGTTGAAGTTTCTAGCTGCCTTTATGGTGA CTTTTAGTATTCCTGTTGTGTCGTTCTCATAAAATG ACTGTTCTACAGTCGATAATAAGCCACTCATCTTCC ACAACTTCAACTGCACTTCCTCCAATGCAACTAGA TCATGCTTTTCAAGCTGCTTGAGATTGATCTTCAGT AATTCTTTAACTTCATCGTGTGATGTGAGCAAGAC GAGTAAATACTTGAGTTTTGTCAAGTTATTACTGCC CTTGTTTGACATGGATTGCTGTATTTGAGAAGAAA AATGAACGTAAACTTGAATCTCCCCAGGTGAACTT GGCGTGTATCTTATCTACCCCAGCTCTAAAGTTTAC CCGATGAGGTAATTCTTAGGGATAATTTGGTGTAT GGATTTGACTAAATTGCCGGAGTTGATTCAATGAC AGAGAAGCTTACATGCAAGGAACATGATTCGTTGA TCAACATTAGATGGGTGGCATGGAG
55	ADE 1 3' seq, for KO	ATGATTAGTACCCTCCTCGCCTTTTTCAGACATCTG AAATTTCCCTTATTCTTCCAATTCCATATAAAATCC TATTTAGGTAATTAGTAAACAATGATCATAAAGTG AAATCATTCAAGTAACCATTCCGTTTATCGTTGATT TAAAATCAATAACGAATGAATGTCGGTCTGAGTAG TCAATTTGTTGCCTTGGAGCTCATTGGCAGGGGGTC TTTTGGCTCAGTATGGAAGGTTGAAAGGAAAACAG

		ATGGAAAGTGGTTCGTCAGAAAAGAGGTATCCTAC ATGAAGATGAATGCCAAAGAGATATCTCAAGTGAT AGCTGAGTTCAGAATTCTTAGTGAGTTAAGCCATC CCAACATTGTGAAGTACCTTCATCACGAACATATTT CTGAGAATAAAACTGTCAATTTATACATGGAATAC TGTGATGGTGGAGATCTCTCCAAGCTGATTCGAAC ACATAGAAGGAACAAAGAGTACATTTCAGAAGAA AAAATATGGAGTATTTTTACGCAGGTTTTATTAGC ATTGTATCGTTGTCATTATGGAACTGATTTCACGGC TTCAAAGGAGTTTGAATCGCTCAATAAAGGTAATA GACGAACCCAGAATCCTTCGTGGGTAGACTCGACA AGAGTTATTATTCACAGGGATATAAAACCCGACAA CATCTTTCTGATGAACAATTCAAACCTTGTCAAACT GGGAGATTTTGGATTAGCAAAAATTCTGGACCAAG AAAACGATTTTGCCAAAACATACGTCGGTACGCCG TATTACATGTCTCCTGAAGTGCTGTTGGACCAACCC TACTCACCATTATGTGATATATGGTCTCTTGGGTGC GTCATGTATGAGCTATGTGCATTGAGGCCTCCTTTT CAAGCCACTACACATTTACAATTACAACAAAAGAT CCAAGAAGGGACATTCCCTCCACTTCCGGACGTAT TTTCACCCCGGTTAAGATCTCTGATCAATGCTTGCA TAACCATAGACCTGAACCAACGACCATCTACTCAC GAACTTCTTCAGGAAAGTTGCTTCAATGTGTATATC AAGGAGGTTAATTTAGAGATAAGGGAGGACAGATT GAATGAGCGTGAACGCAAACTGAAAATACGAGAG AACAAGTTAATCTTGAGCGAAGAGGGAATAGTGAA ACAACTGAATGAAGAACTGGAATTTCAAAGAAAGT TGCTTGAACAAGAAGTAGAGGAAATAAGGAAGTC ATACAAGAACGAATTTCAGTTCGTACTGGAACAAC AGGTGCAACAGGCATTGAGCAAAATTCTAGGTCCC CAATACAATCAAAAGCCATTGAACAGGAATCAGCA ACAAAAACAAATACAACAAATTTACAGCAGACAG GATCCGCAATTATCAAGCCCAAAGTCACAACAAGC TCAGATCCAAGGACCAAGAGAGTTGCTTAAAAGAG G
56	ADE1 gene (including promoter and terminator)	GGGTGCTATCGTTTTGTGCAATTTGGTTTGCTGGAG AGTCGACCAAGAGATGATAACTGTTACTAAGCTTC TCCGTAATTAGTGGTATTTTGTAACTTTTACCAATA ATCGTTTATGAATACGGATATTTTTCGACCTTATCC AGTGCCAAATCACGTAACTTAATCATGGTTTAAAT ACTCCACTTGAACGATTCATTATTCAGAAAAAAGT CAGGTTGGCAGAAACACTTGGGCGCTTTGAAGAGT ATAAGAGTATTAAGCATTAAACATCTGAACTTTCA CCGCCCCAATATACTACTCTAGGAAACTCGAAAAA TTCCTTTCCATGTGTCATCGCTTCCAACACACTTTG CTGTATCCTTCCAAGTATGTCCATTGTGAACACTGA TCTGGACGGAATCCTACCTTTAATCGCCAAAGGAA AGGTTAGAGACATTTATGCAGTCGATGAGAACAAC TTGCTGTTCGTCGCAACTGACCGTATCTCCGCTTAC GATGTGATTATGACAAACGGTATTCCTGATAAGGG AAAGATTTTGACTCAGCTCTCAGTTTTCTGGTTTGA TTTTTTGGCACCCTACATAAAGAATCATTTGGTTGC TTCTAATGACAAGGAAGTCTTTGCTTTACTACCATC AAAACTGTCTGAAGAAAAATACAAATCTCAATTAG

