Yeast-based Therapeutic for Chronic Hepatitis C Infection

Field of the Invention

This invention generally relates to compositions and methods for vaccinating an animal against hepatitis C virus (HCV) and for treating or preventing hepatitis C viral infection in an animal.

Background of the Invention

Hepatitis C virus (HCV) is a major causative agent of acute and chronic hepatitis worldwide. It is estimated that there are 200 million chronically HCV-infected individuals worldwide, 4 million of whom reside in the United States. The foremost source of infection is through parenteral routes including blood transfusions or IV drug use. Despite the high degree of safety associated with current blood banking procedures, the rate of infection continues to increase, presumably due to IV drug use and other forms of exposure.

According to data from the Third National Health and Nutrition Examination Survey (NHANES III), approximately 70% of the patients with HCV infections in the United States will become chronically infected. A significant proportion of chronically infected individuals will suffer a serious sequelae of chronic HCV infection including progression to cirrhosis, hepatic decompensation, liver transplant, hepatocellular carcinoma, and death. Retrospective long term follow-up studies on patients chronically infected with HCV estimate the proportion who will progress to cirrhosis at approximately 20% to 50% with follow-up times ranging from 10 to 29 years **(1-4)**. Prospective long term follow-up studies on patients chronically infected with HCV after post-transfusion exposure estimate the proportion who will progress to cirrhosis at approximately 10% to 15% with relatively short follow-up times ranging from 8 to 16 years **(5-8)**. Of those patients who develop cirrhosis secondary to viral infection it is predicted that approximately 1% to 3%, will develop hepatocellular carcinoma annually with an approximate annual mortality rate of 2% to 6% **(9-10)**. An epidemiologic model utilizing NHANES III seroprevalance data and age-specific incidence rates estimates a peak in U.S. population risk for progression to cirrhosis and related complications by 2015, foretelling of a worsening unmet medical need in the near future **(11)**. Interruption of the chronic viral infection using interferon based regimens has been shown in several large series to favorably alter the rates of progression to cirrhosis, hepatocellular, and death **(12-14)**. However, sustained virologic response rates for the

treatment of genotype 1 chronic hepatitis C, the predominant genotype found in the US, are only approximately 50% with pegylated interferon-α regimens containing ribavirin. Additionally, interferon plus ribavirin based regimens also have significant safety problems including depression, suicidal ideation, flu-like symptoms, and neutropenia. Treatment options are currently limited for partial responders, relapsers, and non-responders to interferon based therapy.

HCV is a member of the *Flaviviridae* family of enveloped, positive-sense RNA viruses. It has a genome of approximately 9600 nucleotides that is translated upon cell entry into a polyprotein of roughly 3000 amino acids. Three structural and seven non-structural proteins are generated co- and post-translationally by cellular and HCV-derived proteases (Table 1). While the roles of some of the viral proteins have yet to be clearly defined, a number of them, such as the HCV structural Core protein, the E1 and E2 surface glycoproteins, the non-structural NS2 and NS3 proteases, and the NS5B RNA-dependent RNA polymerase are known to perform essential functions in the HCV life cycle. Based on genetic heterogeneity of the viral genomes isolated so far, HCV has 6 major genotypes and more than 100 subtypes.

Genotypes 1a, 1b and 2 are found predominantly in North America and Europe, while in South America, HCV genotypes 1a, 1b, and 3 are prevalent. Genotypes 4, 5 and 6 are observed throughout the rest of the world **(19)**. Despite the geographic predominance of certain HCV genotypes, most genotypes have been identified all over the world due to increased population movement. The different HCV genotypes vary in terms of their response to the currently recommended interferon/ribavirin therapy. In particular, ~50% of patients infected with HCV genotype 1 remain refractory to the current treatment regimen **(19)**. Further, response rates to interferon alpha among African-American patients are lower than those of Caucasian descent. These data suggest the need for alternative treatments that ideally augment the individual's pre-existing cellular immune response.

Table 1. HCV genes and gene products

Gene	Function	% homology between HCV genotypes 1a and 1b
Core	Nucleocapsid core protein	98.4
E1	Envelope glycoprotein	81.8
E2	Envelope glycoprotein	79.9
P7	Ion channel	81.0
NS2	metalloprotease	80.1
NS3	protease/helicase	92.1
NS4a	NS3 protease co-factor	91.1
NS4b	Unknown	82.4

NS5a	Unknown	77.7
NS5b	RNA-dependent RNA polymerase	87.5

The HCV protein sequences were obtained from the National Center for Biotechnology Information under Accession No. AF011753 (gi:2327074). The Align program from the Genestream Bioinformatics website (Institut de Génétique Humaine, 141 rue de la Cardonille, Montpellier France) was used to compare the amino acid sequences of the HCV proteins derived from strain 1a and 1b.

Numerous studies suggest that viral replication, the level of viremia and progression to the chronic state in HCV-infected individuals are influenced directly and indirectly by HCV-specific cellular immunity mediated by $CD4^+$ helper (T_H) and $CD8^+$ cytotoxic T lymphocytes (CTLs), and directed against both structural and non-structural viral proteins including Core and NS3 **(15)**. The lack of effective immunity in persons with chronic HCV infection is further implied by the occurrence of superinfection with other genotypes of HCV. As the robustness and breadth of cellular immune responses have been suggested to influence the natural course of HCV infection, the development of immunotherapeutic products that stimulate T cell immune responses in virally exposed individuals is of major importance.

Studies of humans and chimpanzees have revealed that HCV can replicate for weeks before the onset of $CD4^+$ and $CD8^+$ T cell responses in blood and liver. Moreover, there may be a delay in the acquisition of function by $CD8^+$ (and perhaps $CD4^+$) T cells even after their expansion in blood **(15).** The appearance of functional $CD8^+$ T cells is kinetically associated with control of viremia and, at least in some cases, with an elevation in serum transaminases, suggesting that liver damage during acute hepatitis C is immunopathological. At highest risk of persistent HCV infection are those individuals who fail to generate a detectable virus-specific T lymphocyte response in the blood, liver, or both. Perhaps most importantly, generation of a cellular immune response does not necessarily ensure that the infection will be permanently controlled. $CD4^+$ and $CD8^+$ T cell responses must be sustained for weeks or months beyond the point of apparent control of virus replication to prevent relapse and establishment of a persistent infection.

$CD4^+$ T cells play an essential role in anti-HCV immunity by providing help for activating and sustaining $CD8^+$ T cell responses. Protective $CD4^+$ T cells appear to predominantly recognize epitopes in Core, NS3, NS4 and NS5 proteins although responses against the other HCV gene products have also been reported **(20-21)**. In addition to the help that $CD4^+$ T cells provide to $CD8^+$ T cells, it also appears critical that they produce gamma interferon and other pro-inflammatory T_H1-, as opposed to, T_H2-type cytokines.

Equally important for control of chronic infection is the establishment of HCV-specific memory $CD4^+$ T cells **(20 & 22)**.

The finding that $CD4^+$ and $CD8^+$ T cell responses are common to self-limited HCV infections suggests that they cooperate to bring about control of viremia. Memory $CD4^+$ and $CD8^+$ T cells primed during acute resolving hepatitis C infection provide long-term protection from virus persistence in chimpanzees and probably humans. Through antibody-mediated depletion of each memory T cell subset, the chimpanzee model has provided direct proof of the importance of $CD8^+$ T cells in the control of acute hepatitis C and their dependence on $CD4^+$ T cell help **(24)**. In contrast to $CD4^+$ T cells, both acute and memory $CD8^+$ T cells appear to recognize all of the HCV proteins equally and, as with $CD4^+$ T cells, it may be critical that they be capable of producing pro-inflammatory cytokines including gamma interferon **(15)**.

The transition from acute to chronic HCV infection is associated with substantial loss of HCV-specific $CD4^+$ T cells that do not appear to recover during the life of the host. $CD8^+$ T cell activity is also impaired, as it is insufficient for resolution of infection.

A number of experimental approaches to immunotherapy in general have been investigated, including the use of DNA-, recombinant viral-, and autologous dendritic cell-based vaccine strategies. DNA vaccines are good at priming immune responses in humans but are poor at boosting. In contrast, recombinant viruses are good at boosting but suffer from the limitation of vector neutralization. Finally, dendritic cell-based vaccines are patient-specific and labor intensive. Therefore, there remains a need in the art for an effective immunotherapeutic approach against HCV.

Summary of the Invention

One embodiment of the present invention relates to a vaccine comprising: (a) a yeast vehicle; and (b) an HCV fusion protein, wherein the yeast vehicle recombinantly expresses the fusion protein. The HCV fusion protein can be chosen from any of the HCV fusion proteins described below, with an HCV fusion protein comprising at least a portion of an HCV NS3 protease linked to at least a portion of an HCV Core sequence, being particularly preferred.

Accordingly, in one aspect, the HCV fusion protein comprises at least a portion of an HCV NS3 protease linked to at least a portion of an HCV Core sequence. Preferably, the HCV NS3 protease lacks the catalytic domain of a natural HCV NS3 protease. In one

aspect, the HCV NS3 protease consists essentially of the 262 amino acids of HCV NS3 following the initial N-terminal 88 amino acids of the full-length NS3 protein (positions 1115 to 1376 with respect to SEQ ID NO:20). In one aspect, the hydrophobic C-terminal sequence of the HCV Core is truncated. In one aspect, the HCV Core sequence consists essentially of amino acid positions 2 through 140 of the full-length HCV Core sequence (positions 2 to 140, with respect to SEQ ID NO:20). In another aspect, the HCV Core sequence has been appended to include two amino acids, glutamate and aspartate. In another aspect, the HCV Core sequence has been appended to include the amino acid sequence of G-G-G-H-H-H-H-H-H (SEQ ID NO:10). In one aspect, the HCV NS3 protease is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP). In yet another aspect, the fusion protein consists essentially of SEQ ID NO:2.

In another aspect, the fusion protein comprises a full-length, inactivated HCV NS3 protein. In one aspect, the HCV NS3 protein comprises a mutation at residue 1165 of the HCV polyprotein sequence, with respect to SEQ ID NO:20, that results in inactivation of the proteolytic activity of the protein. In another aspect, the HCV NS3 protease is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP). In yet another aspect, the fusion protein consists essentially of SEQ ID NO:4.

In yet another aspect, the fusion protein comprises a truncated HCV E1 protein fused to a truncated HCV E2 protein. In one aspect, the truncated HCV E1 protein consists essentially of amino acids 1 to 156 of HCV E1 (positions 192 to 347, with respect to SEQ ID NO:20). In yet another aspect, the truncated HCV E2 protein consists essentially of amino acids 1 to 334 of HCV E2 (positions 384 to 717, with respect to SEQ ID NO:20). In yet another aspect, the truncated HCV E1 protein is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP). In another aspect, the fusion protein consists essentially of SEQ ID NO:6.

In another aspect, the fusion protein comprises a transmembrane domain-deleted HCV NS4b protein. In one aspect, the transmembrane domain-deleted HCV NS4b protein consists essentially of amino acids 1 to 69 of HCV NS4b (positions 1712 to 1780, with respect to SEQ ID NO:20) linked to amino acids 177 to 261 of HCV NS4b (positions 1888 to 1972, with respect to SEQ ID NO:20). In yet another aspect, the transmembrane domain-deleted HCV NS4b protein is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP). In another aspect, the fusion protein consists essentially of SEQ ID NO:8.

In yet another aspect, the fusion protein comprises a full-length HCV Core protein fused to a full-length HCV E1 protein fused to a full-length HCV E2 protein. In one aspect, the full-length HCV Core protein is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP). In another aspect, the fusion protein consists essentially of SEQ ID NO:12.

In another aspect, the fusion protein comprises a truncated HCV Core protein fused to an HCV E1 protein with deleted transmembrane domain and an HCVE2 protein with deleted transmembrane domain. In one aspect, the truncated HCV Core protein consists essentially of positions 2 to 140 of HCV Core protein (positions 2 to 140, with respect to SEQ ID NO:20). In another aspect, the HCV E1 protein with deleted transmembrane domain consists essentially of positions 1 to 156 of HCV E1 protein (positions 192 to 347, with respect to SEQ ID NO:20). In yet another aspect, the truncated HCV E2 protein consists essentially of positions 1 to 334 of HCV E2 protein (positions 384 to 717, with respect to SEQ ID NO:20). In yet another aspect, the truncated HCV Core protein is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP). In another aspect, the fusion protein consists essentially of SEQ ID NO:14.

In another aspect, the fusion protein comprises HCV NS3 fused to HCV NS4a fused to HCV NS4b, wherein the HCV NS3 protease is inactivated and the HCV NS4b lacks a transmembrane domain. In one aspect, the HCV NS3 protein consists essentially of positions 1 to 631 of HCV HS3 (positions 1027 to 1657, with respect to SEQ ID NO:20), wherein the serine at position 1165 with respect to SEQ ID NO:20 has been substituted with alanine, to inactivate the protease. In one aspect, the HCV NS4a protein consists essentially of positions 1 to 54 of the HCV NS4a protein (positions 635 to 691, with respect to SEQ ID NO:20). In yet another aspect, the HCV NS4b protein consists essentially of positions 1 to 69 of HCV NS4b (positions 1712 to 1780, with respect to SEQ ID NO:20) fused to positions 177 to 261 of HCV NS4b (positions 1888 to 1972, with respect to SEQ ID NO:20). In another aspect, the HCV NS3 protein is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP). In yet another aspect, the fusion protein consists essentially of SEQ ID NO:16.

In yet another aspect, the fusion protein comprises an HCV NS5a protein fused to an HCV NS5b protein, wherein the NS5b protein contains an inactivating deletion of NS5b C-terminus. In one aspect, the HCV NS5a protein consists essentially of 1 to 448 of HCV NS5a (positions 1973 to 2420, with respect to SEQ ID NO:20). In one aspect, the HCV

NS5b protein consists essentially of positions 1 to 539 of HCV NS5b (positions 2421 to 2959, with respect to SEQ ID NO:20). In yet another aspect, the HCV NS5a protein is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP). In yet another aspect, the fusion protein consists essentially of SEQ ID NO:18.

In one embodiment, the expression of the fusion protein is under the control of an inducible promoter, such as *CUP1*.

Another embodiment of the present invention relates to an isolated HCV fusion protein, wherein the HCV protein is any of the above-described proteins and particularly, is chosen from SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:6, SEQ ID NO:8, SEQ ID NO:12, SEQ ID NO:14, SEQ ID NO:16 and SEQ ID NO:18.

Another embodiment of the present invention relates to an isolated nucleic acid molecule comprising a nucleic acid sequence encoding any of the above-described fusion proteins. In one embodiment, the expression of the fusion protein is under the control of an inducible promoter, such as *CUP1*.

Another embodiment of the present invention relates to a recombinant nucleic acid molecule comprising any of such isolated nucleic acid molecules. In one embodiment, the recombinant nucleic acid molecule is a viral vector.

Yet another embodiment of the invention relates to a recombinant cell that has been transfected with any of the recombinant nucleic acid molecules described herein. Such a cell can include, but is not limited to, a tumor cell or a yeast cell.

Another embodiment of the present invention relates to a vaccine comprising: (a) an HCV fusion protein as described above; and (b) a pharmaceutically acceptable carrier.

Yet another embodiment of the present invention relates to a vaccine comprising: (a) a dendritic cell; and (b) an HCV fusion protein as described above. Such a vaccine can further comprise a yeast vehicle, wherein the dendritic cell also contains the yeast vehicle.

Yet another embodiment of the present invention relates to a vaccine comprising an isolated nucleic acid molecule encoding an HCV fusion protein as described above.

Any of the above-described vaccines of the invention that include an isolated HCV fusion protein of the invention can also include at least one biological response modifier. Such biological response modifiers can include, but are not limited to: a cytokine, a hormone, a lipidic derivative, and a small molecule drug. Such biological response modifiers can include, but are not limited to: anti-CTLA-4, anti-CD137, anti-CD28, anti-

CD40, alemtuzumab, denileukin diftitox, anti-CD4, anti-CD25, anti-PD1, anti-PD-L1, anti-PD-L2, FOXP3-blocking agents, Flt-3 ligand, imiquimod, granulocyte-macrophage colony-stimulating factor (GM-CSF), sargramostim, Toll-like receptor (TLR)-7 agonists, and TLR-9 agonists.

Another embodiment of the present invention, relates to a method to protect an animal against hepatitis C virus (HCV) infection, comprising administering to an animal that has been infected with HCV or is at risk of being infected with HCV, any of the vaccines of the present invention as described herein, wherein administration of the vaccine to the animal reduces or prevents HCV infection or at least one symptom resulting from HCV infection in the animal.

Yet another embodiment of the present invention relates to a method to elicit an antigen-specific, cell-mediated immune response against an HCV antigen, comprising administering to an animal any of the vaccines of the present invention as described herein.

Another embodiment of the present invention relates to a method to elicit an antigen-specific, cell-mediated immune response against an HCV antigen in a population of individuals who have been infected with HCV, comprising administering to said population of individuals any of the above-described vaccines.

Yet another embodiment of the present invention relates to a method to immunize against HCV a population of individuals that is at risk of becoming infected with HCV, comprising administering to said population of individuals a vaccine according to any of the above-described vaccines.

In any of the above methods, the vaccine can be administered as a booster to a vaccine comprising a viral vector encoding an HCV antigen. In either of the above-methods, the vaccine can be administered to prime the immune system prior to boosting with a different HCV vaccine.

Another embodiment of the present invention relates to the use of any of the above-described vaccines in a formulation for protecting an animal against HCV infection.

Yet another embodiment of the present invention relates to the use of any of the above-described vaccines in a formulation for eliciting an antigen-specific, cell-mediated immune response against an HCV antigen.

Another embodiment of the present invention relates to the use any of the above-described vaccines in a formulation for treating or preventing a disease or condition.

Yet another embodiment of the present invention relates to the use of any of the above-described vaccines in a formulation for immunizing a population of individuals at risk for becoming infected with HCV.

Another embodiment of the present invention relates to the use any of the above-described vaccines in a formulation for treating a population of individuals that are infected with HCV.

Brief Description of the Drawings of the Invention

Figs. 1A and 1B are digital images of a Western blot (Fig. 1A) and Coomassie stain (Fig. 1B) showing expression of a truncated NS3-Core fusion protein and an inactivated HCV NS3 fusion protein in yeast vehicles according to the present invention.

Fig. 1C is a digital image of a Western blot showing expression of a truncated HCV E1-E2 fusion protein in a yeast vehicle according to the present invention.

Fig. 1D is a digital image of a Western blot showing expression of a transmembrane (TM) domain-deleted HCV NS4b fusion protein in a yeast vehicle according to the present invention.

Fig. 2 is a graph illustrating that a vaccine of the invention expressing a truncated NS3-Core fusion protein induces NS3- and Core-specific lymphocyte proliferation.

Figs. 3A-3C are graphs illustrating that a vaccine of the invention expressing a truncated NS3-Core fusion protein induces NS3-specific cytotoxic effector cells.

Figs. 4A and 4B are graphs demonstrating that a vaccine of the invention expressing a truncated NS3-Core fusion protein induces cytotoxic effector cells that kill tumor cells infected with recombinant vaccinia virus encoding HCV NS3 or Core.

Fig. 5 is a graph illustrating that a vaccine of the invention expressing a truncated NS3-Core fusion protein induces secretion of pro-inflammatory cytokines by mouse splenocytes.

Fig. 6 is a graph showing proliferating lymphocytes induced by one, two or three weekly immunizations with a vaccine of the invention expressing a truncated NS3-Core fusion protein.

Figs. 7A-7D are graphs showing the cytotoxic effector cell activity induced by one, two or three weekly immunizations with a vaccine of the invention expressing a truncated NS3-Core fusion protein.

Figs. 8A and 8B are graphs showing pro-inflammatory yeast-specific cytokine-secreting cells induced by one, two or three weekly immunizations with a vaccine of the invention expressing a truncated NS3-Core fusion protein.

Fig. 9 is a graph illustrating lymphocyte proliferation in spleen cells derived from BALB/c mice that that were immunized and boosted with a vaccine of the invention expressing a truncated NS3-Core fusion protein under different immunization protocols.

Fig. 10 is a graph illustrating cytotoxic effector cell activity in spleen effector cells derived from the BALB/c mice that were immunized and boosted with a vaccine of the invention expressing a truncated NS3-Core fusion protein under different immunization protocols.

Figs. 11A and 11B are graphs demonstrating the durability of lymphocyte proliferative responses induced with a vaccine of the invention expressing a truncated NS3-Core fusion protein.

Figs. 12A and 12B are graphs showing the durability of cytotoxic effector cell responses induced with a vaccine of the invention expressing a truncated NS3-Core fusion protein.

Figs. 13A-13D are graphs showing the durability of yeast- and NS3-specific cytokine-secreting cells induced with a vaccine of the invention expressing a truncated NS3-Core fusion protein.

Figs. 14A-14I are graphs illustrating cytotoxic effector cell activity induced with a vaccine of the invention expressing different amounts of a truncated NS3-Core fusion protein.

Figs. 15A-15C are graphs showing pro-inflammatory cytokine secreting cells induced with a vaccine of the invention expressing different amounts of a truncated NS3-Core fusion protein.