		AGGGACGATCCTTGATAGTAAAAAAGCACAGACTG ATACCTTTGGAAGCCATTGTCAGAGGTTACATCAC TGGAAGTGCATGGAAAGAGTACAAGAACTCAAAA ACTGTCCATGGAGTCAAGGTTGAAAACGAGAACCT TCAAGAGAGCGACGCCTTTCCAACTCCGATTTTCA CACCTTCAACGAAAGCTGAACAGGGTGAACACGAT GAAAACATCTCTATTGAACAAGCTGCTGAGATTGT AGGTAAAGACATTTGTGAGAAGGTCGCTGTCAAGG CGGTCGAGTTGTATTCTGCTGCAAAAAACTTCGCC CTTTTGAAGGGGATCATTATTGCTGATACGAAATT CGAATTTGGACTGGACGAAAACAATGAATTGGTAC TAGTAGATGAAGTTTTAACTCCAGATTCTTCTAGAT TTTGGAATCAAAAGACTTACCAAGTGGGTAAATCG CAAGAGAGTTACGATAAGCAGTTTCTCAGAGATTG GTTGACGGCCAACGGATTGAATGGCAAAGAGGGC GTAGCCATGGATGCAGAAATTGCTATCAAGAGTAA AGAAAAGTATATTGAAGCTTATGAAGCAATTACTG GCAAGAAATGGGCTTGAATGATTAGTACCCTCCTC GCCTTTTTCAGACATCTGAAATTTCCCTTATTCTTC CAATTCCATATAAAATCCTATTTAGGTAATTAGTA AACAATGATCATAAAGTGAAATCATTCAAGTAACC ATTCCGTTTATCGTTGATTTAAAATCAATAACGAAT GAATGTCGGTCTGAGTAGTCAATTTGTTGCCTTGG AGCTCATTGGCAGGGGGTCTTTTGGCTCAG
57	ADE1 aa seq	MSIVNTDLDGILPLIAKGKVRDIYAVDENNLLFVATD RISAYDVIMTNGIPDKGKILTQLSVFWFDFLAPYIKNH LVASNDKEVFALLPSKLSEEKYKSQLEGRSLIVKKHR LIPLEAIVRGYITGSAWKEYKNSKTVHGVKVENENLQ ESDAFPTPIFTPSTKAEQGEHDENISIEQAAEIVGKDIC EKVAVKAVELYSAAKNFALLKGIIIADTKFEFGLDEN NELVLVDEVLTPDSSRFWNQKTYQVGKSQESYDKQF LRDWLTANGLNGKEGVAMDAEIAIKSKEKYIEAYEAI TGKKWA
58	ADE 2 5' seq for KO	AGTTGGGCCCTTAAAATCATCTGCCTCACCCCACC GACCAATGGGAATTCTAGAAACAATTTCATTGCTC TTCTTCTCGTTACCATAAGAATCGGCTGTCATGTTT GACTTAACGAACCCTGGAACAAGGGAATTCACGGT AATACCTTTTGGAGCAAGTTCAACCGATAGAGCCT TCATTAATGAGTTGATTGCACCTTTGGTGGTCGCAT ATACCGATTGATTCGGGTAGGTCACTTCGAAACTG TACAGGGAGGCAGTAAAGATGATCCTACCCTTAAT CTGGTTCTTAATAAAGTGTTTAGTGACTAGCTGTGT CAATCTAAATGGAAAATCGACATTTACCTTTTGGA TAGCCGCGTAATCTTTCTCCGTAAAACTTGTAAACT CAGATTTAATGGCAATGGCAGCGTTGTTGATTAAA ATGTCAATCTTTCCAGTGGAACTCTTCTCCACCGCA GGACTCGTTACGGTCTCTTCCAGCTTTGCAAGATCG GCATCCACTAGATCCAACTCAATTGTATGTATGGA GGCACCATCGGCATTTGACATTCTCACCTCTTCAAT GAAAGCCGTTGGGTCTGTAGAAGGTCTATGGATAA GAATAAGTTCTGCACCTGCTTCATAAAGTCCTCGA ACTATTCCTTGGCCTAATCCGCTGGTACCACCGGTG ATCAAGGCGACCTTACCATTCAAAGAAAACAAATC AGCGGACATTAGCGACTTGAATAGGGAATGGGTTA

		GACAAATGAAAGCCGACGAGCCAGCACTTTATAGT AAGTGCAGGTGAGTCAATAAGAATAAATGTATGGC TTGCTGTCCCTATCGCGTAAGAAGCTTACTAAGATC GCCTAAATTGAAAAGTTGAACAAATCAGTTCTAGC TGGCCTCCATCAGCATTTCGTTCTCCTCTGATCATC TTTGCCAATCGCTAGCATGCCCTCAGCGTGCAAGG AAAAGCACGCTTCTTTCTTATCGACGTATTTTCAAC TATGGCAGAGCCAGGTTAGCAAGTC
59	ADE 2 3' seq, for KO	ATTTAGTATTGTTTTTTAATAGATGTATATATAATA GTACACGTAACTTATCTATTCCATTCATAATTTTAT TTTAAAGGTTCGGTAGAAATTTGTCCTCCAAAAAG TTGGTTAGAGCCTGGCAGTTTTGATAGGCATTATTA TAGATTGGGTAATATTTACCCTGCACCTGGAGGAA CTTTGCAAAGAGCCTCATGTGCTCTAAAAGGATGT CAGAATTCCAACATTTCAAAATTATATCTGCATGC GTCTGTAATACTGGAACTGTTATTTTTCTGGTCAGG ATTTCACCGCTCTTGTCGTCATGTTTCTCGTCGTCT GAAAGTAAACTGACTTTCCTCTTTCCATAAACACA AAAATCGATTGCAACTTGGTTATTCTTGAGATTGA AATTTGCTGTGTCTTCAGTGCTTAGCTGAATATCAA CAAACTTACTTAGTACTAATAACGAAGCACTATGG TAAGTGGCATAACATAGTGGTATTGAAGCGAACAG TGGATATTGAACCCAAGCATTGGCAACATCTGGCT CTGTTGATACTGATCCGGATCGTTTGGCACCAATTC CTGAAACGGCGTAGTGCCACCAAGGTTTCGATTTG AGAACAGGTTCATCATCAGAGTCAACCACCCCAAT GTCAATGGCAGGCTCCAACGAAGTAGGTCCAACAA CAACAGGAAGTATTTGACCTTGAAGATCTGTTCCTT TATGATCCACCACACCTTGCCCCAATTCCAATAACT TTACCAGTCCCGATGCAGACATGATAACTGGTACT AATGATCTCCATTGATTTTCGTCGGCACTACGTAAA GCCTCCAAAAATGAATTCAGAATATCTTCTGAAAC TAGATTCTGCTTCTGTGATTCAAGCATTGCTTTATG TAGACATCTCTTGAATAAAAGCAATTCTCCACATA TTGGTGTGTGTAAGATAGATCTGGAAAGATGTATC TGGAATAGTCCAGTCAACGTTGTGCAATTGATTAG CATTACCTTACTGTGAACATCTCTATCTACAACAAC AGACTCAATTCGATAGACGTTCCGGGAAAGTTTTT CAAGCGCATTCAGTTTGCTGTTGAACAAAGTGACT TTGCTTTCCAATGTGCAAATACCCCTGTATATCAAG TCCATCACATCACTCAAGACCTTGGTGGAAAAGAA TGAAACAGCTGGAGCATAATTTTCGAATGAATTAG GTAAGGTCACTTCATCCTTATCTGTTGTAATGCTAT AATCAATAGCGGAACTAACATCTTCCCATGTAACA GGTTTCTTGATCTCTGAATCTGAATCTTTATTTGAA AAAGAATTGAAAAAAGACTCATCACTCATTGGGAA TTCAAGGTCATTAGGGTATTCCATTGTTAGTTCTGG TCTAGGTTTAAAGGGATCACCTTCGTTAAGACGAT GGAAAATAGCTAATCTGTACAATAACCAGATACTT CTAACGAAGCTCTCTCTATCCATCAGTTGACGTGTT GAGGATATCTGAACTAGCTCTTTCCACTGCGAATC AGGCATGCTCGTATAGCTGGCAAGCATGTTATTCA GCTTTACCAAGTTAGAAGCCCTTTGGAAACCATCT ATAGATTCCCGAAAAAACTTATACCCACTGAGGGT