Fig. 16 is a graph showing that vaccines of the invention expressing a truncated NS3-Core fusion protein or an inactivated HCV NS3 protease fusion protein induces protective immunity in BALB/c mice against challenge with syngeneic tumor cells expressing HCV NS3.

Fig. 17 is a graph illustrating that a vaccine of the invention expressing a truncated NS3-Core fusion protein induces protective immunity in C57BL/6 mice against challenge with syngeneic tumor cells expressing HCV NS3.

Fig. 18 is a graph showing lymphocyte proliferative activity in spleen cells from "protected" mice.

Fig. 19 is a graph showing cytotoxic effector cell activity in spleen cells from "protected" mice.

Fig. 20 is a graph illustrating that a vaccine of the invention expressing a truncated NS3-Core fusion protein stimulates cytotoxic effector cell activity in spleen cells isolated from naïve tumor-bearing mice.

Fig. 21 is a graph showing that a vaccine of the invention expressing a truncated NS3-Core fusion protein induces therapeutic immunity in BALB/c mice bearing syngeneic B cell lymphomas expressing HCV NS3.

Figs. 22A and 22B are graphs showing that a vaccine of the invention expressing a truncated NS3-Core fusion protein induces therapeutic immunity in BALB/c mice bearing syngeneic B cell lymphomas expressing HCV NS3.

Figs. 23A and 23B are graphs showing that a vaccine of the invention expressing a truncated NS3-Core fusion protein induces yeast-specific lymphocyte proliferation in male and female New Zealand White Rabbits.

Detailed Description of the Invention

This invention generally relates to compositions and methods for vaccinating an animal against hepatitis C virus (HCV) and for treating or preventing hepatitis C viral infection in an animal. The invention includes the use of a particular yeast-based vaccine comprising a yeast vehicle and an HCV antigen fusion protein that is selected to elicit an immune response against HCV infection in an animal. The invention also includes the use of the HCV fusion gene and protein described herein in any vaccine and vaccine protocol for HCV.

Clinical evidence suggests that clearance and control of hepatitis C virus (HCV) infection is facilitated by cell-mediated immunity and that enhancement of immunity in chronically-infected individuals may have therapeutic benefits. Previous studies reported by the present inventors and others have shown the potential for using whole, recombinant *S. cerevisiae* yeast as a vaccine and immunotherapy vector (e.g., see U.S. Patent No. 5,830,463, issued November 3, 1998, U.S. Patent Application Serial No. 09/991,363, filed November 15, 2001, each of which is incorporated herein by reference in its entirety). The present inventors' yeast-based immunotherapeutic products have been shown to elicit

immune responses that are capable of killing target cells expressing a variety of viral and cancer antigens *in vivo*, in a variety of animal species, and to do so in an antigen-specific, $CD8^+$ CTL-mediated fashion **(16-17)**.

The present invention is directed to an improvement on the platform technology related to yeast-based immunotherapeutic products as described in U.S. Patent No. 5,830,463, issued November 3, 1998; U.S. Patent Application Serial No. 09/991,363, filed November 15, 2001. The present inventors have previously shown that *S. cerevisiae* are avidly phagocytosed by and directly activate dendritic cells which then present yeast-associated proteins to CD4 and CD8 T cells in a highly efficient manner (Stubbs et al. *Nature Med.* 5:625-629, 2001; and U.S. Patent Application Serial No. 09/991,363, *supra*). *S. cerevisiae* that express mutant Ras oncoproteins were shown to specifically eliminate established tumors bearing the homologous mutations in a mouse model of spontaneous lung cancer (Lu et al., *Cancer Research* 64:5084-5088, 2004) and this approach is currently being tested in a phase 1 human clinical trial in patients with pancreatic, lung and colorectal cancer. Immunotherapeutic products based on this platform technology are straightforward to produce, are not neutralized by host immune responses, can be administered repeatedly to boost antigen-specific immune responses, and do not require a patient-specific approach for manufacturing.

More particularly, and by way of example, the present inventors have developed a yeast-based vaccine that comprises a recombinant heat-inactivated *S. cerevisiae* yeast expressing a novel HCV fusion protein, which in one embodiment, contains at least a portion of both NS3 and Core protein sequences. Other embodiments include a novel full-length inactivated NS3 HCV protein, a novel truncated E1-E2 fusion protein, and a novel TM domain-deleted HCV NS4b fusion protein. Other embodiments of the invention will be apparent in view of the disclosure provided herein.

The HCV Core protein and NS3 protease are abundantly expressed in HCV-infected cells and are essential for virus replication; these characteristics combined with the high degree of sequence conservation make them excellent targets for immunotherapy. The vaccine of the present invention has been shown in animals to generate both antigen specific proliferative T cell responses as well as cytotoxic T cell (CTL) responses against virally infected cells expressing both NS3 and Core antigens and to protect animals against tumors expressing HCV antigens (see Examples and 18). Administration of the vaccine is expected to augment the HCV-specific $CD4^+$ and $CD8^+$ T cell response targeted to the HCV NS3 and

Core proteins, result in a reduction of viral load, and ultimately lead to viral clearance in HCV-infected individuals.

The novel HCV fusion protein that is used as a component of the yeast-based vaccine of the present invention is produced using a novel construct for expression of heterologous antigens in yeast, wherein the desired antigenic protein(s) or peptide(s) are fused at their amino-terminal end to: (a) a specific synthetic peptide described herein; or (b) at least a portion of an endogenous yeast protein, wherein either fusion partner provides significantly enhanced stability of expression of the protein in the yeast and/or a prevents post-translational modification of the proteins by the yeast cells. Also, the fusion peptides provide an epitope that can be designed to be recognized by a selection agent, such as an antibody, and do not appear to negatively impact the immune response against the vaccinating antigen in the construct. Such agents are useful for the identification, selection and purification of proteins useful in the invention.

In addition, the present invention contemplates the use of peptides that are fused to the C-terminus of the antigen construct, particularly for use in the selection and identification of the protein. Such peptides include, but are not limited to, any synthetic or natural peptide, such as a peptide tag (e.g., 6X His) or any other short epitope tag. Peptides attached to the C-terminus of an antigen according to the invention can be used with or without the addition of the N-terminal peptides discussed above.

Finally, the present inventors describe herein several different novel fusion protein HCV antigens for use in a yeast-based vaccine that provide multiple (two or more) immunogenic domains from one or more antigens within the same construct. An exemplary fusion protein comprising multiple immunogenic domains is the fusion protein comprising the HCV NS3 and Core proteins, or immunogenic portions thereof, that is described herein. Others are also described below.

As described above, NS3 and Core are abundantly expressed in infected cells, are required for viral replication and contain epitopes that are recognized by both $CD4^+$ and $CD8^+$ T cells in acute and chronic infection. An additional advantage of targeting these proteins, and particularly both proteins in a single vaccine, is the high degree of conservation at the amino acid level. Both the Core and NS3 proteins are highly conserved among HCV genotypes 1a and 1b, the HCV strains most prevalent in the U.S. (Table 1). The Core protein displays a 98% amino acid identity among strains 1a and 1b, and identities ranging from 86-95% for the other five HCV genotypes are observed compared to the HCV

1a protein sequence. The NS3 protein is also highly conserved among the different HCV strains – a 92% amino acid identity exists between strains 1a and 1b, and identities range from 81-86% for the other HCV genotypes compared to the HCV 1a protein sequence. The high degree of conservation of the Core and NS3 proteins among the various HCV genotypes signals the essential nature of specific overall protein domains for viral function. One vaccine of the present invention, despite being a single product, was designed to target two viral antigens, NS3 protease and Core protein. This approach can readily be expanded to incorporate the protein sequences of other essential and conserved HCV viral proteins to result in an even broader cellular immune response. Such additional fusion proteins and vaccines are exemplified herein.

The nucleic acid and amino acid sequence for HCV polyprotein genes and the polyproteins encoded thereby are known in the art. For example, the nucleic acid sequence of the polyprotein gene for Hepatitis C Virus strain H77 is described in Database Accession No. AF011753 (gi:2327074) and is represented herein by SEQ ID NO:19. SEQ ID NO:19 encodes the HCV strain H77 polyprotein, which has an amino acid sequence represented herein by SEQ ID NO:20. Within SEQ ID NO:20, the HCV proteins comprise the following positions: HCV Core (positions 1 to 191 of SEQ ID NO:20); HCV E1 envelope glycoprotein (positions 192 to 383 of SEQ ID NO:20); HCV E2 envelope glycoprotein (positions 384 to 746 of SEQ ID NO:20); HCV P7 ion channel (positions 747 to 809 of SEQ ID NO:20); HCV NS2 metalloprotease (positions 810 to 1026 of SEQ ID NO:20); HCV NS3 protease/helicase (positions 1027 to 1657 of SEQ ID NO:20); HCV NS4a NS3 protease cofactor (positions 1658 to 1711 of SEQ ID NO:20); HCV NS4b (positions 1712 to 1972 of SEQ ID NO:20); HCV NS5a (positions 1973 to 2420 of SEQ ID NO:20); and HCV NS5b RNA-dependent RNA polymerase (positions 2421 to 3011 of SEQ ID NO:20). As discussed above, strains of HCV display high amino acid identity (*e.g.*, see Table 1). Therefore, using the guidance provided herein and the reference to the exemplary HCV strain, one of skill in the art will readily be able to a variety of HCV-based fusion proteins from any HCV strain for use in the compositions and vaccines of the present invention.

It is clear that control and clearance of HCV requires both $CD4^+$ and $CD8^+$ T cells and that the lack of adequate cellular immunity is associated with development of chronic infection. It is appealing therefore, to propose that stimulation of existing but insufficient HCV-specific $CD4^+$ and $CD8^+$ T cells in chronically HCV infected individuals will have a therapeutic benefit. Without being bound by theory, the present inventors believe that the

ideal HCV immunotherapy consists of a non-pathogenic vector that can deliver antigens into the MHC class I and class II antigen presentation pathways to stimulate potent $CD4^+$ and $CD8^+$ T cell responses. This vector should also be capable of repeated administration, similar to other therapeutic products. The vaccine and compositions of the present invention are ideally suited to these goals.

Some immunotherapeutic vaccine preparations known prior to the present invention consisted of purified viral proteins that are endocytosed by dendritic cells and macrophages (also referred to generally herein as antigen presenting cells or APCs). The proteins in the engulfed material are digested into polypeptides (10-20 amino acids) which are bound to class II MHC molecules in specialized endosomes in APCs. The peptide + class II MHC molecule complex is then expressed on the surface of the APC. An antigen-specific $CD4^+$ helper T cell (T_H) binds to the combination of class II MHC + peptide, becomes activated and produces lymphokines.

Soluble antigens that are administered extracellularly without adjuvants tend to stimulate type 2 helper T cells (T_H2), which produce lymphokines that act on B cells leading to a humoral immune response. T_H2 responses tend to inhibit type 1 helper T cell (T_H1) responses that are important for induction of cell-mediated immunity. If the viral antigen being targeted is on the membrane of the infected cell, approaches that generate antibodies could have a therapeutic effect. However, if the viral antigen being targeted is found inside the infected cell, antibody generally has little effect. In addition, and because of the bias towards a T_H2 response, $CD8^+$ CTL are not normally activated in response to exogenously introduced protein antigens. If $CD8^+$ CTL are required for protection against chronic viral infection, it seems reasonable to postulate that approaches employing recombinant proteins may prove to be unsuccessful.

In contrast to extracellular antigens, $CD8^+$ CTL are induced in response to any antigen that is being synthesized by the cell to be targeted. These antigens are referred to as endogenous antigens. Viral proteins being synthesized by infected cells are digested into peptides (8-10 amino acids) by cytosolic proteasomes coupled with peptide delivery into the endoplasmic reticulum. Proper folding of class I MHC molecules in the endoplasmic reticulum is dependent on binding of proteasome-generated peptides, prior to trafficking to the surface of the infected or tumor cell. $CD8^+$ T cells respond to the combination of MHC I receptor-peptide complexes and produce lymphokines including IFN-γ which, in general, lead to a cell-mediated immune response, including killing of the infected cell.

CTL appear to require IL-2 and IL-12 in order to be effectively activated. While $CD8^+$ CTL can produce some IL-2, it is generally accepted that $CD4^+$ T_H1 cells are the major sources of IL-2 for CTL-mediated responses. IL-12 is produced by dendritic cells and macrophages. In addition, it is also clear that in order to obtain maximal CTL activation, presentation of antigens by dendritic cells is required. Thus, as for CD4+ T_H1 cells, CTL require interaction with an antigen presenting cell (APC) in order to become maximally activated and then respond to virally-infected cells.

It was initially unclear how antigens being synthesized by a virally-infected cell could find their way into the class I MHC pathway in dendritic cells, unless the dendritic cell itself became infected. However, recent data indicates that dendritic cells can recognize infected cells that become apoptotic as a result of infection and that "cross-priming" (delivery of exogenous antigens into the endogenous antigen presentation pathway) can occur such that some of the proteins associated with cells/particles engulfed by dendritic cells and macrophages find their way into the class I MHC pathway **(23)**. In addition, certain "danger" signals (described below) can enhance this process **(25)**.

Immune responses are initiated primarily by dendritic cells and macrophages that take up foreign material from extracellular fluids. A method to increase the ability of these cells to adequately present antigens should lead to an improved T cell-mediated cellular immune response. In this regard, recombinant *S. cerevisiae* yeast exhibit the particulate features of immunostimulatory complexes (ISCOMs) **(26)** with the added advantage that richly glycosylated yeast possess natural adjuvant-like properties and can be readily engineered to express multiple antigens **(16, 27-29)**. *S. cerevisiae* yeast cells are avidly taken up by professional antigen-presenting cells including macrophages and dendritic cells. Yeast-associated proteins are efficiently presented via both class I and class II MHC leading to protective antigen-specific CTL-mediated immunity to tumor cells **(16-17)**.

Dendritic cells and macrophages have a variety of receptors on their surface that act as microbial pattern recognition molecules; i.e., they recognize pathogens on the basis of differences in glycosylation patterns, lipoproteins and nucleic acid composition. Hence, such antigen presenting cells (APCs) have receptors for microbial mannoproteins, peptidoglycans, glucans, lipoproteins, double-stranded RNA and CpG island-containing DNA **(30-32)**. Engagement of these receptors results in what has been termed a "danger" signal leading to dendritic cell maturation, activation, enhanced phagocytosis, and efficient presentation of antigens that were associated with the engaging material **(33)**.

In fact, dendritic cells and macrophages may have more receptors that recognize yeast than any other microbe. These receptors include TLR-2, TLR-4, TLR-6, CD14, Dectin-1, Dectin-2, DEC-205 and the mannose receptor family **(30, 34).** Uptake of zymosan, a crude *Saccharomyces cerevisiae* yeast cell wall preparation, results in up-regulation of a multitude of pro-inflammatory genes **(35).** The present inventors' data indicate that uptake of whole yeast by mouse and human dendritic cells and macrophages results in upregulation of a variety of cell surface molecules including adhesion molecules (ICAM-1, CD54), co-stimulatory molecules (B7-1, B7-2, CD80, CD86), and class I and class II MHC molecules, as well as promoting the secretion of pro-inflammatory T_H1-type cytokines, such as TNF-α, GM-CSF, interferon-γ, IL-2 and IL-12.

In addition to being able to interact directly with dendritic cells, yeast have a variety of other characteristics that make them an ideal platform for immunotherapy. First, multiple antigens may be engineered for expression within a single yeast strain **(29)**, and these formulations share many advantages with DNA vaccines, including ease of construction and the ability to target multiple antigens. Unlike DNA vaccines, yeast-based immunotherapeutic formulations do not require extensive purification to remove potentially toxic contaminants. As will be described in further detail below, the heterologous proteins expressed in recombinant yeast serve as antigens for potent $CD8^+$ CTL-mediated immune responses *in vitro* and *in vivo* **(16-17).** In animal trials as preventative, as well as therapeutic treatments, the yeast formulation was successful at protecting and treating immunized animals from tumor growth **(16-17).** These results suggest that the vaccines of the present invention could be effective for eliciting broad-spectrum immune responses as an HCV immunotherapeutic.

In the present invention, the present inventors have generated a novel recombinant yeast immunotherapeutic, also referred to herein as GI-5005, that expresses an HCVNS3-Core fusion protein under the control of an inducible promoter. Immunoblot analysis of GI-5005 cell lysates using NS3- or Core-specific antibodies reveal a 47 kD protein. The GI-5005 yeast produce greater than 5 μg of the HCV fusion protein per 10 million cells. Injection of GI-5005 yeast in C57BL/6 and BALB/c mice resulted in induction of potent NS3 and Core antigen-specific helper and cytotoxic T cell immune responses as shown by lymphocyte proliferation, cytotoxicity and cytokine release assays. Mice that were vaccinated with GI-5000 series yeast were protected from challenge with HCV antigen-expressing syngeneic tumor cells. Immunogenicity and tumor protection results, as well as

results in a surrogate model of therapy are also presented herein. Finally, a phase 1 trial in chronically HCV infected patients will be described.

Vaccines and Compositions of the Invention

One embodiment of the present invention relates to a composition (vaccine) which can be used in a method to protect an animal against a HCV infection or disease resulting therefrom or to alleviate at least one symptom resulting from the HCV infection. The composition or vaccine. The vaccine comprises: (a) a yeast vehicle; and (b) a heterologous fusion protein expressed by the yeast vehicle. As discussed above, the invention includes several improved HCV fusion proteins for use as antigens in the vaccines of the invention, wherein such vaccines may include yeast vehicles, although other vaccines that do not include yeast vehicles are also contemplated by the present invention (see below). Specifically, the present invention provides new fusion protein constructs that stabilize the expression of the heterologous protein in the yeast vehicle, prevent posttranslational modification of the expressed heterologous protein, and/or that can be used as vaccinating antigens in the absence of the yeast vehicle described herein (i.e., in conventional or other non-yeast-based vaccine compositions). The novel fusion proteins, in some embodiments, also provide a broad cellular immune response by the use of multiple selected antigens in a single vaccine. In conjunction with the yeast vehicle, these fusion proteins are most typically expressed as recombinant proteins by the yeast vehicle (e.g., by an intact yeast or yeast spheroplast, which can optionally be further processed to a yeast cytoplast, yeast ghost, or yeast membrane extract or fraction thereof), although it is an embodiment of the invention that one or much such fusion proteins could be loaded into a yeast vehicle or otherwise complexed or mixed with a yeast vehicle as described above to form a vaccine of the present invention.

One such fusion construct useful in the present invention is a fusion protein that includes: (a) at least one HCV antigen (including immunogenic domains and epitopes of a full-length antigen, as well as various fusion proteins and multiple antigen constructs as described elsewhere herein); and (b) a synthetic peptide.

In one embodiment, the synthetic peptide linked to the N-terminus of the HCV antigen, the peptide consisting of at least two amino acid residues that are heterologous to the HCV antigen, wherein the peptide stabilizes the expression of the fusion protein in the yeast vehicle or prevents posttranslational modification of the expressed fusion protein. The synthetic peptide and N-terminal portion of the antigen together form a fusion protein that

has the following requirements: (1) the amino acid residue at position one of the fusion protein is a methionine (i.e., the first amino acid in the synthetic peptide is a methionine); (2) the amino acid residue at position two of the fusion protein is not a glycine or a proline (i.e., the second amino acid in the synthetic peptide is not a glycine or a proline); (3) none of the amino acid residues at positions 2-6 of the fusion protein is a methionine (i.e., the amino acids at positions 2-6, whether part of the synthetic peptide or the protein, if the synthetic peptide is shorter than 6 amino acids, do not include a methionine); and (4) none of the amino acids at positions 2-6 of the fusion protein is a lysine or an arginine (i.e., the amino acids at positions 2-6, whether part of the synthetic peptide or the protein, if the synthetic peptide is shorter than 5 amino acids, do not include a lysine or an arginine). The synthetic peptide can be as short as two amino acids, but is more preferably at least 2-6 amino acids (including 3, 4, 5 amino acids), and can be longer than 6 amino acids, in whole integers, up to about 200 amino acids.

In one embodiment, the peptide comprises an amino acid sequence of M-X_2-X_3-X_4-X_5-X_6, wherein M is methionine; wherein X_2 is any amino acid except glycine, proline, lysine or arginine; wherein X_3 is any amino acid except methionine, lysine or arginine; wherein X_4 is any amino acid except methionine, lysine or arginine; wherein X_5 is any amino acid except methionine, lysine or arginine; and wherein X_6 is any amino acid except methionine, lysine or arginine. In one embodiment, the X_6 residue is a proline. An exemplary synthetic sequence that enhances the stability of expression of an HCV antigen in a yeast cell and/or prevents post-translational modification of the protein in the yeast includes the sequence M-A-D-E-A-P (SEQ ID NO:9). In addition to the enhanced stability of the expression product, the present inventors believe that this fusion partner does not appear to negatively impact the immune response against the vaccinating antigen in the construct. In addition, the synthetic fusion peptides can be designed to provide an epitope that can be recognized by a selection agent, such as an antibody.

In another embodiment of the invention, the nucleic acids that encode the translation start site of a synthetic peptide used in the invention are A-C-C-A-T-G-G, (SEQ ID NO:21) in accordance with Kozak translation sequence rules, where the ATG in this sequence is the initial translation start site and encodes the methionine of M-A-D-E-A-P (SEQ ID NO:9).