		TTCACTGAGCATAGTCAGTGACATCAAAGAGCATT TCAAATCCATCTCA
60	ADE2 gene (including promoter and terminator)	GTCAAAGCCGTATACTCGGTAGTGTGCTCGCCAAA AATAAATTTGACTTGACTCTTCACTAGCCTATGCAA ATAAGGTTACCTTTTCCAAGAATCGTAGAAACGAT TAAAAAACTTCCAAACTCTCATGGATTCTCAGGTA ATAGGTATTCTAGGAGGAGGCCAGCTAGGCCGAAT GATTGTTGAGGCCGCTAGCAGGCTCAATATCAAGA CCGTGATTCTTGATGATGGTTTTTCACCTGCTAAGC ACATTAATGCTGCGCAAGACCACATCGACGGATCA TTCAAAGATGAGGAGGCTATCGCCAAGTTAGCTGC CAAATGTGATGTTCTCACTGTAGAGATTGAGCATG TCAACACAGATGCTCTAAAGAGAGTTCAAGACAGA ACTGGAATCAAGATATATCCTTTACCAGAGACAAT CGAACTAATCAAGGATAAGTACTTGCAAAAGGAAC ATTTGATCAAGCACAACATTTCGGTGACAAAGTCT CAGGGTATAGAATCTAATGAAAAGGCGCTGCTTTT GTTTGGAGAAGAGAATGGATTTCCATATCTGTTGA AGTCCCGGACTATGGCTTATGATGGAAGAGGCAAT TTTGTAGTGGAGTCTAAAGAGGACATCAGTAAGGC ATTAGAATTCTTGAAAGATCGTCCATTGTATGCCG AGAAGTTTGCTCCTTTTGTTAAAGAATTAGCGGTA ATGGTTGTGAGATCACTGGAAGGCGAAGTATTCTC CTACCCAACCGTAGAAACTGTGCACAAGGACAATA TCTGTCATATTGTGTATGCTCCGGCCAGAGTTAATG ACACCATCCAAAAGAAAGCTCAAATATTAGCTGAA AACACTGTGAAGACTTTCCCAGGCGCTGGAATCTT CGGAGTTGAGATGTTCCTATTGTCTGATGGAGAAC TTCTTGTAAATGAGATTGCTCCAAGGCCCCACAATT CTGGTCACTATACAATCGATGCATGTGTAACATCTC AGTTCGAAGCACATGTAAGAGCCATAACTGGTCTG CCAATGCCACTAGATTTCACCAAACTATCTACTTCC AACACCAACGCTATTATGCTCAATGTTTTGGGTGCT GAAAAATCTCACGGGGAATTAGAGTTTTGTAGAAG AGCCTTAGAAACACCCGGTGCTTCTGTATATCTGTA CGGAAAGACCACCCGATTGGCTCGTAAGATGGGTC ATATCAACATAATAGGATCTTCCATGTTGGAAGCA GAACAAAAGTTAGAGTACATTCTAGAAGAATCAAC CCACTTACCATCCAGTACTGTATCAGCTGACACTA AACCGTTGGTTGGAGTTATCATGGGTTCAGACTCT GATCTACCTGTGATTTCGAAAGGTTGCGATATTTTA AAACAGTTTGGTGTTCCATTCGAAGTTACTATTGTC TCTGCTCATAGAACACCACAGAGAATGACCAGATA TGCCTTTGAAGCCGCTAGTAGAGGTATCAAGGCTA TCATTGCAGGTGCTGGTGGTGCTGCTCATCTTCCAG GAATGGTTGCTGCCATGACTCCGTTGCCAGTCATTG GTGTTCCTGTCAAGGGCTCTACGTTGGATGGTGTA GACTCGCTACACTCGATTGTCCAAATGCCTAGAGG TGTTCCTGTGGCTACGGTTGCTATCAACAACGCCAC CAATGCCGCTCTGTTGGCCATCAGGATTTTAGGTAC AATTGACCACAAATGGCAAAAGGAAATGTCCAAGT ATATGAATGCAATGGAGACCGAAGTGTTGGGGAAG GCATCCAACTTGGAATCTGAAGGGTATGAATCCTA TTTGAAGAATCGTCTTTGAATTTAGTATTGTTTTTT