It is to be understood that various embodiments of the invention as described herein may also be combined. For example, in one aspect of the invention, when the synthetic peptide is M-A-D-E-A-P (SEQ ID NO:9), the nucleic acids encoding the start site for this

peptide can be A-C-C-A-T-G-G (SEQ ID NO:10) as described above. Various other combinations of embodiments of the invention will be apparent to those of skill in the art.

Another specific embodiment of the present invention that is similar to the embodiment above and that can include the limitations of the embodiment above (although this is not required) includes a vaccine comprising: (iii) a peptide linked to the C-terminus of the HCV antigen, the peptide consisting of at least two amino acid residues that are heterologous to the HCV antigen, wherein the peptide stabilizes the expression of the fusion protein in the yeast vehicle or prevents posttranslational modification of the expressed fusion protein. In one exemplary aspect of the invention, the peptide comprises an amino acid sequence of E-D (Glu-Asp). Such a sequence works to counteract hydrophobicity.

According to the present invention, "heterologous amino acids" are a sequence of amino acids that are not naturally found (i.e., not found in nature, *in vivo*) flanking the specified amino acid sequence, or that are not related to the function of the specified amino acid sequence, or that would not be encoded by the nucleotides that flank the naturally occurring nucleic acid sequence encoding the specified amino acid sequence as it occurs in the gene, if such nucleotides in the naturally occurring sequence were translated using standard codon usage for the organism from which the given amino acid sequence is derived. Therefore, at least two amino acid residues that are heterologous to the HCV antigen are any two amino acid residues that are not naturally found flanking the HCV antigen.

Another embodiment of the present invention relates to a composition (vaccine) that can be used for protecting an animal against HCV infection or a symptom resulting from such infection comprising: (a) a yeast vehicle; and (b) a heterologous fusion protein expressed by the yeast vehicle. In one embodiment, the fusion protein comprises: (i) at least one HCV antigen (including immunogenic domains and epitopes of a full-length antigen, as well as various fusion proteins and multiple antigen constructs as described elsewhere herein) that is fused to (ii) a yeast protein linked to the N-terminus of the HCV antigen, wherein the yeast protein consists of between about two and about 200 amino acids of an endogenous yeast protein, wherein the yeast protein provides significantly enhanced stability of the expression of the fusion protein in the yeast vehicle or prevents posttranslational modification of the expressed fusion protein by the yeast cells. In addition, the endogenous yeast antigen, as with the synthetic peptide, this fusion partner does not appear to negatively impact the immune response against the vaccinating antigen in the

construct. This aspect of the invention may be used in connection with other embodiments of the invention described above.

The endogenous yeast protein consists of between about two and about 200 amino acids (or 22kDa maximum) of an endogenous yeast protein, wherein the yeast protein stabilizes the expression of the fusion protein in the yeast vehicle or prevents posttranslational modification of the expressed fusion protein. Any suitable endogenous yeast protein can be used in this embodiment, and particularly preferred proteins include, but are not limited to, SUC2 (yeast invertase; which is a good candidate for being able to express a protein both cytosolically and directing it into the secretory pathway from the same promoter, but is dependent on the carbon source in the medium); alpha factor signal leader sequence; SEC7; CPY; phosphoenolpyruvate carboxykinase PCK1, phosphoglycerokinase PGK and triose phosphate isomerase TPI gene products for their repressible expression in glucose and cytosolic localization; Cwp2p for its localization and retention in the cell wall; the heat shock proteins SSA1, SSA3, SSA4, SSC1 and KAR2, whose expression is induced and whose proteins are more thermostable upon exposure of cells to heat treatment; the mitochondrial protein CYC1 for import into mitochondria; BUD genes for localization at the yeast cell bud during the initial phase of daughter cell formation; ACT1 for anchoring onto actin bundles.

In one embodiment, the endogenous yeast protein/peptide or the synthetic peptide used in fusion proteins herein comprise an antibody epitope for identification and purification of the fusion protein. Antibodies may already be available that selectively bind to an endogenous antigen or can be readily generated. Finally, if it is desired to direct a protein to a particular cellular location (e.g., into the secretory pathway, into mitochondria, into the nucleus), then the construct can use the endogenous signals for the yeast protein to be sure that the cellular machinery is optimized for that delivery system. Preferably, an antibody is available or produced that selectively binds to the fusion partner. According to the present invention, the phrase "selectively binds to" refers to the ability of an antibody, antigen binding fragment or binding partner of the present invention to preferentially bind to specified proteins. More specifically, the phrase "selectively binds" refers to the specific binding of one protein to another (*e.g.*, an antibody, fragment thereof, or binding partner to an antigen), wherein the level of binding, as measured by any standard assay (*e.g.*, an immunoassay), is statistically significantly higher than the background control for the assay. For example, when performing an immunoassay, controls typically include a reaction

well/tube that contain antibody or antigen binding fragment alone (*i.e.*, in the absence of antigen), wherein an amount of reactivity (*e.g.*, non-specific binding to the well) by the antibody or antigen binding fragment thereof in the absence of the antigen is considered to be background. Binding can be measured using a variety of methods standard in the art including enzyme immunoassays (*e.g.*, ELISA), immunoblot assays, etc.).

In one embodiment, a vaccine of the present invention can comprise a peptide linked to the C-terminus of the HCV antigen, wherein the peptide allows for recognition of the fusion protein by an antibody directed against the peptide. In one aspect, the peptide comprises an amino acid sequence of G-G-G-H-H-H-H-H-H (SEQ ID NO:10). This embodiment can be used alone or in conjunction with other aspects of the fusion proteins described above.

As discussed above, the fusion proteins used in the vaccines and compositions of the invention include at least one HCV antigen for vaccinating an animal. The composition or vaccine can include, one, two, a few, several or a plurality of HCV antigens, including one or more immunogenic domains of one or more HCV antigens, as desired. For example, any fusion protein described herein can include at least a portion of any one or more HCV proteins selected from: HCV E1 envelope glycoprotein, HCV E2 envelope glycoprotein, HCV P7 ion channel, HCV NS2 metalloprotease, HCV NS3 protease/helicase, HCV NS4a NS3 protease cofactor, HCV NS4b, HCV NS5a, HCV NS5b RNA-dependent RNA polymerase, and HCV Core sequence. In a preferred embodiment, a portion of an HCV protein other than the HCV Core sequence is linked to at least a portion of an HCV Core sequence. In another aspect, the fusion protein comprises at least one or more immunogenic domains of one or more HCV antigens.

According to the present invention, the general use herein of the term "antigen" refers: to any portion of a protein (peptide, partial protein, full-length protein), wherein the protein is naturally occurring or synthetically derived, to a cellular composition (whole cell, cell lysate or disrupted cells), to an organism (whole organism, lysate or disrupted cells) or to a carbohydrate or other molecule, or a portion thereof, wherein the antigen elicits an antigen-specific immune response (humoral and/or cellular immune response), or alternatively acts as a toleragen, against the same or similar antigens that are encountered within the cells and tissues of the animal to which the antigen is administered.

In one embodiment of the present invention, when it is desirable to stimulate an immune response, the term “antigen” can be used interchangeably with the term

"immunogen", and is used herein to describe a protein, peptide, cellular composition, organism or other molecule which elicits a humoral and/or cellular immune response (i.e., is antigenic), such that administration of the immunogen to an animal (e.g., via a vaccine of the present invention) mounts an antigen-specific immune response against the same or similar antigens that are encountered within the tissues of the animal. Therefore, to vaccinate an animal against a particular antigen means, in one embodiment, that an immune response is elicited against the antigen or immunogenic or toleragenic portion thereof, as a result of administration of the antigen. Vaccination preferably results in a protective or therapeutic effect, wherein subsequent exposure to the antigen (or a source of the antigen) elicits an immune response against the antigen (or source) that reduces or prevents a disease or condition in the animal. The concept of vaccination is well known in the art. The immune response that is elicited by administration of a therapeutic composition of the present invention can be any detectable change in any facet of the immune response (e.g., cellular response, humoral response, cytokine production), as compared to in the absence of the administration of the vaccine.

A "vaccinating antigen" can be an immunogen or a toleragen, but is an antigen used in a vaccine, where a biological response (elicitation of an immune response, tolerance) is to be elicited against the vaccinating antigen.

An immunogenic domain (portion, fragment, epitope) of a given antigen can be any portion of the antigen (i.e., a peptide fragment or subunit or an antibody epitope or other conformational epitope) that contains at least one epitope that acts as an immunogen when administered to an animal. For example, a single protein can contain multiple different immunogenic domains. Immunogenic domains need not be linear sequences within a protein, in the case of a humoral response.

An epitope is defined herein as a single immunogenic site within a given antigen that is sufficient to elicit an immune response, or a single toleragenic site within a given antigen that is sufficient to suppress, delete or render inactive an immune response. Those of skill in the art will recognize that T cell epitopes are different in size and composition from B cell epitopes, and that epitopes presented through the Class I MHC pathway differ from epitopes presented through the Class II MHC pathway. Epitopes can be linear sequence or conformational epitopes (conserved binding regions). depending on the type of immune response. An antigen can be as small as a single epitope, or larger, and can include multiple epitopes. As such, the size of an antigen can be as small as about 5-12 amino

acids (e.g., a peptide) and as large as: a full length protein, including a multimer and fusion proteins, chimeric proteins, whole cells, whole microorganisms, or portions thereof (e.g., lysates of whole cells or extracts of microorganisms). In addition, antigens can include carbohydrates, which can be loaded into a yeast vehicle or into a composition of the invention. It will be appreciated that in some embodiments (i.e., when the antigen is expressed by the yeast vehicle from a recombinant nucleic acid molecule), the antigen is a protein, fusion protein, chimeric protein, or fragment thereof, rather than an entire cell or microorganism. Preferred HCV fusion proteins of the invention are described herein.

In yet another embodiment of the invention, the HCV antigen portion of the vaccine is produced as a fusion protein comprising two or more antigens. In one aspect, the fusion protein can include two or more immunogenic domains or two or more epitopes of one or more antigens (e.g., the HCV NS3 sequence and the HCV Core sequence described herein). Such a vaccine may provide antigen-specific immunization in a broad range of patients. For example, a multiple domain fusion protein useful in the present invention may have multiple domains, wherein each domain consists of a peptide from a particular protein, the peptide consisting of at least 4 amino acid residues flanking either side of and including a mutated amino acid that is found in the protein, wherein the mutation is associated with a particular disease or condition (e.g., HCV infection).

In one embodiment of the present invention, any of the amino acid sequences described herein can be produced with from at least one, and up to about 20, additional heterologous amino acids flanking each of the C- and/or N-terminal ends of the specified amino acid sequence. The resulting protein or polypeptide can be referred to as "consisting essentially of" the specified amino acid sequence. As discussed above, according to the present invention, the heterologous amino acids are a sequence of amino acids that are not naturally found (i.e., not found in nature, *in vivo*) flanking the specified amino acid sequence, or that are not related to the function of the specified amino acid sequence, or that would not be encoded by the nucleotides that flank the naturally occurring nucleic acid sequence encoding the specified amino acid sequence as it occurs in the gene, if such nucleotides in the naturally occurring sequence were translated using standard codon usage for the organism from which the given amino acid sequence is derived. Similarly, the phrase "consisting essentially of", when used with reference to a nucleic acid sequence herein, refers to a nucleic acid sequence encoding a specified amino acid sequence that can be flanked by from at least one, and up to as many as about 60, additional heterologous

nucleotides at each of the 5' and/or the 3' end of the nucleic acid sequence encoding the specified amino acid sequence. The heterologous nucleotides are not naturally found (i.e., not found in nature, *in vivo*) flanking the nucleic acid sequence encoding the specified amino acid sequence as it occurs in the natural gene or do not encode a protein that imparts any additional function to the protein or changes the function of the protein having the specified amino acid sequence.

In one preferred aspect of the invention, the HCV antigen is an HCV protein consisting of HCV NS3 protease and Core sequence. In another aspect, the HCV antigen consists of an HCV NS3 protein lacking the catalytic domain of the natural NS3 protein which is linked to HCV Core sequence. In another aspect, the HCV antigen consists of the 262 amino acids of HCV NS3 following the initial N-terminal 88 amino acids of the natural NS3 protein (i.e., positions 89-350 of HCV NS3; SEQ ID NO:20) linked to HCV Core sequence. In one aspect, the HCV Core sequence lacks the hydrophobic C-terminal sequence. In another aspect, the HCV Core sequence lacks the C-terminal two amino acids, glutamate and aspartate. In a preferred aspect, the HCV Core sequence consists of amino acid positions 2 through 140 of the natural HCV Core sequence.

An example of such a vaccine is described in Example 1. In this embodiment, a yeast (*e.g., Saccharomyces cerevisiae*) was engineered to express a HCV NS3-Core fusion protein under the control of the copper-inducible promoter, *CUP1*. The fusion protein is a single polypeptide with the following sequence elements fused in frame from N- to C-terminus (HCV polyprotein (SEQ ID NO:20) numbering in parentheses, with the amino acid sequence of the fusion protein being represented herein by SEQ ID NO:2): 1) the sequence MADEAP (SEQ ID NO:9) to impart resistance to proteasomal degradation (positions 1 to 6 of SEQ ID NO:2); 2) amino acids 89 to 350 of (1115 to 1376 of SEQ ID NO:20) of the HCV NS3 protease protein (positions 6 to 268 of SEQ ID NO:2); 3) a single threonine amino acid residue introduced in cloning (position 269 of SEQ ID NO:2); 4) amino acids 2 to 140 (2 to 140 of SEQ ID NO:20) of the HCV Core protein (positions 270 to 408 of SEQ ID NO:2); and 5) the sequence E-D to increase the hydrophilicity of the Core variant (positions 409 to 410 of SEQ ID NO:2). A nucleic acid sequence encoding the fusion protein of SEQ ID NO:2 is represented herein by SEQ ID NO:1.

In another preferred aspect of the invention, the HCV antigen is an inactivated full-length HCV NS3 that is part of a fusion protein according to the invention. An example of such a vaccine is described in Example 2. In this embodiment, a yeast (*e.g., Saccharomyces*

cerevisiae) was engineered to express an inactivated full-length HCV NS3 fusion protein under the control of the copper-inducible promoter, *CUP1*. The fusion protein comprising the full-length HCV NS3 is a single polypeptide with the following sequence elements fused in frame from N- to C-terminus (HCV polyprotein numbering in parentheses, with the amino acid sequence of the fusion protein being represented herein by SEQ ID NO:4): 1) the sequence MADEAP (SEQ ID NO:9) to impart resistance to proteasomal degradation (positions 1 to 6 of SEQ ID NO:4); and 2) amino acids 1 to 631 (1027 to 1657 of SEQ ID NO:20) of the HCV NS3 protease protein (positions 7 to 637 of SEQ ID NO:4) (note that the amino acid at HCV polypeptide residue 1165 has been changed from a serine to an alanine in order to inactivate the proteolytic activity). A nucleic acid sequence encoding the fusion protein of SEQ ID NO:4 is represented herein by SEQ ID NO:3.

In another preferred aspect of the invention, the yeast vaccine comprises a truncated HCV E1-E2 fusion protein. An example of such a vaccine is described in Example 3. In this embodiment, a yeast (*e.g., Saccharomyces cerevisiae*) is engineered to express an E1-E2 fusion protein as a single polypeptide having the following sequence elements fused in frame from N- to C-terminus (HCV polyprotein numbering in parentheses, where the amino acid sequence of the fusion protein is represented herein by SEQ ID NO:6): 1) The sequence MADEAP (SEQ ID NO:9) to impart resistance to proteasomal degradation (positions 1 to 6 of SEQ ID NO:6); 2) amino acids 1 to 156 (192 to 347 of SEQ ID NO:20) of HCV protein E1 (positions 7 to162 of SEQ ID NO:6); and 3) amino acids 1 to 334 (384 to 717 of SEQ ID NO:20) of HCV protein E2 (positions 163 to 446 of SEQ ID NO:6). It is noted that in this particular fusion protein, 36 C-terminal hydrophobic amino acids of E1 and 29 C-terminal hydrophobic amino acids of E2 were omitted from the fusion protein to promote cytoplasmic accumulation in yeast. A nucleic acid sequence encoding the fusion protein of SEQ ID NO:6 is represented herein by SEQ ID NO:5.

In yet another preferred aspect of the invention, the yeast vaccine comprises a transmembrane (TM) domain-deleted HCV NS4b fusion protein. An example of such vaccine is described in Example 4. The fusion protein is a single polypeptide with the following sequence elements arranged in tandem, in frame, from N- to C-terminus (polyprotein numbering in parentheses, with the amino acid sequence of the fusion protein being represented herein by SEQ ID NO:8): 1) The sequence MADEAP (SEQ ID NO:9) to impart resistance to proteosomal degradation (positions 1 to 6 of SEQ ID NO:8); 2) amino acids 1 to 69 (1712 to 1780 of SEQ ID NO:20) of HCV protein NS4b (positions 7 to 75 of

SEQ ID NO:8); and 3) amino acids 177 to 261 (1888 to 1972 of SEQ ID NO:20) of HCV protein NS4b (positions 76 to 160 of SEQ ID NO:8). A 107 amino acid region corresponding to NS4b amino acids 70 to 176 (1781 to 1887 of SEQ ID NO:20) that contains multiple membrane spanning domains was omitted to promote cytoplasmic accumulation in yeast. A nucleic acid sequence encoding the fusion protein of SEQ ID NO:8 is represented herein by SEQ ID NO:7.

In yet another preferred aspect of the invention, the yeast vaccine comprises a Core-E1-E2 fusion protein. The fusion protein is a single polypeptide with the following sequence elements arranged in tandem, in frame, from N- to C-terminus (polyprotein numbering in parentheses, with the amino acid sequence of the fusion protein being represented herein by SEQ ID NO:12): 1) The sequence MADEAP (SEQ ID NO:9) to impart resistance to proteosomal degradation (positions 1-6 of SEQ ID NO:12); and 2) amino acids 1 to 746 (2 to 746 of SEQ ID NO:20) of unmodified HCV polyprotein encoding full-length Core, E1, and E2 proteins (positions 7 to 751 of SEQ ID NO:12: Core spanning from position 7 to 196; E1 spanning from positions 197 to 387; and E2 spanning from positions 388 to 751). A nucleic acid sequence encoding the fusion protein of SEQ ID NO:12 is represented herein by SEQ ID NO:11.

In another preferred aspect of the invention, the yeast vaccine comprises a Core-E1-E2 fusion protein with transmembrane domains deleted. The fusion protein is a single polypeptide with the following sequence elements fused in frame from N- to C-terminus (polyprotein numbering in parentheses, with the amino acid sequence of the fusion protein being represented herein by SEQ ID NO:14): 1) The sequence MADEAP (SEQ ID NO:9) to impart resistance to proteasomal degradation, 2) amino acids 2 to 140 (2 to 140 of SEQ ID NO:20) of HCV Core protein (positions 7 to 145 of SEQ ID NO:14), 3) amino acids 1 to 156 (192 to 347 of SEQ ID NO:20) of HCV protein E1 (positions 146 to 301 of SEQ ID NO:14), and 4) amino acids 1 to 334 (384 to 717 of SEQ ID NO:20) of HCV protein E2 (positions 302 to 635 of SEQ ID NO:14). The 51 C-terminal hydrophobic amino acids of Core protein, the 36 C-terminal hydrophobic amino acids of E1 and the 29 C-terminal hydrophobic amino acids of E2 were omitted from the fusion protein to promote cytoplasmic accumulation in yeast. A nucleic acid sequence encoding the fusion protein of SEQ ID NO:14 is represented herein by SEQ ID NO:13.

In yet another preferred aspect of the invention, the yeast vaccine comprises an NS3-NS4a-NS4b fusion protein wherein the NS3 protease is inactivated and the NS4b lacks a

transmembrane domain. The NS3-NS4a-NS4b fusion protein is a single polypeptide with the following sequence elements fused in frame from N- to C-terminus (polyprotein numbering in parentheses, with the amino acid sequence of the fusion protein being represented herein by SEQ ID NO:16): 1) The sequence MADEAP (SEQ ID NO:9) to impart resistance to proteasomal degradation (positions 1 to 6 of SEQ ID NO:16); 2) amino acids 1 to 631 (1027 to 1657 of SEQ ID NO:20) corresponding to full-length HCV NS3 protein (note: Serine 139 (position 1165, with respect to SEQ ID NO:20) is changed to alanine to inactivate the proteolytic potential of NS3) (positions 7 to 634 of SEQ ID NO:16); 3) amino acids 1 to 54 (1658 to 1711 of SEQ ID NO:20) of NS4a protein (positions 635 to 691 of SEQ ID NO:16); 4) amino acids 1 to 69 (1712 to 1780 of SEQ ID NO:20) of HCV protein NS4b (positions 692 to 776 of SEQ ID NO:16); and 5) amino acids 177 to 261 (1888 to 1972 of SEQ ID NO:20) of HCV protein NS4b (positions 777 to 845 of SEQ ID NO:16). A 107 amino acid region corresponding to NS4b amino acids 70 to 176 (1781 to 1887 of SEQ ID NO:20) that contains multiple membrane spanning domains was omitted to promote cytoplasmic accumulation in yeast. A nucleic acid sequence encoding the fusion protein of SEQ ID NO:16 is represented herein by SEQ ID NO:15.