		AATAGATGTATATATAATAGTACACGTAACTTATC TATTCCATTCATAATTTTATTTTAAAGGTTCGGTAG AAATTTGTCCTCCAAAAAGTTGGTTAGAGCCTGGC AGTTTTGATAGGCATTATTATAGATTGGGTAATATT TACCCTGCACCTGGAGGAACTTTGCAAAGAGCCTC ATGTGC
61	ADE2 aa seq	MDSQVIGILGGGQLGRMIVEAASRLNIKTVILDDGFSP AKHINAAQDHIDGSFKDEEAIAKLAAKCDVLTVEIEH VNTDALKRVQDRTGIKIYPLPETIELIKDKYLQKEHLI KHNISVTKSQGIESNEKALLLFGEENGFPYLLKSRTM AYDGRGNFVVESKEDISKALEFLKDRPLYAEKFAPFV KELAVMVVRSLEGEVFSYPTVETVHKDNICHIVYAPA RVNDTIQKKAQILAENTVKTFPGAGIFGVEMFLLSDG ELLVNEIAPRPHNSGHYTIDACVTSQFEAHVRAITGLP MPLDFTKLSTSNTNAIMLNVLGAEKSHGELEFCRRAL ETPGASVYLYGKTTRLARKMGHINIIGSSMLEAEQKL EYILEESTHLPSSTVSADTKPLVGVIMGSDSDLPVISK GCDILKQFGVPFEVTIVSAHRTPQRMTRYAFEAASRGI KAIIAGAGGAAHLPGMVAAMTPLPVIGVPVKGSTLD GVDSLHSIVQMPRGVPVATVAINNATNAALLAIRILG TIDHKWQKEMSKYMNAMETEVLGKASNLESEGYES YLKNRL
62	S.c. ADE2 aa seq	MDSRTVGILGGGQLGRMIVEAANRLNIKTVILDAENS PAKQISNSNDHVNGSFSNPLDIEKLAEKCDVLTIEIEH VDVPTLKNLQVKHPKLKIYPSPETIRLIQDKYIQKEHLI KNGIAVTQSVPVEQASETSLLNVGRDLGFPFVLKSRT LAYDGRGNFVVKNKEMIPEALEVLKDRPLYAEKWAP FTKELAVMIVRSVNGLVFSYPIVETIHKDNICDLCYAP ARVPDSVQLKAKLLAENAIKSFPGCGIFGVEMFYLET GELLINEIAPRPHNSGHYTIDACVTSQFEAHLRSILDLP MPKNFTSFSTITTNAIMLNVLGDKHTKDKELETCERA LATPGSSVYLYGKESRPNRKVGHINIIASSMAECEQRL NYITGRTDIPIKISVAQKLDLEAMVKPLVGIIMGSDSD LPVMSAACAVLKDFGVPFEVTIVSAHRTPHRMSAYAI SASKRGIKTIIAGAGGAAHLPGMVAAMTPLPVIGVPV KGSCLDGVDSLHSIVQMPRGVPVATVAINNSTNAALL AVRLLGAYDSSYTTKMEQFLLKQEEEVLVKAQKLET VGYEAYLENK