In another preferred aspect of the invention, the yeast vaccine comprises a NS5a-NS5b fusion protein with an inactivating deletion of NS5b C-terminus. This NS5a-NS5b fusion protein is a single polypeptide with the following sequence elements fused in frame from N- to C-terminus (polyprotein numbering in parentheses, with the amino acid sequence of the fusion protein being represented herein by SEQ ID NO:18): 1) The sequence MADEAP (SEQ ID NO:9) to impart resistance to proteasomal degradation (positions 1 to 6 of SEQ ID NO:18); 2) the entirety of NS5a protein corresponding to amino acids 1 to 448 (1973 to 2420 of SEQ ID NO:20) (positions 7 to 454 of SEQ ID NO:18); and 3) amino acids 1 to 539 (2421 to 2959 of SEQ ID NO:20) of NS5b (positions 455 to 993 of SEQ ID NO:18). The 52 C-terminal residues that are required for the activity of NS5b in HCV replication were deleted to inactivate the protein. A nucleic acid sequence encoding the fusion protein of SEQ ID NO:18 is represented herein by SEQ ID NO:17.

According to the present invention, any of the fusion proteins described herein can comprise a peptide linked to the N-terminus of the fusion protein that consists of at least 2-6 amino acid residues that are heterologous to the HCV antigen. In one aspect, the peptide comprises an amino acid sequence of M-X_2-X_3-X_4-X_5-X_6, wherein X_2 is any amino acid except glycine, proline, lysine or arginine; wherein X_3 is any amino acid except methionine,

lysine or arginine; wherein X_4 is any amino acid except methionine, lysine or arginine; wherein X_5 is any amino acid except methionine, lysine or arginine; and wherein X_6 is any amino acid except methionine. In one aspect, X_6 is a proline. In another aspect, the peptide comprises an amino acid sequence of M-A-D-E-A-P (SEQ ID NO:9).

In a particular aspect of the invention, the above-described fusion protein contains a heterologous linker sequence between two HCV proteins (*e.g.*, the HCV NS3 sequence and the HCV Core sequence). In a preferred embodiment, the heterologous linker sequence consists of a single heterologous amino acid residue. In a more preferred embodiment, the heterologous linker sequence consists of a single threonine residue.

In any of the above-described compositions (e.g., vaccines) of the present invention, the following aspects related to the yeast vehicle are included in the invention. In one embodiment, yeast vehicle is selected from the group consisting of a whole yeast, a yeast spheroplast, a yeast cytoplast, a yeast ghost, and a subcellular yeast membrane extract or fraction thereof. In one aspect, a yeast cell or yeast spheroplast used to prepare the yeast vehicle was transformed with a recombinant nucleic acid molecule encoding the antigen(s) such that the antigen is recombinantly expressed by the yeast cell or yeast spheroplast. In this aspect, the yeast cell or yeast spheroplast that recombinantly expresses the antigen(s) is used to produce a yeast vehicle comprising a yeast cytoplast, a yeast ghost, or a subcellular yeast membrane extract or fraction thereof. In one aspect, the yeast vehicle is from a non-pathogenic yeast. In another aspect, the yeast vehicle is from a yeast selected from the group consisting of: *Saccharomyces, Schizosaccharomyces, Kluveromyces, Hansenula, Candida* and *Pichia*. In one aspect, the *Saccharomyces* is *S. cerevisiae*.

In general, the yeast vehicle and antigen can be associated by any technique described herein. In one aspect, the yeast vehicle was loaded intracellularly with the HCV antigen. In another aspect, the HCV antigen was covalently or non-covalently attached to the yeast vehicle. In yet another aspect, the yeast vehicle and the HCV antigen were associated by mixing. In another aspect, the antigen is expressed recombinantly by the yeast vehicle or by the yeast cell or yeast spheroplast from which the yeast vehicle was derived.

More specifically, according to the present invention, a yeast vehicle is any yeast cell (e.g., a whole or intact cell) or a derivative thereof (see below) that can be used in conjunction with an antigen in a vaccine or therapeutic composition of the invention, or as an adjuvant. The yeast vehicle can therefore include, but is not limited to, a live intact yeast

microorganism (i.e., a yeast cell having all its components including a cell wall), a killed (dead) intact yeast microorganism, or derivatives thereof including: a yeast spheroplast (i.e., a yeast cell lacking a cell wall), a yeast cytoplast (i.e., a yeast cell lacking a cell wall and nucleus), a yeast ghost (i.e., a yeast cell lacking a cell wall, nucleus and cytoplasm), or a subcellular yeast membrane extract or fraction thereof (also referred to previously as a subcellular yeast particle).

Yeast spheroplasts are typically produced by enzymatic digestion of the yeast cell wall. Such a method is described, for example, in Franzusoff et al., 1991, *Meth. Enzymol.* 194, 662-674., incorporated herein by reference in its entirety. Yeast cytoplasts are typically produced by enucleation of yeast cells. Such a method is described, for example, in Coon, 1978, *Natl. Cancer Inst. Monogr.* 48, 45-55 incorporated herein by reference in its entirety. Yeast ghosts are typically produced by resealing a permeabilized or lysed cell and can, but need not, contain at least some of the organelles of that cell. Such a method is described, for example, in Franzusoff et al., 1983, *J. Biol. Chem.* 258, 3608-3614 and Bussey et al., 1979, *Biochim. Biophys. Acta* 553, 185-196, each of which is incorporated herein by reference in its entirety. A subcellular yeast membrane extract or fraction thereof refers to a yeast membrane that lacks a natural nucleus or cytoplasm. The particle can be of any size, including sizes ranging from the size of a natural yeast membrane to microparticles produced by sonication or other membrane disruption methods known to those skilled in the art, followed by resealing. A method for producing subcellular yeast membrane extracts is described, for example, in Franzusoff et al., 1991, *Meth. Enzymol.* 194, 662-674. One may also use fractions of yeast membrane extracts that contain yeast membrane portions and, when the antigen was expressed recombinantly by the yeast prior to preparation of the yeast membrane extract, the antigen of interest.

Any yeast strain can be used to produce a yeast vehicle of the present invention. Yeast are unicellular microorganisms that belong to one of three classes: Ascomycetes, Basidiomycetes and Fungi Imperfecti. While pathogenic yeast strains, or nonpathogenic mutants thereof can be used in accordance with the present invention, nonpathogenic yeast strains are preferred. Preferred genera of yeast strains include *Saccharomyces*, *Candida* (which can be pathogenic), *Cryptococcus*, *Hansenula*, *Kluyveromyces*, *Pichia*, *Rhodotorula*, *Schizosaccharomyces* and *Yarrowia*, with *Saccharomyces*, *Candida*, *Hansenula*, *Pichia* and *Schizosaccharomyces* being more preferred, and with *Saccharomyces* being particularly preferred. Preferred species of yeast strains include *Saccharomyces cerevisiae*,

Saccharomyces carlsbergensis, *Candida albicans*, *Candida kefyr*, *Candida tropicalis*, *Cryptococcus laurentii*, *Cryptococcus neoformans*, *Hansenula anomala*, *Hansenula polymorpha*, *Kluyveromyces fragilis*, *Kluyveromyces lactis*, *Kluyveromyces marxianus* var. *lactis*, *Pichia pastoris*, *Rhodotorula rubra*, *Schizosaccharomyces pombe*, and *Yarrowia lipolytica*. It is to be appreciated that a number of these species include a variety of subspecies, types, subtypes, etc. that are meant to be included within the aforementioned species. More preferred yeast species include *S. cerevisiae*, *C. albicans*, *H. polymorpha*, *P. pastoris* and *S. pombe*. *S. cerevisiae* is particularly preferred due to it being relatively easy to manipulate and being "Generally Recognized As Safe" or "GRAS" for use as food additives (GRAS, FDA proposed Rule 62FR18938, April 17, 1997). One embodiment of the present invention is a yeast strain that is capable of replicating plasmids to a particularly high copy number, such as a *S. cerevisiae* cir° strain.

In one embodiment, a preferred yeast vehicle of the present invention is capable of fusing with the cell type to which the yeast vehicle and antigen is being delivered, such as a dendritic cell or macrophage, thereby effecting particularly efficient delivery of the yeast vehicle, and in many embodiments, the antigen(s), to the cell type. As used herein, fusion of a yeast vehicle with a targeted cell type refers to the ability of the yeast cell membrane, or particle thereof, to fuse with the membrane of the targeted cell type (e.g., dendritic cell or macrophage), leading to syncytia formation. As used herein, a syncytium is a multinucleate mass of protoplasm produced by the merging of cells. A number of viral surface proteins (including those of immunodeficiency viruses such as HIV, influenza virus, poliovirus and adenovirus) and other fusogens (such as those involved in fusions between eggs and sperm) have been shown to be able to effect fusion between two membranes (i.e., between viral and mammalian cell membranes or between mammalian cell membranes). For example, a yeast vehicle that produces an HIV gp120/gp41 heterologous antigen on its surface is capable of fusing with a CD4+ T-lymphocyte. It is noted, however, that incorporation of a targeting moiety into the yeast vehicle, while it may be desirable under some circumstances, is not necessary. The present inventors have previously shown that yeast vehicles of the present invention are readily taken up by dendritic cells (as well as other cells, such as macrophages).

Yeast vehicles can be formulated into compositions of the present invention, including preparations to be administered to a patient directly or first loaded into a carrier such as a dendritic cell, using a number of techniques known to those skilled in the art. For

example, yeast vehicles can be dried by lyophilization. Formulations comprising yeast vehicles can also be prepared by packing yeast in a cake or a tablet, such as is done for yeast used in baking or brewing operations. In addition, prior to loading into a dendritic cell, or other type of administration with an antigen, yeast vehicles can also be mixed with a pharmaceutically acceptable excipient, such as an isotonic buffer that is tolerated by the host cell. Examples of such excipients include water, saline, Ringer's solution, dextrose solution, Hank's solution, and other aqueous physiologically balanced salt solutions. Nonaqueous vehicles, such as fixed oils, sesame oil, ethyl oleate, or triglycerides may also be used. Other useful formulations include suspensions containing viscosity-enhancing agents, such as sodium carboxymethylcellulose, sorbitol, glycerol or dextran. Excipients can also contain minor amounts of additives, such as substances that enhance isotonicity and chemical stability. Examples of buffers include phosphate buffer, bicarbonate buffer and Tris buffer, while examples of preservatives include thimerosal, m- or o-cresol, formalin and benzyl alcohol. Standard formulations can either be liquid injectables or solids which can be taken up in a suitable liquid as a suspension or solution for injection. Thus, in a non-liquid formulation, the excipient can comprise, for example, dextrose, human serum albumin, and/or preservatives to which sterile water or saline can be added prior to administration.

According to the present invention, the term "yeast vehicle-antigen complex" or "yeast-antigen complex" is used generically to describe any association of a yeast vehicle with an antigen. Such association includes expression of the antigen by the yeast (a recombinant yeast), introduction of an antigen into a yeast, physical attachment of the antigen to the yeast, and mixing of the yeast and antigen together, such as in a buffer or other solution or formulation. These types of complexes are described in detail below.

In one embodiment, a yeast cell used to prepare the yeast vehicle is transformed with a heterologous nucleic acid molecule encoding the antigen such that the antigen is expressed by the yeast cell. Such a yeast is also referred to herein as a recombinant yeast or a recombinant yeast vehicle. The yeast cell can then be loaded into the dendritic cell as an intact cell, or the yeast cell can be killed, or it can be derivatized such as by formation of yeast spheroplasts, cytoplasts, ghosts, or subcellular particles, any of which is followed by loading of the derivative into the dendritic cell. Yeast spheroplasts can also be directly transfected with a recombinant nucleic acid molecule (e.g., the spheroplast is produced from

a whole yeast, and then transfected) in order to produce a recombinant spheroplast that expresses an antigen.

According to the present invention, an isolated nucleic acid molecule or nucleic acid sequence, is a nucleic acid molecule or sequence that has been removed from its natural milieu. As such, "isolated" does not necessarily reflect the extent to which the nucleic acid molecule has been purified. An isolated nucleic acid molecule useful for transfecting yeast vehicles include DNA, RNA, or derivatives of either DNA or RNA. An isolated nucleic acid molecule can be double stranded or single stranded. An isolated nucleic acid molecule useful in the present invention includes nucleic acid molecules that encode a protein or a fragment thereof, as long as the fragment contains at least one epitope useful in a composition of the present invention.

Nucleic acid molecules transformed into yeast vehicles of the present invention can include nucleic acid sequences encoding one or more proteins, or portions (fragments, domains, conformational epitopes) thereof. Such nucleic acid molecules can comprise partial or entire coding regions, regulatory regions, or combinations thereof. One advantage of yeast strains is their ability to carry a number of nucleic acid molecules and of being capable of producing a number of heterologous proteins. A preferred number of antigens to be produced by a yeast vehicle of the present invention is any number of antigens that can be reasonably produced by a yeast vehicle, and typically ranges from at least one to at least about 5 or more, with from about 2 to about 5 heterologous antigens being more preferred.

A peptide or protein encoded by a nucleic acid molecule within a yeast vehicle can be a full-length protein, or can be a functionally equivalent protein in which amino acids have been deleted (e.g., a truncated version of the protein), inserted, inverted, substituted and/or derivatized (e.g., acetylated, glycosylated, phosphorylated, tethered by a glycerophosphatidyl inositol (GPI) anchor) such that the modified protein has a biological function substantially similar to that of the natural protein (or which has enhanced or inhibited function as compared to the natural protein, if desired). Modifications can be accomplished by techniques known in the art including, but not limited to, direct modifications to the protein or modifications to the nucleic acid sequence encoding the protein using, for example, classic or recombinant DNA techniques to effect random or targeted mutagenesis. Functionally equivalent proteins can be selected using assays that measure the biological activity of the protein. Preferred HCV antigens are discussed above.

Expression of an antigen in a yeast vehicle of the present invention is accomplished using techniques known to those skilled in the art. Briefly, a nucleic acid molecule encoding at least one desired antigen is inserted into an expression vector in such a manner that the nucleic acid molecule is operatively linked to a transcription control sequence in order to be capable of effecting either constitutive or regulated expression of the nucleic acid molecule when transformed into a host yeast cell. Nucleic acid molecules encoding one or more antigens can be on one or more expression vectors operatively linked to one or more transcription control sequences.

In a recombinant molecule of the present invention, nucleic acid molecules are operatively linked to expression vectors containing regulatory sequences such as transcription control sequences, translation control sequences, origins of replication, and other regulatory sequences that are compatible with the yeast cell and that control the expression of nucleic acid molecules. In particular, recombinant molecules of the present invention include nucleic acid molecules that are operatively linked to one or more transcription control sequences. The phrase "operatively linked" refers to linking a nucleic acid molecule to a transcription control sequence in a manner such that the molecule is able to be expressed when transfected (i.e., transformed, transduced or transfected) into a host cell.

Transcription control sequences, which can control the amount of protein produced, include sequences which control the initiation, elongation, and termination of transcription. Particularly important transcription control sequences are those which control transcription initiation, such as promoter and upstream activation sequences. Any suitable yeast promoter can be used in the present invention and a variety of such promoters are known to those skilled in the art. Preferred promoters for expression in *Saccharomyces cerevisiae* include, but are not limited to, promoters of genes encoding the following yeast proteins: alcohol dehydrogenase I (ADH1) or II (ADH2), CUP1, phosphoglycerate kinase (PGK), triose phosphate isomerase (TPI), glyceraldehyde-3-phosphate dehydrogenase (GAPDH; also referred to as TDH3, for triose phosphate dehydrogenase), galactokinase (GAL1), galactose-1-phosphate uridyl-transferase (GAL7), UDP-galactose epimerase (GAL10), cytochrome c_1 (CYC1), Sec7 protein (SEC7) and acid phosphatase (PHO5), with hybrid promoters such as ADH2/GAPDH and CYC1/GAL10 promoters being more preferred, and the ADH2/GAPDH promoter, which is induced when glucose concentrations in the cell are low (e.g., about 0.1 to about 0.2 percent), being even more preferred. Likewise, a number

of upstream activation sequences (UASs), also referred to as enhancers, are known. Preferred upstream activation sequences for expression in *Saccharomyces cerevisiae* include, but are not limited to, the UASs of genes encoding the following proteins: PCK1, TPI, TDH3,CYC1, ADH1, ADH2, SUC2, GAL1, GAL7 and GAL10, as well as other UASs activated by the GAL4 gene product, with the ADH2 UAS being particularly preferred. Since the ADH2 UAS is activated by the ADR1 gene product, it is preferable to overexpress the ADR1 gene when a heterologous gene is operatively linked to the ADH2 UAS. Preferred transcription termination sequences for expression in *Saccharomyces cerevisiae* include the termination sequences of the α-factor, GAPDH, and CYC1 genes.

Preferred transcription control sequences to express genes in methyltrophic yeast include the transcription control regions of the genes encoding alcohol oxidase and formate dehydrogenase.

Transfection of a nucleic acid molecule into a yeast cell according to the present invention can be accomplished by any method by which a nucleic acid molecule administered into the cell and includes, but is not limited to, diffusion, active transport, bath sonication, electroporation, microinjection, lipofection, adsorption, and protoplast fusion. Transfected nucleic acid molecules can be integrated into a yeast chromosome or maintained on extrachromosomal vectors using techniques known to those skilled in the art. Examples of yeast vehicles carrying such nucleic acid molecules are disclosed in detail herein. As discussed above, yeast cytoplast, yeast ghost, and subcellular yeast membrane extract or fractions thereof can also be produced recombinantly by transfecting intact yeast microorganisms or yeast spheroplasts with desired nucleic acid molecules, producing the antigen therein, and then further manipulating the microorganisms or spheroplasts using techniques known to those skilled in the art to produce cytoplast, ghost or subcellular yeast membrane extract or fractions thereof containing desired antigens.

Effective conditions for the production of recombinant yeast vehicles and expression of the antigen by the yeast vehicle include an effective medium in which a yeast strain can be cultured. An effective medium is typically an aqueous medium comprising assimilable carbohydrate, nitrogen and phosphate sources, as well as appropriate salts, minerals, metals and other nutrients, such as vitamins and growth factors. The medium may comprise complex nutrients or may be a defined minimal medium. Yeast strains of the present invention can be cultured in a variety of containers, including, but not limited to, bioreactors, Erlenmeyer flasks, test tubes, microtiter dishes, and petri plates. Culturing is

carried out at a temperature, pH and oxygen content appropriate for the yeast strain. Such culturing conditions are well within the expertise of one of ordinary skill in the art (see, for example, Guthrie et al. (eds.), 1991, *Methods in Enzymology*, vol. 194, Academic Press, San Diego).

In one embodiment of the present invention, as an alternative to expression of an antigen recombinantly in the yeast vehicle, a yeast vehicle is loaded intracellularly with the protein or peptide antigen, or with carbohydrates or other molecules that serve as an antigen. Subsequently, the yeast vehicle, which now contains the antigen intracellularly, can be administered to the patient or loaded into a carrier such as a dendritic cell (described below). As used herein, a peptide comprises an amino acid sequence of less than or equal to about 30-50 amino acids, while a protein comprises an amino acid sequence of more than about 30-50 amino acids; proteins can be multimeric. A protein or peptide useful as an antigen can be as small as a T cell epitope (i.e., greater than 5 amino acids in length) and any suitable size greater than that which comprises multiple epitopes, protein fragments, full-length proteins, chimeric proteins or fusion proteins. Peptides and proteins can be derivatized either naturally or synthetically; such modifications can include, but are not limited to, glycosylation, phosphorylation, acetylation, myristylation, prenylation, palmitoylation, amidation and/or addition of glycerophosphatidyl inositol. Peptides and proteins can be inserted directly into yeast vehicles of the present invention by techniques known to those skilled in the art, such as by diffusion, active transport, liposome fusion, electroporation, phagocytosis, freeze-thaw cycles and bath sonication. Yeast vehicles that can be directly loaded with peptides, proteins, carbohydrates, or other molecules include intact yeast, as well as spheroplasts, ghosts or cytoplasts, which can be loaded with antigens after production, but before loading into dendritic cells. Alternatively, intact yeast can be loaded with the antigen, and then spheroplasts, ghosts, cytoplasts, or subcellular particles can be prepared therefrom. Any number of antigens can be loaded into a yeast vehicle in this embodiment, from at least 1, 2, 3, 4 or any whole integer up to hundreds or thousands of antigens, such as would be provided by the loading of a microorganism, by the loading of a mammalian tumor cell, or portions thereof, for example.