WHAT IS CLAIMED:

1. An expression system comprising:

(a) a host cell in which the endogenous gene encoding an auxotrophic selectable marker protein has been removed from the genome of the host cell; and

(b) an integration vector comprising:

(1) a nucleic acid having an open reading frame (ORF) encoding a function that is complementary to the function of the endogenous gene encoding the auxotrophic selectable marker protein and which is operably linked to a weak promoter, an attenuated endogenous or heterologous promoter, a cryptic promoter, a truncated endogenous or heterologous promoter, or no promoter;

(2) a nucleic acid having an insertion site for the insertion of one or more expression cassettes comprising a nucleic acid encoding peptides, proteins, and/or functional nucleic acids of interest, and

(3) a targeting nucleic acid that directs insertion of the integration vector into a particular location of the genome of the host cell by homologous recombination.

2. The expression system of claim 2 wherein the auxotrophic selectable marker protein is encoded by a gene selected from the group consisting of *ADE, URA*, and *LYS.*

3. The expression system of claim 2 wherein the auxotrophic selectable marker protein is encoded by the *ADE1* gene.

4. The expression system of claim 2 wherein the auxotrophic selectable marker protein is encoded by the *ADE2* gene.

5. The expression system of claim 2, wherein the integration vector comprises multiple insertion sites for the insertion of one or more expression cassettes encoding the one or more heterologous peptides or proteins.

6. The expression system of claim 2, wherein the integration vector comprises more than one expression cassette.

7. The expression system of claim 6, wherein the integration vector comprises little or no homologous DNA sequence between the expression cassettes.

8. The expression system of claim 6, wherein the integration vector comprises a first expression cassette encoding a light chain of a monoclonal antibody and a second expression cassette encoding a heavy chain of a monoclonal antibody.

9. The expression system of claim 2, wherein the host cell is a lower eukaryote.

10. The expression system of claim 9, wherein the host cell is from a species selected from the group consisting of *Pichia pastoris*, *Pichia finlandica*, *Pichia trehalophila*, *Pichia koclamae*, *Pichia membranaefaciens*, *Pichia minuta* (*Ogataea minuta*, *Pichia lindneri*), *Pichia opuntiae*, *Pichia thermotolerans*, *Pichia salictaria*, *Pichia guercuum*, *Pichia pijperi*, *Pichia stiptis*, *Pichia methanolica*, *Pichia* sp., *Saccharomyces cerevisiae*, *Saccharomyces* sp., *Hansenula polymorpha*, *Kluyveromyces* sp., *Kluyveromyces lactis*, *Candida albicans*, *Aspergillus nidulans*, *Aspergillus niger*, *Aspergillus oryzae*, *Trichoderma reesei*, *Chrysosporium lucknowense*, *Fusarium* sp., *Fusarium gramineum*, *Fusarium venenatum*, *Physcomitrella patens*, and *Neurospora crassa*.

11. The expression system of claim 2, wherein the host cell is *Pichia pastoris*.

12. The expression system of claim 11, wherein the *Pichia pastoris* cell has been modified to be capable of producing glycoproteins having hybrid or complex *N*-glycans.

13. A method for expressing a recombinant peptide, proteins, and/or nucleic acid of interest in a host cell comprising:

(a) providing the host cell in which the endogenous gene encoding an auxotrophic selectable marker protein has been removed from the genome of the host cell; and

(a) transforming the host cell with an integration vector comprising:

(1) a nucleic acid having an open reading frame (ORF) encoding a function that is complementary to the function of the endogenous gene encoding the auxotrophic selectable marker protein and which is operably linked to a weak promoter, an attenuated endogenous or heterologous promoter, a cryptic promoter, a truncated endogenous or heterologous promoter, or no promoter;

(2) a nucleic acid having one or more expression cassettes comprising a nucleic acid encoding peptides, proteins, and/or functional nucleic acids of interest, and

(3) a targeting nucleic acid that directs insertion of the integration vector into a particular location of the genome of the host cell by homologous recombination,

wherein the transformed host cell produces the recombinant peptide, protein and/or nucleic acid of interest.

14. The method of claim 14 wherein the auxotrophic marker is encoded by a gene selected from the group consisting of *ADE, URA*, and *LYS*.