In another embodiment of the present invention, an antigen is physically attached to the yeast vehicle. Physical attachment of the antigen to the yeast vehicle can be accomplished by any method suitable in the art, including covalent and non-covalent association methods which include, but are not limited to, chemically crosslinking the

antigen to the outer surface of the yeast vehicle or biologically linking the antigen to the outer surface of the yeast vehicle, such as by using an antibody or other binding partner. Chemical cross-linking can be achieved, for example, by methods including glutaraldehyde linkage, photoaffinity labeling, treatment with carbodiimides, treatment with chemicals capable of linking di-sulfide bonds, and treatment with other cross-linking chemicals standard in the art. Alternatively, a chemical can be contacted with the yeast vehicle that alters the charge of the lipid bilayer of yeast membrane or the composition of the cell wall so that the outer surface of the yeast is more likely to fuse or bind to antigens having particular charge characteristics. Targeting agents such as antibodies, binding peptides, soluble receptors, and other ligands may also be incorporated into an antigen as a fusion protein or otherwise associated with an antigen for binding of the antigen to the yeast vehicle.

In yet another embodiment, the yeast vehicle and the antigen are associated with each other by a more passive, non-specific or non-covalent binding mechanism, such as by gently mixing the yeast vehicle and the antigen together in a buffer or other suitable formulation. In one embodiment of the invention, the yeast vehicle and the antigen are both loaded intracellularly into a carrier such as a dendritic cell or macrophage to form the therapeutic composition or vaccine of the present invention. Alternatively, an antigen of the invention (*i.e.,* a novel HCV fusion protein of the invention) can be loaded into a dendritic cell in the absence of the yeast vehicle. Various forms in which the loading of both components can be accomplished are discussed in detail below. As used herein, the term "loaded" and derivatives thereof refer to the insertion, introduction, or entry of a component (e.g., the yeast vehicle and/or antigen) into a cell (e.g., a dendritic cell). To load a component intracellularly refers to the insertion or introduction of the component to an intracellular compartment of the cell (e.g., through the plasma membrane and at a minimum, into the cytoplasm, a phagosome, a lysosome, or some intracellular space of the cell). To load a component into a cell references any technique by which the component is either forced to enter the cell (e.g., by electroporation) or is placed in an environment (e.g., in contact with or near to a cell) where the component will be substantially likely to enter the cell by some process (e.g., phagocytosis). Loading techniques include, but are not limited to: diffusion, active transport, liposome fusion, electroporation, phagocytosis, and bath sonication. In a preferred embodiment, passive mechanisms for loading a dendritic cell

with the yeast vehicle and/or antigen are used, such passive mechanisms including phagocytosis of the yeast vehicle and/or antigen by the dendritic cell.

It is noted that any of the above-described HCV fusion proteins can be provided in a vaccine without one or more of the N-terminal and/or C-terminal modifications that are particularly advantageous for expression of such proteins in yeast. Such HCV fusion proteins are useful in other non-yeast based vaccines, such as by combining the fusion proteins with a conventional adjuvant, pulsing dendritic cells with such fusion proteins, providing DNA or nucleic acid or viral vector vaccines including nucleic acid molecules encoding such fusion proteins, or constructing pseudovirions compose of particular HCV fusion proteins of the invention (*e.g.*, E1-E2 fusions of the invention).

Accordingly, yet another embodiment of the present invention relates to a composition to protect an animal against HCV infection or a symptom resulting from such infection, the composition (which can be a vaccine) comprising: (a) any one or more of the HCV fusion proteins as described above (with or without the various N- and C-terminal modifications described herein); and (b) a pharmaceutically acceptable delivery vehicle (which can include a pharmaceutically acceptable excipient or adjuvant).

Yet another embodiment of the present invention relates to a nucleic acid-based vaccine, such as a DNA vaccine or viral vector vaccine, comprising a nucleic acid construct (*e.g.*, a viral vector or other recombinant nucleic acid molecule) encoding an HCV fusion protein as described herein (with or without the various N- and C-terminal modifications described herein). The vaccine can further include any pharmaceutically acceptable delivery vehicle (which can include a pharmaceutically acceptable excipient or adjuvant).

Another embodiment of the present invention relates to a pseudovirion which is composed of various HCV fusion proteins of the invention, and particularly, an E1-E2 fusion as described herein. Again, the N- or C-terminal modifications that are particularly useful in connection with a yeast-based vaccine of the invention may be included or not included.

In one embodiment of the present invention, a composition or vaccine can also include biological response modifier compounds, or the ability to produce such modifiers (i.e., by transfection with nucleic acid molecules encoding such modifiers), although such modifiers are not necessary to achieve a robust immune response according to the invention. For example, a yeast vehicle can be transfected with or loaded with at least one antigen and at least one biological response modifier compound, or a vaccine or composition of the

invention can be administered in conjunction with at least one biological response modifier. Biological response modifiers include compounds that can modulate immune responses, which may be referred to as immunomodulatory compounds. Certain biological response modifiers can stimulate a protective immune response whereas others can suppress a harmful immune response. Certain biological response modifiers preferentially enhance a cell-mediated immune response whereas others preferentially enhance a humoral immune response (i.e., can stimulate an immune response in which there is an increased level of cellular compared to humoral immunity, or vice versa.). There are a number of techniques known to those skilled in the art to measure stimulation or suppression of immune responses, as well as to differentiate cellular immune responses from humoral immune responses.

Suitable biological response modifiers include cytokines, hormones, lipidic derivatives, small molecule drugs and other growth modulators, such as, but not limited to, interleukin 2 (IL-2), interleukin 4 (IL-4), interleukin 10 (IL-10), interleukin 12 (IL-12), interferon gamma (IFN-gamma) insulin-like growth factor I (IGF-I), transforming growth factor beta (TGF-β) steroids, prostaglandins and leukotrienes. The ability of a yeast vehicle to express (i.e., produce), and possibly secrete, IL-2, IL-12 and/or IFN-gamma preferentially enhances cell-mediated immunity, whereas the ability of a yeast vehicle to express, and possibly secrete, IL-4, IL-5 and/or IL-10 preferentially enhances humoral immunity. Other suitable biological response modifiers include, but are not limited to, anti-CTLA-4 antibody (*e.g.,* to release anergic T cells); T cell co-stimulators (*e.g.,* anti-CD137, anti-CD28, anti-CD40); alemtuzumab (*e.g.,* CamPath®), denileukin diftitox (*e.g.,* ONTAK®), anti-CD4, anti-CD25, anti-PD-1, anti-PD-L1, anti-PD-L2 or agents that block FOXP3 (e.g., to abrogate the activity/kill CD4+/CD25+ T regulatory cells); Flt3 ligand, imiquimod (Aldara™), GM-CSF, sargramostim (Leukine®), Toll-like receptor (TLR)-7 agonists, or TLR-9 agonists (e.g., agents that increase the number of, or increase the activation state, of dendritic cells, macrophages and other professional antigen-presenting cells). Such biological response modifiers are well known in the art and are publicly available.

Compositions and therapeutic vaccines of the invention can further include any other compounds that are useful for protecting a subject from HCV infection or that treats or ameliorates any symptom of such an infection.

As mentioned above, the present invention also includes the use of any of the HCV fusion proteins described herein, or a nucleic acid molecule encoding such HCV fusion proteins, in a composition or vaccine in the absence of the yeast vehicle of the present invention, such as in any conventional or non-yeast-based composition or vaccine. Such a composition can include, in addition to the HCV fusion protein, a pharmaceutically acceptable carrier, such as an adjuvant. In addition, yeast-based vaccines of the invention may be provided in conjunction with a pharmaceutically acceptable carrier.

As used herein, a pharmaceutically acceptable carrier refers to any substance or vehicle suitable for delivering an HCV fusion protein useful in a method of the present invention to a suitable *in vivo* or *ex vivo* site. Such a carrier can include, but is not limited to, an adjuvant, an excipient, or any other type of delivery vehicle or carrier.

According to the present invention, adjuvants are typically substances that generally enhance the immune response of an animal to a specific antigen. Suitable adjuvants include, but are not limited to, Freund's adjuvant; other bacterial cell wall components; aluminum-based salts; calcium-based salts; silica; polynucleotides; toxoids; serum proteins; viral coat proteins; other bacterial-derived preparations; gamma interferon; block copolymer adjuvants, such as Hunter's Titermax adjuvant (CytRx™, Inc. Norcross, GA); Ribi adjuvants (available from Ribi ImmunoChem Research, Inc., Hamilton, MT); and saponins and their derivatives, such as Quil A (available from Superfos Biosector A/S, Denmark).

Carriers are typically compounds that increase the half-life of a therapeutic composition in the treated animal. Suitable carriers include, but are not limited to, polymeric controlled release formulations, biodegradable implants, liposomes, oils, esters, and glycols.

Therapeutic compositions of the present invention can also contain one or more pharmaceutically acceptable excipients. As used herein, a pharmaceutically acceptable excipient refers to any substance suitable for delivering a therapeutic composition useful in the method of the present invention to a suitable *in vivo* or *ex vivo* site. Preferred pharmaceutically acceptable excipients are capable of maintaining a composition (or a yeast vehicle or dendritic cell comprising the yeast vehicle) in a form that, upon arrival of the composition at a target cell, tissue, or site in the body, the composition is capable of eliciting an immune response at the target site (noting that the target site can be systemic). Suitable excipients of the present invention include excipients or formularies that transport, but do not specifically target the vaccine to a site (also referred to herein as non-targeting

carriers). Examples of pharmaceutically acceptable excipients include, but are not limited to water, saline, phosphate buffered saline, Ringer's solution, dextrose solution, serum-containing solutions, Hank's solution, other aqueous physiologically balanced solutions, oils, esters and glycols. Aqueous carriers can contain suitable auxiliary substances required to approximate the physiological conditions of the recipient, for example, by enhancing chemical stability and isotonicity. Suitable auxiliary substances include, for example, sodium acetate, sodium chloride, sodium lactate, potassium chloride, calcium chloride, and other substances used to produce phosphate buffer, Tris buffer, and bicarbonate buffer. Auxiliary substances can also include preservatives, such as thimerosal, m- or o-cresol, formalin and benzol alcohol.

Methods of the Invention

Another embodiment of the present invention relates to a method to protect an animal against an HCV infection or disease resulting therefrom. The method includes the step of administering to an animal that has or is at risk of developing a HCV infection, a vaccine or composition of the present invention as described herein, to reduce or prevent the HCV infection or at least one symptom resulting from the HCV infection in the animal.

Yet another embodiment of the present invention relates to a method to elicit an antigen-specific humoral immune response and/or an antigen-specific cell-mediated immune response in an animal. The method includes administering to the animal a vaccine or composition of the present invention as described herein. The method of the present invention preferentially elicits an antigen-specific cell-mediated immune response in an animal.

In the above-embodiments, the vaccine or composition can include (1) a composition comprising (a) a yeast vehicle; and (b) any one or more of the above-described HCV fusion proteins; and/or (2) (a) any one or more of the above-described HCV fusion proteins; and (b) a pharmaceutically acceptable delivery vehicle (which can include or consist of a pharmaceutically acceptable excipient or adjuvant); and/or (3) (a) an isolated nucleic acid molecule (*e.g.*, a DNA construct, a vector, a viral vector) encoding any one or more of the above-described HCV fusion proteins; and/or (4) isolated dendritic cells (*e.g.*, autologous dendritic cells containing (pulsed with) (a) a yeast vehicle; and/or (b) any one or more of the above-described HCV fusion proteins; and/or (5) HCV pseudovirions composed of any of the E1-E2 containing HCV fusion proteins of described herein.

In one embodiment of the present invention, the vaccine or composition of the invention as described herein can be administered in a protocol that includes the administration of one or more other vaccine or immunotherapy compositions, including any conventional vaccine or composition. For example, such other vaccines or immunotherapy compositions can include any other antigen-containing, antigen-encoding, or antigen-expressing composition, such as a DNA vaccine encoding an HCV antigen or other viral vectors comprising an HCV antigen. Viral vectors for vaccines are known in the art and include, but are not limited to, pox viruses (vaccinia, canary, avipox), adeno viruses, adeno-associated viruses, alpha viruses (Sindbis, VEE). Other types of vaccines, including protein-based vaccines, are also encompassed by this embodiment. In one aspect, such a conventional vaccine or vaccine that is not a part of the present invention or a vaccine of the present invention that does not include a yeast vehicle (*e.g.*, a vaccine comprising a novel HCV fusion protein of the invention in combination with a pharmaceutically acceptable carrier, or a DNA vaccine encoding a novel HCV fusion protein of the invention) can be administered initially to a subject to prime the immune response of the subject against the HCV antigen(s). Subsequently, the vaccine or composition of the present invention, and particularly, a yeast-based vaccine of the present invention, can be administered to the subject in order to boost the immune response. Alternatively, the vaccine or composition of the present invention can be administered to the subject to prime the immune response, including particularly a yeast-based vaccine of the present invention, and the conventional or other vaccine or composition (*e.g.*, a non-yeast-based vaccine comprising a novel HCV fusion protein of the invention or DNA vaccine encoding a novel HCV fusion protein of the invention) can be used to boost the response.

The method of use of the therapeutic composition or vaccine of the present invention preferably elicits an immune response in an animal such that the animal is protected from HCV infection or from disease conditions or symptoms resulting from HCV infection. As used herein, the phrase "protected from a disease" refers to reducing the symptoms of the disease; reducing the occurrence of the disease, and/or reducing the severity of the disease. Protecting an animal can refer to the ability of a therapeutic composition of the present invention, when administered to an animal, to prevent a disease from occurring and/or to cure or to alleviate disease symptoms, signs or causes. As such, to protect an animal from a disease includes both preventing disease occurrence (prophylactic treatment or prophylactic vaccine) and treating an animal that has a disease or that is experiencing initial symptoms of

a disease (therapeutic treatment or a therapeutic vaccine). In particular, protecting an animal from a disease is accomplished by eliciting an immune response in the animal by inducing a beneficial or protective immune response which may, in some instances, additionally suppress (e.g., reduce, inhibit or block) an overactive or harmful immune response. The term, "disease" refers to any deviation from the normal health of an animal and includes a state when disease symptoms are present, as well as conditions in which a deviation (e.g., infection, gene mutation, genetic defect, etc.) has occurred, but symptoms are not yet manifested.

In one embodiment, any of the vaccines of the present invention is administered to an individual, or to a population of individuals, who have been infected with HCV. In another embodiment, any of the vaccines of the present invention is administered to an individual, or to a population of individuals, who are at risk of being infected with HCV. Such individuals can include populations identified as higher-risk for HCV infection than, for example, the normal or entire population of individuals. Such populations can be defined by any suitable parameter. In another embodiment, any of the vaccines of the present invention is administered to any individual, or to any population of individuals, regardless of their known or predicted infection status or susceptibility to becoming infected with HCV.

More specifically, a vaccine as described herein, when administered to an animal by the method of the present invention, preferably produces a result which can include alleviation of the disease (e.g., reduction of at least one symptom or clinical manifestation of the disease), elimination of the disease, prevention or alleviation of a secondary disease resulting from the occurrence of a primary disease, prevention of the disease, and stimulation of effector cell immunity against the disease.

The present invention includes the delivery of a composition or vaccine of the invention to an animal. The administration process can be performed *ex vivo* or *in vivo*. *Ex vivo* administration refers to performing part of the regulatory step outside of the patient, such as administering a composition of the present invention to a population of cells (dendritic cells) removed from a patient under conditions such that a yeast vehicle and antigen are loaded into the cell, and returning the cells to the patient. The therapeutic composition of the present invention can be returned to a patient, or administered to a patient, by any suitable mode of administration.

Administration of a vaccine or composition, including a dendritic cell loaded with the yeast vehicle and antigen, a yeast vehicle alone, or a composition comprising a novel HCV fusion protein, alone or in combination with a carrier according to the present invention, can be systemic, mucosal and/or proximal to the location of the target site (e.g., near a tumor). The preferred routes of administration will be apparent to those of skill in the art, depending on the type of condition to be prevented or treated, the antigen used, and/or the target cell population or tissue. Preferred methods of administration include, but are not limited to, intravenous administration, intraperitoneal administration, intramuscular administration, intranodal administration, intracoronary administration, intraarterial administration (e.g., into a carotid artery), subcutaneous administration, transdermal delivery, intratracheal administration, subcutaneous administration, intraarticular administration, intraventricular administration, inhalation (e.g., aerosol), intracranial, intraspinal, intraocular, aural, intranasal, oral, pulmonary administration, impregnation of a catheter, and direct injection into a tissue. Particularly preferred routes of administration include: intravenous, intraperitoneal, subcutaneous, intradermal, intranodal, intramuscular, transdermal, inhaled, intranasal, oral, intraocular, intraarticular, intracranial, and intraspinal. Parenteral delivery can include intradermal, intramuscular, intraperitoneal, intrapleural, intrapulmonary, intravenous, subcutaneous, atrial catheter and venal catheter routes. Aural delivery can include ear drops, intranasal delivery can include nose drops or intranasal injection, and intraocular delivery can include eye drops. Aerosol (inhalation) delivery can also be performed using methods standard in the art (see, for example, Stribling et al., *Proc. Natl. Acad. Sci. USA* 189:11277-11281, 1992, which is incorporated herein by reference in its entirety). For example, in one embodiment, a composition or vaccine of the invention can be formulated into a composition suitable for nebulized delivery using a suitable inhalation device or nebulizer. Oral delivery can include solids and liquids that can be taken through the mouth, and is useful in the development of mucosal immunity and since compositions comprising yeast vehicles can be easily prepared for oral delivery, for example, as tablets or capsules, as well as being formulated into food and beverage products. Other routes of administration that modulate mucosal immunity are useful in the treatment of viral infections. Such routes include bronchial, intradermal, intramuscular, intranasal, other inhalatory, rectal, subcutaneous, topical, transdermal, vaginal and urethral routes.

In one embodiment of any of the above-identified methods, the vaccine is administered to the respiratory tract. In another embodiment, the vaccine is administered by a parenteral route of administration. In yet another embodiment, the vaccine further comprises dendritic cells or macrophages, wherein a yeast vehicle expressing the fusion protein is delivered to dendritic cells or macrophages *ex vivo* and wherein the dendritic cell or macrophage containing the yeast vehicle expressing the HCV antigen is administered to the animal. In one aspect of this embodiment, the dendritic cell or the yeast vehicle has been additionally loaded with free antigen. In one aspect, the vaccine is administered as a therapeutic vaccine. In another aspect, the vaccine is administered as a prophylactic vaccine.

According to the present invention, an effective administration protocol (i.e., administering a vaccine or therapeutic composition in an effective manner) comprises suitable dose parameters and modes of administration that result in elicitation of an immune response in an animal that has a disease or condition, or that is at risk of contracting a disease or condition, preferably so that the animal is protected from the disease. Effective dose parameters can be determined using methods standard in the art for a particular disease. Such methods include, for example, determination of survival rates, side effects (i.e., toxicity) and progression or regression of disease.

In accordance with the present invention, a suitable single dose size is a dose that is capable of eliciting an antigen-specific immune response in an animal when administered one or more times over a suitable time period. Doses can vary depending upon the disease or condition being treated. For example, in one embodiment, a single dose of a yeast vehicle of the present invention is from about 1×10^5 to about 5×10^7 yeast cell equivalents per kilogram body weight of the organism being administered the composition. In a preferred embodiment, the yeast cells per dose are not adjusted for weight of the organism. In this embodiment, a single dose of a yeast vehicle of the present invention is from about 1×10^4 to about 1×10^9 yeast cells per dose. More preferably, a single dose of a yeast vehicle of the present invention is from about 0.1 Y.U. (1×10^6 cells) to about 100 Y.U. (1×10^9 cells) per dose (i.e., per organism), including any interim dose, in increments of 0.1×10^6 cells (i.e., 1.1×10^6, 1.2×10^6, 1.3×10^6...). This range of doses can be effectively used in any organism of any size, including mice, monkeys, humans, etc.

When the vaccine is administered by loading the yeast vehicle and antigen into dendritic cells, a preferred single dose of a vaccine of the present invention is from about

0.5 x 10^6 to about 40 x 10^6 dendritic cells per individual per administration. Preferably, a single dose is from about 1 x 10^6 to about 20 x 10^6 dendritic cells per individual, and more preferably from about 1 x 10^6 to about 10 x 10^6 dendritic cells per individual.

When the vaccine comprises a fusion protein of the present invention and a carrier, a preferred single dose is from about 0.01 microgram x kilogram^{-1} and about 10 milligram x kilogram^{-1} body weight of an animal. A more preferred single dose of an agent comprises between about 1 microgram x kilogram^{-1} and about 10 milligram x kilogram^{-1} body weight of an animal. An even more preferred single dose of an agent comprises between about 5 microgram x kilogram^{-1} and about 7 milligram x kilogram^{-1} body weight of an animal. An even more preferred single dose of an agent comprises between about 10 microgram x kilogram^{-1} and about 5 milligram x kilogram^{-1} body weight of an animal. A particularly preferred single dose of an agent comprises between about 0.1 milligram x kilogram^{-1} and about 5 milligram x kilogram^{-1} body weight of an animal, if the an agent is delivered by aerosol. Another particularly preferred single dose of an agent comprises between about 0.1 microgram x kilogram^{-1} and about 10 microgram x kilogram^{-1} body weight of an animal, if the agent is delivered parenterally.

"Boosters" or "boosts" of a therapeutic composition are preferably administered when the immune response against the antigen has waned or as needed to provide an immune response or induce a memory response against a particular antigen or antigen(s). Boosters can be administered from about 2 weeks to several years after the original administration. In one embodiment, an administration schedule is one in which from about 1 x 10^5 to about 5 x 10^7 yeast cell equivalents of a composition per kg body weight of the organism is administered from about one to about 4 times over a time period of from about 1 month to about 6 months.