15. The method of claim 14 wherein the auxotrophic marker protein is encoded by the *ADE1* gene

16. The method of claim 14 wherein the auxotrophic marker protein is encoded by the *ADE2* gene.

17. The method of claim 13, wherein the recombinant vector comprises multiple insertion sites for the insertion of one or more expression cassettes encoding the one or more heterologous peptides or proteins.

18. The method of claim 13, wherein the recombinant vector comprises more than one expression cassette.

19. The method of claim 18, wherein the recombinant vector comprises little or no homologous DNA sequence between the expression cassettes.

20. The method of claim 18, wherein the recombinant vector comprises a first expression cassette encoding a light chain of a monoclonal antibody and a second expression cassette encoding a heavy chain of a monoclonal antibody.

21. The method of claim 13, wherein the host cell is a lower eukaryote.

22. The method of claim 21, wherein the host cell is from a species selected from the group consisting of *Pichia pastoris*, *Pichia finlandica*, *Pichia trehalophila*, *Pichia koclamae*, *Pichia membranaefaciens*, *Pichia minuta* (*Ogataea minuta*, *Pichia lindneri*), *Pichia opuntiae*, *Pichia thermotolerans*, *Pichia salictaria*, *Pichia guercuum*, *Pichia pijperi*, *Pichia stiptis*, *Pichia methanolica*, *Pichia* sp., *Saccharomyces cerevisiae*, *Saccharomyces* sp., *Hansenula polymorpha*, *Kluyveromyces* sp., *Kluyveromyces lactis*, *Candida albicans*, *Aspergillus nidulans*, *Aspergillus niger*, *Aspergillus oryzae*, *Trichoderma reesei*, *Chrysosporium lucknowense*, *Fusarium* sp., *Fusarium gramineum*, *Fusarium venenatum*, *Physcomitrella patens*, and *Neurospora crassa*.

23. The method of claim 13, wherein the host cell is *Pichia pastoris*.

24. The method of claim 23, wherein the *Pichia pastoris* cell has been modified to be capable of producing glycoproteins having hybrid or complex *N*-glycans.

25. An isolated nucleic acid comprising the *ADE2* gene of *Pichia pastoris*.

26. The nucleic acid of Claim 25 wherein the nucleic acid comprises the open reading frame that encodes the Ade2p protein.

27. The nucleic acid of Claim 26 wherein the nucleic acid has a nucleotide sequence with 95% identity to the nucleic acid sequence shown in SEQ ID NO:60 from nucleotide 127 to nucleotide 1,815.

28. A vector comprising the nucleic acid of Claim 27.

29. A *Pichia pastoris* cell comprising a deletion or disruption of the endogenous *ADE2* gene, or any other modification, rendering the *ADE2* gene or Ade2p non-functional.

30. The *Pichia pastoris* of Claim 29 wherein a vector comprising an *ADE2* open reading frame is integrated into a location in the *Pichia pastoris* genome other than the location where the endogenous *ADE2* gene had been located.

31. An isolated polypeptide comprising an amino acid sequence with 95% identity to the amino acid sequence shown in SEQ ID NO:61.

32. An expression system comprising:

(a) a *Pichia pastoris* host cell in which the endogenous *ADE2* gene encoding Ade2p has been removed from the genome of the host cell; and

(b) an integration vector comprising:

(1) a nucleic acid encoding the Ade2p;

(2) a nucleic acid having an insertion site for the insertion of one or more expression cassettes comprising a nucleic acid encoding one or more heterologous peptides, proteins, and/or functional nucleic acids of interest, and

(3) a targeting nucleic acid that directs insertion of the integration vector into a particular location of the genome of the host cell by homologous recombination.

33. A method for producing a recombinant *Pichia pastoris* host cell that expresses a heterologous peptide, proteins, and/or nucleic acid of interest comprising:

(a) providing the host cell in which the endogenous *ADE2* gene encoding an Ade2p has been removed from the genome of the host cell; and

(a) transforming the host cell with an integration vector comprising:

(1) a nucleic acid encoding the Ade2p;

(2) a nucleic acid having one or more expression cassettes comprising a nucleic acid encoding one or more heterologous peptides, proteins, and/or functional nucleic acids of interest, and

(3) a targeting nucleic acid that directs insertion of the integration vector into a particular location of the genome of the host cell by homologous recombination,

wherein the transformed host cell produces the recombinant peptide, protein, and/or nucleic acid of interest.