In the method of the present invention, vaccines and therapeutic compositions can be administered to animal, including any vertebrate, and particularly to any member of the Vertebrate class, Mammalia, including, without limitation, primates, rodents, livestock and domestic pets. Livestock include mammals to be consumed or that produce useful products (e.g., sheep for wool production). Preferred mammals to protect include humans, dogs, cats, mice, rats, goats, sheep, cattle, horses and pigs, with humans being particularly preferred. According to the present invention, the term “patient” or "subject" can be used to describe any animal that is the subject of a diagnostic, prophylactic, or therapeutic treatment as described herein.

Isolated Fusion Proteins, Nucleic Acid Molecules, and Cells

Another embodiment of the present invention includes an isolated protein, comprising any of the isolated fusion protein comprising an HCV antigen(s) as described herein. Also included in the present invention are isolated nucleic acid molecules encoding any of such proteins, recombinant nucleic acid molecules comprising nucleic acid sequences encoding such proteins, and cells and vectors, including viral vectors, that contain or are transfected/transformed with such nucleic acid molecules or recombinant nucleic acid molecules.

As used herein, reference to an isolated protein or polypeptide in the present invention includes full-length proteins, fusion proteins, or any fragment, domain, conformational epitope, or homologue of such proteins. More specifically, an isolated protein, according to the present invention, is a protein (including a polypeptide or peptide) that has been removed from its natural milieu (i.e., that has been subject to human manipulation) and can include purified proteins, partially purified proteins, recombinantly produced proteins, and synthetically produced proteins, for example. As such, "isolated" does not reflect the extent to which the protein has been purified. Preferably, an isolated protein of the present invention is produced recombinantly. According to the present invention, the terms "modification" and "mutation" can be used interchangeably, particularly with regard to the modifications/mutations to the amino acid sequence of proteins or portions thereof (or nucleic acid sequences) described herein.

As used herein, the term "homologue" is used to refer to a protein or peptide which differs from a naturally occurring protein or peptide (i.e., the "prototype" or "wild-type" protein) by minor modifications to the naturally occurring protein or peptide, but which maintains the basic protein and side chain structure of the naturally occurring form. Such changes include, but are not limited to: changes in one or a few amino acid side chains; changes one or a few amino acids, including deletions (e.g., a truncated version of the protein or peptide) insertions and/or substitutions; changes in stereochemistry of one or a few atoms; and/or minor derivatizations, including but not limited to: methylation, glycosylation, phosphorylation, acetylation, myristoylation, prenylation, palmitation, amidation and/or addition of glycosylphosphatidyl inositol. A homologue can have either enhanced, decreased, or substantially similar properties as compared to the naturally occurring protein or peptide. A homologue can include an agonist of a protein or an antagonist of a protein. Homologues can be produced using techniques known in the art for

the production of proteins including, but not limited to, direct modifications to the isolated, naturally occurring protein, direct protein synthesis, or modifications to the nucleic acid sequence encoding the protein using, for example, classic or recombinant DNA techniques to effect random or targeted mutagenesis.

The minimum size of a protein and/or a homologue or fragment or other portion thereof of the present invention is, in one aspect, a size sufficient to have the requisite biological activity, such as serving as an antigen(s) or immunogen(s) in a fusion protein or other composition of the invention, or as a target in an *in vitro* assay. In one embodiment, a protein of the present invention is at least about 8 amino acids in length, or at least about 25 amino acids in length, or at least about 30 amino acids in length, or at least about 40 amino acids in length, or at least about 50 amino acids in length, or at least about 75 amino acids in length, or at least about 100 amino acids in length, or at least about 125 amino acids in length, or at least about 150 amino acids in length, or at least about 175 amino acids in length, or at least about 200 amino acids in length, or at least about 250 amino acids in length, or at least about 300 amino acids in length, or at least about 350 amino acids in length, or at least about 400 amino acids in length, or at least about 450 amino acids in length, or at least about 500 amino acids in length, or at least about 550 amino acids in length, or at least about 600 amino acids in length, and so on, in any length between 8 amino acids and up to the full length of a protein of the invention, the full-length of a combination of proteins or portions thereof, or longer, in whole integers (e.g., 8, 9, 10,...25, 26,...102, 103,...). There is no limit, other than a practical limit, on the maximum size of such a protein in that the protein can include a portion of a protein, a functional domain, or a biologically active or useful fragment thereof, or a full-length protein, plus additional sequence (e.g., a fusion protein sequence), if desired.

Preferred fusion proteins according to the present invention include any of the fusion proteins described herein. Exemplary fusion proteins encompassed by the present invention include those fusion proteins comprising, consisting essentially of, or consisting of, and amino acid sequence selected from SEQ ID NO:2, SEQ ID NO:4, SEQ ID NO:6, SEQ ID NO:8, SEQ ID NO:12, SEQ ID NO:14, SEQ ID NO:16 AND SEQ ID NO:18. Other fusion protein sequences will be apparent to those of skill in the art given the guidance provided herein, since various HCV protein sequences are well-known in the art.

The present invention also includes any nucleic acid molecules comprising, consisting essentially of, or consisting of, a nucleic acid sequence encoding any of the

fusion proteins described herein. In accordance with the present invention, an isolated nucleic acid molecule is a nucleic acid molecule that has been removed from its natural milieu (i.e., that has been subject to human manipulation), its natural milieu being the genome or chromosome in which the nucleic acid molecule is found in nature. As such, "isolated" does not necessarily reflect the extent to which the nucleic acid molecule has been purified, but indicates that the molecule does not include an entire genome or an entire chromosome in which the nucleic acid molecule is found in nature. An isolated nucleic acid molecule can include a gene. An isolated nucleic acid molecule that includes a gene is not a fragment of a chromosome that includes such gene, but rather includes the coding region and regulatory regions associated with the gene, but no additional genes that are naturally found on the same chromosome. An isolated nucleic acid molecule can also include a specified nucleic acid sequence flanked by (i.e., at the 5' and/or the 3' end of the sequence) additional nucleic acids that do not normally flank the specified nucleic acid sequence in nature (i.e., heterologous sequences). Isolated nucleic acid molecule can include DNA, RNA (e.g., mRNA), or derivatives of either DNA or RNA (e.g., cDNA). Although the phrase "nucleic acid molecule" primarily refers to the physical nucleic acid molecule and the phrase "nucleic acid sequence" primarily refers to the sequence of nucleotides on the nucleic acid molecule, the two phrases can be used interchangeably, especially with respect to a nucleic acid molecule, or a nucleic acid sequence, being capable of encoding a protein or domain of a protein.

Preferably, an isolated nucleic acid molecule of the present invention is produced using recombinant DNA technology (e.g., polymerase chain reaction (PCR) amplification, cloning) or chemical synthesis. Isolated nucleic acid molecules include natural nucleic acid molecules and homologues thereof, including, but not limited to, natural allelic variants and modified nucleic acid molecules in which nucleotides have been inserted, deleted, substituted, and/or inverted in such a manner that such modifications provide the desired effect. Protein homologues (e.g., proteins encoded by nucleic acid homologues) have been discussed in detail above.

A nucleic acid molecule homologue can be produced using a number of methods known to those skilled in the art (see, for example, Sambrook et al., *Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Labs Press (1989)). For example, nucleic acid molecules can be modified using a variety of techniques including, but not limited to, classic mutagenesis techniques and recombinant DNA techniques, such as site-directed

mutagenesis, chemical treatment of a nucleic acid molecule to induce mutations, restriction enzyme cleavage of a nucleic acid fragment, ligation of nucleic acid fragments, PCR amplification and/or mutagenesis of selected regions of a nucleic acid sequence, synthesis of oligonucleotide mixtures and ligation of mixture groups to "build" a mixture of nucleic acid molecules and combinations thereof. Nucleic acid molecule homologues can be selected from a mixture of modified nucleic acids by screening for the function of the protein encoded by the nucleic acid and/or by hybridization with a wild-type gene.

A recombinant nucleic acid molecule expressing a fusion protein of the present invention is a molecule that can include at least one of any nucleic acid sequence encoding any one or more fusion proteins described herein operatively linked to at least one of any transcription control sequence capable of effectively regulating expression of the nucleic acid molecule(s) in the cell to be transfected. Although the phrase "nucleic acid molecule" primarily refers to the physical nucleic acid molecule and the phrase "nucleic acid sequence" primarily refers to the sequence of nucleotides on the nucleic acid molecule, the two phrases can be used interchangeably, especially with respect to a nucleic acid molecule, or a nucleic acid sequence, being capable of encoding a protein. In addition, the phrase "recombinant molecule" primarily refers to a nucleic acid molecule operatively linked to a transcription control sequence, but can be used interchangeably with the phrase "nucleic acid molecule" which is administered to an animal.

A recombinant nucleic acid molecule includes a recombinant vector, which is any nucleic acid sequence, typically a heterologous sequence, which is operatively linked to the isolated nucleic acid molecule encoding a fusion protein of the present invention, which is capable of enabling recombinant production of the fusion protein, and which is capable of delivering the nucleic acid molecule into a host cell according to the present invention. Such a vector can contain nucleic acid sequences that are not naturally found adjacent to the isolated nucleic acid molecules to be inserted into the vector. The vector can be either RNA or DNA, either prokaryotic or eukaryotic, and preferably in the present invention, is a virus or a plasmid.. Recombinant vectors can be used in the cloning, sequencing, and/or otherwise manipulating of nucleic acid molecules, and can be used in delivery of such molecules (*e.g.*, as in a DNA vaccine or a viral vector-based vaccine). Recombinant vectors are preferably used in the expression of nucleic acid molecules, and can also be referred to as expression vectors. Preferred recombinant vectors are capable of being expressed in a transfected host cell.

In a recombinant molecule of the present invention, nucleic acid molecules are operatively linked to expression vectors containing regulatory sequences such as transcription control sequences, translation control sequences, origins of replication, and other regulatory sequences that are compatible with the host cell and that control the expression of nucleic acid molecules of the present invention. In particular, recombinant molecules of the present invention include nucleic acid molecules that are operatively linked to one or more transcription control sequences. The phrase "operatively linked" refers to linking a nucleic acid molecule to a transcription control sequence in a manner such that the molecule is expressed when transfected (i.e., transformed, transduced or transfected) into a host cell.

Transcription control sequences are sequences that control the initiation, elongation, and termination of transcription. Particularly important transcription control sequences are those that control transcription initiation, such as promoter, enhancer, operator and repressor sequences. Suitable transcription control sequences include any transcription control sequence that can function in a host cell according to the present invention. A variety of suitable transcription control sequences are known to those skilled in the art.

According to the present invention, the term "transfection" is used to refer to any method by which an exogenous nucleic acid molecule (i.e., a recombinant nucleic acid molecule) can be inserted into a cell. The term "transformation" can be used interchangeably with the term "transfection" when such term is used to refer to the introduction of nucleic acid molecules into microbial cells, such as algae, bacteria and yeast, or into plant cells. In microbial systems and plant systems, the term "transformation" is used to describe an inherited change due to the acquisition of exogenous nucleic acids by the microorganism or plant and is essentially synonymous with the term "transfection." Therefore, transfection techniques include, but are not limited to, transformation, chemical treatment of cells, particle bombardment, electroporation, microinjection, lipofection, adsorption, infection and protoplast fusion.

One type of recombinant vector useful in a recombinant nucleic acid molecule of the present invention is a recombinant viral vector. Such a vector includes a recombinant nucleic acid sequence encoding a fusion protein of the present invention that is packaged in a viral coat that can be expressed in a host cell in an animal or *ex vivo* after administration. A number of recombinant viral vectors can be used, including, but not limited to, those based on alphaviruses, poxviruses, adenoviruses, herpesviruses, lentiviruses, adeno-

associated viruses and retroviruses. Particularly preferred viral vectors are those based on adenoviruses and adeno-associated viruses. Viral vectors suitable for gene delivery are well known in the art and can be selected by the skilled artisan for use in the present invention. A detailed discussion of current viral vectors is provided in "Molecular Biotechnology," Second Edition, by Glick and Pasternak, ASM Press, Washington D.C., 1998, pp. 555-590, the entirety of which is incorporated herein by reference.

Suitable host cells to transfect with a recombinant nucleic acid molecule according to the present invention include any cell that can be transfected or transformed, including any animal, insect, bacterial, fungal (including yeast) cell. In one embodiment, the host cell is an animal cell, including a tumor cell, that has been transfected with and expresses a fusion protein of the present invention. Such a cell is exemplified in the Examples section and is useful, for example, for assessing antigen-specific T cell responses that are induced by a vaccine or composition of the present invention. Other vaccines or compositions directed against an HCV antigen can also be tested such transfected tumor cells.

The following experimental results are provided for purposes of illustration and are not intended to limit the scope of the invention.

Examples

Example 1

The following example describes the engineering of GI-5005, a truncated NS3-Core fusion protein yeast vaccine of the present invention.

The GI-5005 *Saccharomyces cerevisiae* was engineered to express a HCV NS3-Core fusion protein under the control of the copper-inducible promoter, *CUP1*. Two regions of the HCV genome (genotype 1a, H77 strain, cDNA was provided by the NIH) were amplified by PCR in order to generate the product. The NS3-Core fusion protein is a single polypeptide with the following sequence elements fused in frame from N- to C-terminus (HCV polyprotein numbering in parentheses) (represented herein by SEQ ID NO:2): 1) the sequence MADEAP to impart resistance to proteasomal degradation; 2) amino acids 89 to 350 (1115 to 1376) of the HCV NS3 protease protein; 3) a single threonine amino acid residue introduced in cloning; 4) amino acids 2 to 140 (2 to 140) of the HCV Core protein; and 5) the sequence ED to increase the hydrophilicity of the Core variant.

Expression of the HCV NS3-Core fusion protein was confirmed by Western blot analysis of lysates from copper-induced, heat-inactivated GI-5005 yeast. Monoclonal antibodies specific for HCV NS3 (Virostat) or HCV Core protein (Anogen) were used for protein detection (See Fig. 1A and Fig. 1B).

Example 2

The following example describes the engineering of GI-5003, an inactivated HCV NS3 yeast vaccine of the present invention.

The GI-5003 *Saccharomyces cerevisiae* was engineered to express an inactivated full-length HCV NS3 protein under the control of the copper-inducible promoter, *CUP1*. A single region of the HCV genome (genotype 1a, H77 strain, cDNA was provided by the NIH) was amplified by PCR in order to generate the product. The inactivated NS3 protein is a single polypeptide with the following sequence elements fused in frame from N- to C-terminus (HCV polyprotein numbering in parentheses) (represented herein by SEQ ID NO:4): 1) the sequence MADEAP to impart resistance to proteasomal degradation; and 2) amino acids 1 to 631 (1027 to 1657) of the HCV NS3 protease protein (note that the amino acid at HCV polypeptide residue 1165 has been changed from a serine to an alanine in order to inactivate the proteolytic activity).

Expression of the HCV NS3 protein was confirmed by Western blot analysis of lysates from copper-induced, heat-inactivated GI-5003 yeast. Monoclonal antibodies specific for HCV NS3 (Virostat) were used for protein detection (See Fig. 1A and Fig. 1B).

Example 3

The following example describes the engineering of the GI-5000 series truncated HCV E1-E2 fusion protein yeast vaccine of the present invention.

The E1-E2 fusion protein is a single polypeptide with the following sequence elements fused in frame from N- to C-terminus (HCV polyprotein numbering in parentheses) (represented herein by SEQ ID NO:6): 1) The sequence MADEAP to impart resistance to proteasomal degradation, 2) amino acids 1 to 156 (192 to 347) of HCV protein E1, 3) amino acids 1 to 334 (384-717) of HCV protein E2. 36 C-terminal hydrophobic amino acids of E1 and 29 C-terminal hydrophobic amino acids of E2 were omitted from the fusion protein to promote cytoplasmic accumulation in yeast.

Expression of the HCV E1/E2 fusion protein was confirmed by Western blot analysis of lysates from copper-induced, heat-inactivated yeast (See Fig. 1C).

Example 4

The following example describes the engineering of the GI-5000 series TM domain-deleted HCV NS4b fusion protein yeast vehicle of the present invention.

The NS4b protein is a single polypeptide with the following sequence elements arranged in tandem, in frame, from N- to C-terminus (polyprotein numbering in parentheses) (represented herein by SEQ ID NO:8): 1) The sequence MADEAP to impart resistance to proteosomal degradation, 2) amino acids 1 to 69 (1712 to 1780) of HCV protein NS4b, 3) amino acids 177 to 261 (1888 to 1972) of HCV protein NS4b. A 107 amino acid region corresponding to NS4b amino acids 70 to 176 (1781 to 1887) that contains multiple membrane spanning domains was omitted to promote cytoplasmic accumulation in yeast.

Expression of the HCV NS4b fusion protein was confirmed by Western blot analysis of lysates from copper-induced, heat-inactivated yeast (See Fig. 1D).

Example 5

The following example describes non-clinical pharmacology studies in mice using the GI-5005 yeast vehicles (also referred to herein as Tarmogen™) expressing HCV antigens: immunogenicity studies.

GI-5005 consists of *S. cerevisiae* yeast (W303 strain obtained from the ATCC) that have been stably transduced with a yeast expression plasmid encoding a fusion protein of truncated HCV genotype 1a-derived *NS3* and *core* gene products under the control of the yeast copper-inducible (*CUP1*) promoter (SEQ ID NO:2), as described in Example 1. In the following studies, C57BL/6 (H-2^b) and BALB/cBy (H-2^d) mice were injected subcutaneously with GI-5005 yeast. *In vitro* and *in vivo* assays that detect induction of antigen-specific lymphocytes by GI-5005 were employed, including lymphocyte proliferation, cell-mediated cytotoxicity, cytokine secretion, and protection from tumor challenge. To support these studies, the following yeast strains, cell lines and recombinant viruses have been generated and maintained:

- **GI-5003:** HCV-NS3 protein-expressing yeast strain. GI-5003 expresses full-length NS3 in which the catalytic domain has been inactivated by a single point mutation.
- **GI-5005-L:** GI-5005 yeast strain expressing less than 50 ng HCV-NS3-Core fusion protein per YU.
- **GI-5005-M:** GI-5005 yeast strain expressing approximately 500 ng HCV-NS3-Core fusion protein per YU
- **GI-5005-H:** GI-5005 yeast strain expressing approximately 1400 ng HCV-NS3-Core fusion protein per YU

- **EL4-NS3:** C57BL/6-derived EL4 lymphoma cells (H-2^b) stably transfected with DNA encoding HCV NS3.
- **A20-NS3:** BALB/c-derived A20 lymphoma cells (H-2^d) stably transfected with DNA encoding HCV NS3.
- **P815-NS3:** DBA/2-derived P815 leukemia cells (H-2^d) stably transfected with DNA encoding HCV NS3.
- Recombinant vaccinia viruses (rVV) encoding beta-galactosidase (**rVV-lac**), HIV-1 Gag (**rVV-Gag**), HCV NS3 (**rVV-NS3**) and HCV Core (**rVV-Core**) proteins.

In the studies that are described below, and unless otherwise indicated in a particular experiment, female BALB/c and/or C57BL/6 mice (5 per group; aged 6-10 weeks) were injected subcutaneously on a weekly basis with 5 YU (50 million) GI-5005 or GI-5003 and were sacrificed seven days after the final injection. Spleen cell suspensions, pooled from each group, were prepared in RPMI-1640 tissue culture medium supplemented with 10% heat-inactivated fetal calf serum, L-glutamine, HEPES and 2-mercaptoethanol and were subjected to *in vitro* stimulation (IVS) conditions utilizing both HCV antigen-specific (typically rVV-NS3 and/or rVV-Core) and yeast antigen-specific (typically GI-5005) stimuli as specified. Standard assays were employed to evaluate immune responses induced by administration of GI-5005 and included lymphocyte proliferation as assessed by ^{3}H-thymidine incorporation, cell-mediated cytotoxicity assays employing ^{51}Cr-labeled target cells, quantification of cytokine secretion, and protection from tumor challenge.

(a) *GI-5005 induces antigen-specific lymphocyte proliferation.*

In a preliminary experiment to evaluate the immunogenicity of GI-5005, C57BL/6 mice were injected weekly for three weeks with 5 YU (50 million) heat-inactivated GI-5005 yeast cells. The mice showed no apparent adverse effects from immunization. Spleen cells were obtained seven days after the final immunization and single cell suspensions were stimulated *in vitro* with either nothing, EL4 lymphoma cells, EL4-NS3 (EL4 stably expressing HCV NS3), rVV-NS3 (recombinant vaccinia virus encoding HCV NS3) or rVV-Core. Lymphocyte proliferation was assessed using a standard thymidine incorporation assay after 5 days in culture. More specifically, spleen cells from C57BL/6 mice that were injected with 5 YU GI-5005 were placed in individual wells of 96-well U-bottomed tissue culture plates (400,000 cells/well) and stimulated *in vitro* with: nothing, mitomycin C-treated EL4 (10,000 cells/well), mitomycin C-treated EL4-NS3 (10,000 cells/well), rVV-NS3 (400,000 pfu/well) or rVV-Core (400,000 pfu/well). 3HTdR was added on day 5 and

the plates were harvested 18 hours thereafter. Results are expressed as the average CPM +/- S.D. for triplicate samples. The results presented in Fig. 2 show that GI-5005 induces NS3- and Core-specific lymphocyte proliferation.

(b) *GI-5005 induces antigen-specific cytotoxic effector cell responses*:

GI-5005 induces cytotoxic effector cells that kill tumor cells stably expressing HCV NS3

Fig. 3 shows that immunization with GI-5005 induces cytotoxic effector cells that can kill HCV NS3-expressing tumor cells. Specifically, spleen cells from C57BL/6 mice that were injected weekly for three weeks with 5 YU GI-5005 were placed in individual wells of either 25 cm^2 tissue culture flasks at 30 x 10^6 cells/flask (Figs. 3A-3B) or 24-well flat-bottomed tissue culture plates at 6 x 10^6/well (Fig. 3C). Spleen cells were stimulated *in vitro* (IVS) for 6 days with either 1 YU (10^7 yeast cells) GI-5005/flask (Fig. 3A); with nothing, 1 YU/flask GI-1001 or 1 YU/flask GI-5005 (Fig. 3B); or with 6 x 10^6 pfu/well rVV-lac or rVV-NS3 (Fig. 3C). Spleen cells in culture with rVV-lac or rVV-NS3 were expanded for an additional 3 days in the presence of 10% T-stim as a source of T cell growth factors. At the end of the 6 (Figs. 3A,3B) or 9 (Fig. 3C) day IVS culture period, doubling dilutions of the spleen cell cultures were mixed with ten thousand ^{51}Cr-labeled EL4 or EL4-NS3 cells as indicated. E:T ratio refers to the effector:target ratio based on spleen effector cell concentrations at the start of the IVS culture period. Results are expressed as the average percent specific lysis +/- S.D. for triplicate samples isolated after six hours of co-culture in 96-well V-bottomed plates. Percent spontaneous chromium release values were 19% for EL-4 (Fig. 3A), 40% for EL4-NS3 (Figs. 3A,3B) and 29% for EL4-NS3 (Fig. 3C).

In the results presented in Fig. 3A, spleen cells derived from GI-5005 immunized C57BL/6 mice were stimulated *in vitro* with GI-5005 yeast, at a yeast to spleen cell ratio of 1:3, for 6 days prior to testing on ^{51}Cr-labeled non-transfected EL4 lymphoma cells or on EL4 cells stably expressing HCV-NS3 (EL4-NS3). The stimulated spleen cells killed EL4-NS3 targets in a dose-dependent manner. In contrast, significantly less killing was observed on non-transfected EL4 cells. In addition to providing evidence that immunization with GI-5005 induced NS3-specific cytotoxic effector cells, these data also indicated that GI-5005 yeast could be used *in vitro* to re-stimulate NS3-specific cytotoxic effector cells. The results presented in Fig. 3B provide further confirmation for this finding and show that *in vitro* stimulation (IVS) of spleen cells from GI-5005-immunized mice with GI-5005 reveals

cytotoxic effector cells capable of enhanced cytotoxic activity against EL4-NS3, as compared to IVS with nothing (nil) or with vector control yeast (GI-1001). The requirement for exposure to some form of HCV NS3 antigen to activate cytotoxic effector cells activity during the IVS period was further investigated using stimulation with recombinant vaccinia virus encoding NS3 (rVV-NS3; Fig. 3C). These data show that NS3-specific cytotoxic effector cells present in the spleen of immunized mice are stimulated by IVS with rVV-NS3 as compared to IVS with rVV-lac, a recombinant virus encoding the irrelevant antigen beta-galactosidase.

GI-5005 induces cytotoxic effector cells that kill tumor cells infected with recombinant vaccinia virus encoding HCV NS3 or Core

The results presented above demonstrated that immunization with GI-5005 leads to induction of cytotoxic effector cells that can kill syngeneic tumor cells expressing NS3. However, GI-5005 also expresses the HCV Core antigen. Attempts to derive stably transfected tumor cell lines expressing HCV Core protein were unsuccessful. To overcome the lack of a Core- expressing target cell, the studies presented in Fig. 4 were performed. In brief, H-2^d-bearing P815 leukemia cells were infected overnight with recombinant vaccinia viruses encoding either HCV NS3 or HCV Core prior to their use in a standard chromium release assay employing spleen cells from BALB/c mice that had been immunized with either GI-5005 or GI-5003 (a Tarmogen™™ expressing full-length HCV-NS3 but not Core) and stimulated *in vitro* for 5 days in the presence of GI-5005. More particularly, spleen cells from BALB/c mice that were injected weekly for three weeks with 5 YU GI-5005 (GI-5005) or 5 YU GI-5003 (GI-5003) were placed in individual wells of 24-well flat-bottomed tissue culture plates (8 x 10^6/well) and were stimulated *in vitro* with GI-5005 (1 x 10^6/well) for 5 days. At the end of the IVS culture period, doubling dilutions of the spleen cell cultures were mixed with ten thousand 51Cr-labeled P815 leukemia cells that had been infected overnight with recombinant vaccinia virus encoding HCV NS3 (Fig. 4A) or HCV Core (Fig. 4B). E:T ratio refers to the effector:target cell ratio based on spleen effector cell concentrations at the start of the IVS culture period. Results are expressed as the average percent specific lysis +/- S.D. for triplicate samples isolated after 6 hours of co-culture in 96-well V-bottomed plates. Percent spontaneous chromium release values were 21% for P815-rVV-NS3 and 40% for P815-rVV-Core.

Figs. 4A and 4B shows that GI-5005 induces cytotoxic cells that can kill tumor cells infected with either rVV-NS3 (Fig. 4A) or rVV-Core (Fig. 4B) whereas killing induced by

GI-5003 is restricted to NS3. In summary, the results presented in Figs. 3 and 4 indicate that immunization with GI-5005 induces NS3- and Core-specific cytotoxic effector cell activity.

(c) *GI-5005 induces cells that secrete pro-inflammatory cytokines*

Fig. 5 shows the cytokines that are secreted when spleen cells from either naïve or GI-5005 immunized C57BL/6 mice are placed in tissue culture with GI-5005 yeast. Cell-free supernatants were collected 48 hours after initiation of culture and cytokine concentrations were determined using the flow cytometer-based Luminex™ assay (Biosource). More specifically, spleen cells from naïve C57BL/6 mice or from C57BL/6 mice that received three weekly injections of 5 YU GI-5005 were placed in individual wells of 24-well flat-bottomed tissue culture plates (10 x 10^6/well). Spleen cells were stimulated with either GI-5005 (1 x 10^6 yeast cells/well) or PMA (15 ng/mL) plus Ionomycin (750 ng/mL). Cell-free supernatants were collected at 48 hours after initiation of culture and cytokines were quantified by the University of Colorado Cancer Center Flow Cytometer Facility using the flow-cytometer LuminexTM assay (Biosource). IFN-g = IFN-γ; TNF-a = TNF-α.

These results show that GI-5005 administration elicits T cells that secrete IL-2 and IL-5, as well as the pro-inflammatory cytokines IL-6, GM-CSF, IFN-γ and TNF-α. It is important to note that the cytokine response of spleen cells from immunized mice exposed to yeast *in vitro* is comparable in magnitude to that observed upon polyclonal stimulation of T cells from naïve C57BL/6 mice with PMA plus ionomycin. In addition, Fig. 5 also shows the cytokine response of naïve C57BL/6 spleen cells to yeast and indicates that the innate response to yeast includes secretion of IL-6, IL-12 and TNF-α, presumably derived from monocytes and dendritic cells in the population. Similar results were obtained with spleen cells from naïve and immunized BALB/c mice (see Figs. 8 and 11).

(d) *Effect of repeated administration on immune responses induced with GI-5005*

The results presented in Figs. 6, 7 and 8 are from experiments comparing one, two or three weekly immunizations with GI-5005 conducted in both C57BL/6 and BALB/c mice. Fig. 6 examines NS3- and Core-specific lymphocyte proliferation, Fig. 7 shows the induction of NS3- and Core-specific cytotoxic cell activity and Fig. 8 shows cytokine secretion profiles. Overall, these results indicate that a single injection of GI-5005 induces a weak response that is significantly enhanced by additional administrations.

Fig. 6 shows the results of a lymphocyte proliferation assay performed with spleen cells from C57BL/6 mice that received one, two or three weekly immunizations with GI-5005. Specifically, spleen cells from C57BL/6 mice that received one, two or three weekly injections with 5YU GI-5005 were placed in individual wells of 96-well U-bottomed tissue culture plates (400,000 cells/well) and stimulated *in vitro* with either nothing, rVV-NS3, rVV-Core or rVV-rastafar (100,000 pfu/well). 3HTdR was added on day 5 and the plates were harvested 18 hours thereafter. Results are expressed as the average CPM +/- S.D. for triplicate samples. The response of HCV NS3 and Core-specific lymphocytes increased in proportion with the number of immunizations and the calculated stimulation indices improved from 1.8 to 2.8 against rVV-NS3 and from 6.5 to 8.6 against rVV-Core with one vs. three immunizations. No stimulation was observed against rVV-rastafar (encoding human Ras), confirming the antigen-specificity of the response induced by GI-5005.

Fig. 7 shows the results of chromium release assays performed with spleen effector cells derived from C57BL/6 and BALB/c mice that received one, two or three immunizations with GI-5005. Specifically, spleen cells from C57BL/6 mice (Figs. 7A and 7B) or BALB/c mice (Figs. 7C and 7D) that received one, two or three weekly injections with 5 YU GI-5005 were placed in individual wells of 24-well flat-bottomed tissue culture plates (10 x 10^6/well) and stimulated *in vitro* with GI-5005 (1 x 10^6/well) for 5 days. At the end of the IVS culture period, doubling dilutions of the spleen cell cultures were mixed with ten thousand 51Cr-labeled EL4 lymphoma cells (Figs. 7A and 7B) or P815 leukemia cells (Figs. 7C and 7D) that had been infected overnight with recombinant vaccinia virus encoding HCV NS3 (Figs. 7A and 7C) or HCV Core (Figs. 7B and 7D). E:T ratio refers to the effector:target cell ratio based on spleen effector cell concentrations at the start of the IVS culture period. Results are expressed as the average percent specific lysis +/- S.D. for triplicate samples isolated after 6 hours of co-culture in 96-well, V-bottomed plates. Percent spontaneous ^{51}Cr release was 10% for EL-4-rVV-NS3, 10% for EL4-rVV-Core, 12% for P815-rVV-NS3 and 11% for P815-rVV-Core. Confirming the findings reported in Fig. 4, the results presented in Fig. 7 show dose-dependent killing on syngeneic tumor cell targets infected with either rVV-NS3 or rVV-Core which increases in proportion to the number of immunizations.

The results presented in Fig. 8 show the cytokine secretion profiles of spleen cells derived from C57BL/6 and BALB/c mice that received one, two or three immunizations with GI-5005 in response to *in vitro* stimulation with GI-5005. Specifically, spleen cells

from C57BL/6 mice (upper panels) or BALB/c mice (lower panels) that received one, two or three weekly injections with 5 YU GI-5005 were placed in individual wells of 24-well flat-bottomed tissue culture plates (10 x 10^6/well) and stimulated *in vitro* with GI-5005 (1 x 10^6/well). Cell-free supernatants were collected at 48 hours after initiation of culture and cytokines were quantified by the University of Colorado Cancer Center Flow Cytometer Facility using the flow-cytometer based LuminexTM assay (Biosource). IFN-g = IFN-γ; TNF-a = TNF-α. These results show that the cytokine response of cells from immunized mice against yeast antigens is predominantly of the T_H1-like, pro-inflammatory variety and that more than one immunization is required to see the full spectrum of response. It is important to further note that the T_H2 cytokines IL-4 and IL-10 are generally not detected, suggesting that yeast vehicles of the invention primarily induce cellular rather than humoral immunity.

The data presented above indicated that immune responses induced by GI-5005 were enhanced by repeated weekly administrations. To explore boosting of immune responses with GI-5005, the experiment outlined in Table 2 was undertaken. In brief, female BALB/c mice received five weekly injections of GI-5005 followed by no boosting or by boosting at weekly, bi-weekly, monthly or bimonthly intervals. Mice were sacrificed 16 days after the last boosting. The results importantly show that repeated weekly immunization does not result in induction of neutralization and/or tolerance in that even after 12 weekly injections a subsequent administration resulted in boosting as measured by lymphocyte proliferation and cell-mediated cytotoxicity assays.

Table 2: Immunization and boosting schedule with GI-5005

Group	D 0	D 7	D 14	D 21	D 28	D 35	D 42	D 49	D 56	D 63	D 70	D 77	D 84	D 100
PBS control	-	-	-	-	-	-	-	-	-	-	-	-	-	Sacrifice
No boost	I	I	I	I	I	-	-	-	-	-	-	-	-	Sacrifice
2 month boost	I	I	I	I	I	-	-	-	-	-	-	-	I	Sacrifice
Monthly boost	I	I	I	I	I	-	-	-	I	-	-	-	I	Sacrifice
Bi-weekly boost	I	I	I	I	I	-	I	-	I	-	I	-	I	Sacrifice
Weekly boost	I	I	I	I	I	I	I	I	I	I	I	I	I	Sacrifice

I = immunization with GI-5005

Fig. 9 shows the results of a lymphocyte proliferation assay performed with spleen cells derived from the BALB/c mice that received GI-5005 on the immunization schedule outlined in Table 2. Briefly, spleen cells from BALB/c mice that were immunized with 5 YU GI-5005 on the schedule as described in Table 2 were placed in individual wells of 96-

well U-bottomed tissue culture plates (400,000 cells/well) and stimulated *in vitro* with either nothing (Bkgd), GI-5005 (320,000 or 20,000 yeast cells/well), Concanavlin A (ConA; 2.5 μg/mL) or Lipopolysaccharide + dextran sulfate (LPS+DS; 25 μg/ml and 20 μg/mL). 3HTdR was added on day 3 and the plates were harvested 18 hours thereafter. Results are expressed as the average CPM +/- S.D. for triplicate samples. Fig. 9 shows that the boostable response against yeast-associated antigens is quite evident and there is no apparent induction of tolerance.

Fig. 10 shows the results of a chromium release assay performed with spleen effector cells derived from the BALB/c mice that were immunized and boosted as described in Table 2. Briefly, spleen cells from BALB/c mice that were immunized with 5 YU GI-5005 on the schedule as described in Table 2 were placed in individual wells of 24-well flat-bottomed tissue culture plates (10 x 10^6/well) and stimulated *in vitro* with GI-5005 (1 x 10^6/well) for 5 days. At the end of the IVS culture period, doubling dilutions of the spleen cell cultures were mixed with ten thousand ^{51}Cr-labeled P815-NS3 leukemia cells. E:T ratio refers to the effector:target cell ratio. Results are expressed as the average percent specific lysis +/- S.D. for triplicate samples isolated after 6 hours of co-culture in 96-well, V-bottomed plates. Percent spontaneous 51Cr release was 12% for P815-NS3. Confirming the findings reported in Fig. 9, the results presented in Fig. 10 show dose-dependent killing on syngeneic tumor cells stably expressing HCV NS3 and further demonstrate the durability as well as boostability of the CTL response induced by GI-5005.

(e) *Durability of immune responses induced with GI-5005*

In order to evaluate the robustness of the cellular immune responses induced upon immunization with GI-5005, C57BL/6 and BALB/c mice that received three weekly doses of GI-5005 were sacrificed one month and two months post-dosing. Fig. 11 examines the durability of yeast-specific lymphocyte proliferation while Fig. 12 examines the durability of NS3- and Core-specific cytotoxic cell activity and Fig. 13 shows yeast- as well as NS3-specific cytokine secretion profiles. Overall, these results suggest that administration of GI-5005 induces memory T cell responses that are long lasting and robust.

Durability of lymphocyte proliferative responses induced with GI-5005

The results presented in Fig. 11 show that proliferative responses against yeast antigens last at least 2 months following three weekly immunizations. Briefly, spleen cells from C57BL/6 (Fig. 11A) or BALB/c (Fig. 11B) mice that received either nothing (Naïve) or three weekly immunizations with 5 YU GI-5005, and were rested for five (1 month

durability) or nine (2 month durability) weeks prior to sacrifice, were placed in individual wells of 96-well U-bottomed tissue culture plates (400,000 cells/well) and stimulated *in vitro* with either nothing (Bkgd) or GI-5005, (400,000 yeast cells/well). ^{3}HTdR was added on day 5 and the plates were harvested 18 hours thereafter. Results are expressed as the average CPM +/- S.D. for triplicate samples. It is important to note these results examine yeast-specific as opposed to HCV NS3- or Core-specific proliferative responses as described in Figs. 2 and 6. The stimulation indices against yeast antigens in these particular experiments range from approximately 11 to 77.

Durability of cytotoxic effector cell responses induced with GI-5005

As shown in Fig. 12, and similar to results regarding lymphocyte proliferative responses, the durability of cytotoxic effector cell activity induced with GI-5005 is at least two months. Briefly, spleen cells from C57BL/6 (Fig. 12A) or BALB/c (Fig. 12B) mice that received either nothing (Naïve) or three weekly immunizations with 5 YU GI-5005, and were rested for five (1 month durability) or nine (2 month durability) weeks prior to sacrifice, were placed in individual wells of 24-well flat-bottomed tissue culture plates (10 x 10^{6}/well) and stimulated *in vitro* with GI-5005 (1 x 10^{6}/well) for 5 days. At the end of the IVS culture period, doubling dilutions of the spleen cell cultures were mixed with ten thousand ^{51}Cr-labeled EL4-NS3 lymphoma cells (Fig. 12A) or P815-NS3 leukemia cells (Fig. 12B). E:T ratio refers to the effector:target cell ratio based on spleen effector cell concentrations at the start of the IVS culture period. Results are expressed as the average percent specific lysis +/- S.D. for triplicate samples isolated after 6 hours of co-culture in 96-well, V-bottomed plates. Percent spontaneous ^{51}Cr release was 11% for EL-4-NS3 and 11% for P815-NS3.

Durability of cytokine secretion responses induced with GI-5005

Fig. 13 shows the durability of the cytokine secretion profiles of spleen cells derived from C57BL/6 and BALB/c mice that received three weekly immunizations with GI-5005 in response to *in vitro* stimulation with GI-5005 and rVV-NS3. Briefly, spleen cells from C57BL/6 (Figs. 13A and 13B) or BALB/c (Figs. 13C and 13D) mice that received nothing (Naïve) or three weekly immunizations with 5 YU GI-5005 and were rested for five (1 month durability) or nine (2 month durability) weeks prior to sacrifice were placed in individual wells of 24-well flat-bottomed tissue culture plates (10 x 10^{6}/well) and stimulated *in vitro* with GI-5005 (1 x 10^{7}/well) or rVV-NS3 (1 x 10^{7} pfu/well). Cell-free supernatants were collected at 48 hours (IVS w/ GI-5005) or 120 hours (IVS w/ rVV-NS3) after

initiation of culture. Cytokines were quantified using the LuminexTM assay (Biosource). IFN-g = IFN-γ; TNF-a = TNF-α. These results show that durability of cytokine-secreting cells induced by immunization with GI-5005 is at least two months. In contrast to the yeast-specific profile of cytokines, these data also show that the antigen-specific (i.e., NS3-specific) response, using rVV-NS3 as a stimulus, is limited predominantly to GM-CSF and IFN-γ.

(f) *Comparison of administration of different doses of GI-5005*

The results summarized in Figs. 14 and 15 compare the induction of cytotoxic effector cells and cytokine-secreting cells respectively by GI-5005 Tarmogen™s that express different amounts of antigen. This study was undertaken as part of the development of a potency assay.

In brief, GI-5005 Tarmogen™s were produced that express approximately 1400, 500 and <50 ng/YU of HCV NS3-Core fusion protein. This was accomplished by varying the amount of copper present during the induction period. The three Tarmogen™s are designated as GI-5005-H (1400 ng/YU; 0.02 ng protein/ng total protein), GI-5005-M (500 ng/YU; 0.008 ng fusion protein/total protein) and GI-5005-L (<50 ng/YU; <0.001 ng protein/ng total protein). Groups of five female BALB/c mice (H-2^d) were immunized weekly with the three different GI-5005 Tarmogen™s at three doses, 0.1, 1 and 10 YU. Mice were sacrificed seven days after the third weekly injection and their spleen cells were subjected to *in vitro* stimulation (IVS) as will now be described.

In Fig. 14, spleen cells from the immunized mice, pooled by group, were placed into IVS separately with each of the three different GI-5005 Tarmogen™s. Cell-mediated cytotoxic activity of the IVS cultures was assessed on H-2^d-bearing P815 cells stably expressing HCV NS3. Briefly, spleen cells from BALB/c mice that received three weekly injections of 0.1, 1 or 10 YU of either GI-5005-H (Figs. 14A-14C), GI-5005-M (Figs. 14D-14F) or GI-5000-L (Figs. 14G-14I) were placed in individual wells of 24-well flat-bottomed tissue culture plates (10 x 10^6 spleen cells/well) and stimulated *in vitro* (IVS) with the indicated GI-5005 Tarmogen™ (2 x 10^6 yeast cells/well) for 5 days. At the end of the IVS culture period, doubling dilutions of the spleen cell cultures were mixed with ten thousand ^{51}Cr-labeled P815-NS3 leukemia cells. E:T ratio refers to the effector:target cell ratio based on spleen effector cell concentrations at the start of the IVS culture period. Results are expressed as the average percent specific lysis +/- S.D. for triplicate samples isolated after 6 hours of co-culture in 96-well, V-bottomed plates. Percent spontaneous ^{51}Cr release was

12% for P815-NS3. 10 YU, 1 YU & 0.1 YU in the legend of each figure refer to the amount of GI-5005 used for immunization. The data show clear dose responses based on a single parameter; that is, the amount of HCV antigen being expressed in the Tarmogen™™ used for immunization or for *in vitro* stimulation. A similar conclusion can be drawn from the data presented in Fig. 15.

Fig. 15 shows the levels of IL-6 secreted in response to yeast-specific antigens vs. GM-CSF secreted in response to HCV NS3-specific antigen. Specifically, spleen cells from BALB/c mice that received three weekly injections of 0.1, 1 or 10 YU (X-axis) of either GI-5005-H (Fig. 15A), GI-5005-M (Fig. 15B) or GI-5000-L (Fig. 15C) were placed in individual wells of 24-well flat-bottomed tissue culture plates (10×10^6 spleen cells/well) and stimulated *in vitro* (IVS) with either GI-5005-H (2×10^6 yeast cells/well) or rVV-NS3 (100×10^6 pfu/well). Cell-free supernatants were collected at 72 hours (IVS w/ GI-5005) or 120 hours (IVS w/ rVV-NS3) after initiation of culture. Cytokines were quantified using the LuminexTM assay (Biosource). In brief, these data indicate that the induction of IL-6-secreting cells is dependent on the number of Tarmogen™s that are used for immunization but is independent of the amount of HCV antigen being expressed in the Tarmogen™™. In contrast, the induction of cells secreting GM-CSF is dependent on both criteria. Based on the data presented in Figs. 14 and 15 a minimum of 500 ng fusion protein/YU or 0.008 ng protein/ng total protein is required for inducing an antigen-specific response.

Example 6

The following example shows non-clinical pharmacology studies in mice using the GI-5005 Tarmogen™ expressing HCV antigens: tumor protection and therapy studies.

Because an *in vivo* animal model of protection or therapy against HCV is not available, the present inventors have used protection and therapy against HCV antigen-bearing tumors *in vivo* to demonstrate the activity of GI-5005.

(a) *GI-5005 induces protective immunity against NS3-expressing tumor cells*

The experiments described above demonstrate the immunogenicity of GI-5005 in C57BL/6 and BALB/c mice. In order to determine if injection of GI-5005 yeast elicited protective immunity, BALB/c mice were injected subcutaneously once a week for three weeks with 0.1, 0.7 or 5 YU of either GI-5005 or GI-5003 (a Tarmogen™ that expresses only HCV NS3 protease), with 5 YU GI-4014 (a Tarmogen™ expressing a mutated Ras protein) as a negative control, or with nothing. One week after the final immunization, the mice were challenged with subcutaneously injected syngeneic A20 tumor cells stably

transfected with HCV NS3 (A20-NS3). Tumor volume was measured on day 21 after challenge. The data presented in Fig. 16 show that the mice that were immunized with a Tarmogen™ expressing HCV NS3 antigens, GI-5005 or GI-5003, were protected from challenge with A20-NS3 tumor cells, whereas mice immunized with nothing or with GI-4014 were not. Results are expressed as the mean tumor volume +/- S.D. These results show that GI-5005 induces dose- and antigen-dependent immune responses that protect mice from syngeneic tumor cells expressing HCV NS3.

This experiment was repeated in C57BL/6 mice that were injected weekly for three weeks with GI-5005 and challenged seven days thereafter with EL4-NS3 lymphoma cells injected subcutaneously. Briefly, C57BL/6 mice (5 per group) were injected subcutaneously weekly for three weeks with nothing (Naive) or with 5 YU GI-5005. Mice were challenged 7 days after the final immunization with 5 x 10^4 A20-NS3 injected subcutaneously. Tumors were measured on the indicated day after challenge. Results are expressed as the mean tumor volume +/- S.D. Numbers refer to the number of animals with measurable tumors (* Tumors excised from immunized mice were found to no longer express NS3). The results presented in Fig. 17 show that mice injected with GI-5005 were protected from challenge with EL4-NS3 whereas naïve mice were not. Injection of GI-5005 did not protect mice from challenge with EL4 alone indicating that protective immunity was antigen-specific (data not shown). To determine whether the tumors that had grown in the immunized mice were still expressing HCV NS3, the tumors were excised from the two GI-5005 immunized mice that showed evidence of tumor growth, as well as from the five naïve mouse controls, and placed in tissue culture medium containing the antibiotic G4.18. In EL4-NS3, the mammalian expression vector encoding HCV NS3 also contains a neomycin resistance gene that allows transfectants to grow in the presence of the neomycin analog G4.18, thereby maintaining stable expression of HCV NS3. Whereas EL4-NS3 tumor cells excised from naïve mice grew out in the presence of G4.18, tumors from the GI-5005-immunized mice did not. This observation suggests that there was immunological pressure to eliminate expression of the transfected antigen. These observations indicate that GI-5005 induces protective immune responses *in vivo* against challenge with syngeneic tumor cells expressing NS3.

(b) *Immune responses in "protected" mice*

The availability of "protected" mice that had rejected syngeneic tumor cells expressing HCV NS3 provided the opportunity to examine antigen-specific immune

responses in the setting of protective immunity. Spleen cells from the five mice described above that rejected EL4-NS3 tumor cells were pooled and placed in individual wells of 96-well U-bottomed tissue culture plates (4 x 10^5 cells/well) and stimulated with either nothing, GI-1001 (2 x 10^5 yeast cells/well), GI-5005 (2 x 10^5 yeast cells/well), rVV-Gag (1 x 10^5 pfu/well), rVV-NS3 (1 x 10^5 pfu/well), or rVV-Core (1 x 10^5 pfu/well). ^{3}HTdR was added on day 5 and the cells were harvested 18 hours thereafter. Results are expressed as the average CPM +/- S.D. for quadruplicate samples. Fig. 18 shows the proliferative response of spleen cells derived from protected mice to yeast-specific, as well as HCV NS3- and HCV Core-specific stimuli. Fig. 19 examines their cytotoxic effector cell activity. In this experiment, spleen cells from the five immunized mice that rejected EL4-NS3 tumor cells or from naïve mice were pooled together and placed in individual wells of 24-well flat-bottomed tissue culture plates (8 x 10^6 spleen cells/well) and stimulated *in vitro* (IVS) with either GI-5005 (1 x 10^6 yeast cells/well) or rVV-NS3 (8 x 10^5 pfu/well) for 5 days. At the end of the IVS culture period, doubling dilutions of the spleen cell cultures were mixed with ten thousand ^{51}Cr-labeled EL4 target cells that had been infected overnight with rVV-NS3. E:T ratio refers to the effector:target cell ratio based on spleen effector cell concentrations at the start of the IVS culture period. Results are expressed as the average percent specific lysis +/- S.D. for triplicate samples isolated after 5 hours of co-culture in 96-well, V-bottomed plates. Percent spontaneous ^{51}Cr release was 33% for EL4-rVV-NS3. Taken together, these findings suggest that protected mice, *i.e.* immunized mice that rejected NS3-expressing tumor cells, have enhanced immune responses to HCV NS3 as compared to mice that were simply immunized as shown in Example 5 above.

(c) *GI-5005 stimulates cytotoxic effector cell activity in spleen cells isolated from naïve tumor-bearing mice*

The results presented above suggest that exposure of GI-5005 mice to a secondary source of HCV antigen, namely tumor cells expressing HCV NS3, results in a boosting effect as evidenced by enhanced proliferative and cytotoxic effector cell responses. In order to determine if GI-5005 yeast could further stimulate T cell activity from antigen-bearing mice, thus mimicking T cell activation in chronic HCV-infected patients, naïve C57BL/6 mice were injected subcutaneously with EL4-NS3 tumor cells. After 3 weeks, when tumor volumes reached approximately 2500 mm^3, the mice were sacrificed and spleen cells were incubated with either vector control (GI-1001) or GI-5005 yeast. Cytotoxic effector cell activity against rVV-NS3 infected EL4 target cells was assessed six days after initiation of

in vitro stimulation. Specifically, spleen cells from five naive mice that were injected with EL4-NS3 tumor cells 21 days previously were pooled together and placed in individual wells of 24-well flat-bottomed tissue culture plates (8 x 10^6 spleen cells/well) and stimulated *in vitro* (IVS) with either GI-1001 or GI-5005 (1 x 10^6 yeast cells/well) for 6 days. At the end of the IVS culture period, doubling dilutions of the spleen cell cultures were mixed with ten thousand ^{51}Cr-labeled EL4 target cells that had been infected overnight with rVV-NS3. E:T ratio refers to the effector:target cell ratio based on spleen effector cell concentrations at the start of the IVS culture period. Results are expressed as the average percent specific lysis +/- S.D. for triplicate samples isolated after 5 hours of co-culture in 96-well, V-bottomed plates. Percent spontaneous ^{51}Cr release was 33% for EL4-rVV-NS3. The results presented in Fig. 20 show that GI-5005 can stimulate cytotoxic effector cells derived from mice bearing tumors expressing HCV-NS3.

(d) *GI-5005 induces therapeutic activity against NS3-expressing tumor cells*

The results presented in Fig. 20 show that GI-5005 can re-stimulate NS3-specific cytotoxic effector activity from spleen cells of C57BL/6 mice bearing EL4-NS3-expressing tumors. This suggests that a therapeutic effect might also be attainable. To assess this possibility, BALB/c mice (5 per group) were injected subcutaneously with syngeneic 1.25 x 10^5 A20-NS3 B lymphoma cells stably transfected with DNA encoding HCV NS3. Beginning seven days after tumor implantation, the mice were immunized once a week for three weeks with either PBS or with YU GI-5005. Tumor growth was monitored and the mice were sacrificed 28 days after tumor implantation when the tumors in the PBS group reached 2500 mm^3. Results in Fig. 21 are expressed as the mean tumor volume +/- S.D and numbers refer to the number of animals with measurable tumors (* Tumors excised from all tumor bearing mice were found to still express NS3).

Fig. 21 shows that therapeutic administration of GI-5005 results in tumor remission. In brief, whereas all five tumor-bearing mice that were treated with PBS showed tumor growth, only three out five that were treated with GI-5005 exhibited tumor growth and the tumors that arose in the treated animals appeared to be growing much more slowly (mean tumor volume in tumor-bearing mice in the PBS treated group was 2488 +/- 636 vs. 1264 +/- 548 mm^3 in the GI-5005 treated group). However, in contrast to the results obtained with EL4-NS3 as described above, the HCV NS3 protein was still being expressed in all of the tumors from A20-NS3 tumor bearing mice (data not shown).

The immunotherapeutic property of GI-5005 was confirmed in a second study as shown in Fig. 22 in which the number of implanted tumor cells was varied. Briefly, BALB/c mice (5 per group) were injected subcutaneously with 2.5 x 10^4, 5.0 x 10^4, or 1 x 10^5 A20-NS3 B lymphoma cells. Mice were therapeutically immunized by subcutaneous injection at skin sites distal to the tumor on days 7, 14 and 21 after tumor implantation with either PBS or with 10 YU GI-5005. Tumor volume was measured on the indicated day after initiation of therapy. Results are expressed as the mean tumor volume +/- S.D (Fig. 22A) and as the percentage of tumor bearing mice (Fig. 22B) on day 24 after initiation of therapy.

Example 7

The following example describes toxicity studies with the yeast vaccines of the present invention.

As described above, the GI-5005 Tarmogen™ has been administered to more than 300 mice in a number of different studies to date and no grossly observable toxicity has been evident. Other related products using the yeast-based vaccine platform have been administered to mice, rats, rabbits, pig-tailed and rhesus macaque monkeys with no major observable toxicity. Because of the similarity, and therefore relevance of safety data, of other yeast based products to the GI-5005 Tarmogen™, a number of non-clinical safety assessments with these other Tarmogen™s are detailed following the toxicity data or GI-5005.

The objective of this study was to determine the toxic effects of GI-5005 in male and female New Zealand rabbits following once weekly subcutaneous administration at a fixed dose volume of 1 mL for up to thirteen consecutive weeks (dosing on Days 1, 8, 15, 22, 29, 36, 43, 50, 57, 64, 71, 78, 85 and 92), followed by specified recovery/necropsy intervals (Table 3). The dose levels were selected on the basis of available data from previous studies. The subcutaneous route is the intended route of administration of this test article in humans. The interim report as summarized below. Three treatment groups (Groups 2 to 4) of five male and five female New Zealand White rabbits were administered the test article at respective dose levels of 1, 10 and 100 Yeast Units (YU). A control group (Group 1) of five animals/sex received the vehicle, sterile phosphate buffered saline (PBS). The test article or vehicle was administered once on Days 1, 8, 15, 22, and 29. Additionally, three treatment groups (Groups 6 to 8) of five animals/sex/group (low and middle dose groups) and ten animals/sex/group (high dose group) were administered the test article at respective dose levels of 1, 10 and 100 YU. A control group (Group 5) of ten animals/sex received the

vehicle PBS. In groups 5-8, the test article or vehicle was administered once on Days 1, 8, 15, 22, 29, 36, 43, 50, 57, 64, 71, 78, 85, an 92. Five animals/sex of groups 5-8 were sacrificed on Day-94. The remaining 5 animals/sex in Groups 5 and 8 were maintained for a recovery period of approximately 23 days.

Table 3. Rabbit GLP toxicity study design

GROUP NUMBER	TREAT-MENT	DOSE LEVEL Yeast Units (YU)*	INITIAL M/F	TERMINAL NECROPSY (DAY 31) M/F	TERMINAL NECROPSY (Day 97) M/F	RECOVERY NECROPSY (DAY 120)* M/F
1	PBS	0	5/5	5/5		
2	GI-5005	1	5/5	5/5		
3	GI-5005	10	5/5	5/5		
4	GI-5005	100	5/5	5/5		
5	PBS	0	10/10		5/5	5/5
6	GI-5005	1	5/5		5/5	
7	GI-5005	10	5/5		5/5	
8	GI-5005	100	10/10		5/5	5/5
*The test and control articles will be administered as single subcutaneous injections (1.0 mL total volume) on Days 1, 8, 15, 22, 29, 36, 43, 50, 57, 64, 71, 78, 85, and 92. One yeast unit equals 10 million heat-killed yeast cells. For reporting purposes, yeast units will be abbreviated as YU.						

All animals were observed for morbidity, mortality, injury, and availability of food and water twice daily. Detailed clinical examinations, injection site irritation evaluations, ophthalmoscopic examinations, and body weight and food consumption measurements were conducted during the course of the study. Clinical pathology evaluations (hematology, clinical chemistry, and urinalysis) were conducted on all surviving animals predose, the day following each dose, and for animals in Groups 1 to 4 at the Day 31 necropsy. Additional blood samples were collected from all surviving animals predose and 1 hour postdose for serum antibody analysis and for animals in Groups 1 to 4 at the Day 31 necropsy for serum antibody analysis. At the Day 31, Day 97 and Day 120 necropsies, all animals in the appropriate groups were euthanized and complete macroscopic and microscopic examinations were conducted, along with protocol-designated organ weight measurements.

No treatment-related effects on survival, clinical findings, food consumption, ophthalmology, or organ weights were observed. Microscopically, treatment-related changes were observed at the injection sites of both sexes at all dose levels, and included fibrosis, subacute inflammation, and necrosis. In addition, findings of granulomatous inflammation were also noted in some but not all of the injection sites. The incidence and severity of these findings were generally dose related. Granulocytic hyperplasia in the bone marrow of females at 1 YU and both sexes at 10 and 100 YU, and follicular lymphoid

hyperplasia and/or reactive red pulp/stromal hyperplasia in the spleen of females at 10 YU and both sexes at 100 YU were considered a secondary response to the observed inflammation at the injection sites. These findings correlated with the microscopic findings of tissue thickening at the injection sites. Treatment related irritation, consisting of both erythema and edema, was observed at the injection sites of both sexes at 100 YU, Minimal findings were also noted in both sexes at 10 YU, suggesting a relationship to treatment. There was no indication of any sign of recovery following dosing at any of the injection sites. Although the effect was a modest, a loss of body weight was noted in both sexes at 100 YU, suggesting a relationship to treatment with GI-5005.

Treatment-related effects in hematology and clinical chemistry were observed and were considered secondary to the local inflammatory responses observed at the injection sites. Treatment-related increases in leukocyte counts, reflecting increases in neutrophil counts, were noted in all GI-5005-treated groups, with the onset and severity generally dose related. Some recovery in neutrophil levels was noted prior to the next dose. Treatment-related increases in globulin values were observed, with the onset and severity generally dose related. The increases tended to be progressive over time, with no indication of recovery.

Based on the conditions and findings of this study, administration of GI-5005 at dose levels of 1, 10 and 100 YU to male and female rabbits did not result in any apparent systemic toxicity. Primary treatment related findings were limited to local effects of fibrosis, subacute inflammation, and necrosis at the injection sites, which were infrequent and mild to moderate except at the highest dose tested. Injection site reactions may represent a potential dose limiting effect in the clinical setting. Concomitant increases in neutrophil counts and globulin values that were considered secondary to the local inflammatory response.

To demonstrate the immunogenicity of GI-5005 in the rabbit toxicity study, and therefore immuno-toxicologic relevance of the study, a lymphocyte proliferation assay was performed. While there are no standardized methods for assaying lymphocyte proliferation in rabbits, a non-optimized assay of lymphocyte proliferation in response to yeast proteins was performed using lymphocytes isolated from ileocecocolic and axillary lymph nodes harvested two days after the fifth immunization (Day 31). Lymph node cell suspensions from individual rabbits were placed in tissue culture in 96-well U-bottomed plates (4×10^5 per well) with the indicated number of heat-killed GI-5005 yeast cells. Lymphocyte

proliferation was determined on day 3 of culture by pulsing with 1 μCi/well of ^{3}H-TdR for 18 hr. Average stimulation indices obtained with male (Fig. 23A) vs. female (Fig. 23B) lymph node cells are shown in Fig. 23 (Results are presented as average stimulation indices +/- S.E.M. obtained for evaluable lymph node cell samples from individual rabbits within each dose group). Overall, the data show that only 1 out of 10 rabbits immunized with the vehicle, PBS, showed a stimulation index of greater than 10 against the GI-5005 yeast, whereas 9 out of 10, 7 out of 10 and 8 out of 10 the rabbits immunized with 1, 10 or 100 YU GI-5005 respectively responded with a stimulation index of greater than 10. No differences between the response of male versus female rabbit lymph node cells could be discerned and a dose-response effect was not apparent.

An enzyme linked immunosorbent assay (ELISA) was used to detect and titer anti-*Saccharomyces cerevisiae* antibodies (ASCA) in the sera of rabbits (groups 1-4) that were injected with GI-5005 as part of MPI study 962-003. The serum samples examined were obtained on day 1, prior to the first injection, and on day 29, prior to the fifth weekly injection. All rabbits displayed ASCA titers of less than 1:100 at the initiation of the study (Table 4). In contrast, all rabbits that received GI-5005 showed elevated ASCA titers after administration of four weekly injections. However, the titers were low, less than 1:10,000, and no dose-response effect was observed.

Table 4. Summary of anti-*Saccharomyces cerevisiae* antibody (ASCA) units in sera of rabbits (Groups 1-4) that were injected with GI-5005 as part of MPI Study 962-003

Injection	Mean ASCA units (day 1)	Mean ASCA units (day 15)	Mean ASCA units (day 29)
PBS	4 +/- 5	3 +/- 4	6 +/- 8
GI-5005 (1 YU)	4 +/- 7	3 +/- 4	84 +/- 43
GI-5005 (10 YU)	2 +/- 2	6 +/- 10	127 +/- 162
GI-5005 (100 YU)	6 +/- 10	19 +/- 17	165 +/- 84
Positive rabbit antiserum*	311 +/- 85	311 +/- 85	311 +/- 85

* A 1:1000 dilution of the positive control rabbit antiserum contained 311 +/- 85 ASCA units when run in this assay suggesting that within 95% confidence an observed ASCA unit value of less than 300 would represent a titer of less than 1:1000. Averaged data +/- S.D. is shown in the following table.

The presence of HCV-NS3- and Core-specific serum antibodies produced in rabbits immunized weekly for five weeks with PBS or with 1, 10 or 100 YU of the GI-5005 Tarmogen™ were qualitatively evaluated by Western blot analysis to gain a better understanding of the humoral antibody responses induced against the heterologous protein contained in this Tarmogen™. No HCV-specific antibodies were observed in sera obtained

from any animals prior to immunization. In contrast, antibodies reacting specifically with NS3 and Core proteins were detected in serum samples from 7 of 9 tested rabbits at Day 31 after receiving 5 weekly doses of 100 YU GI-5005, and in serum samples from 1 of 3 animals in the 10 YU dose group. No HCV-specific antibodies were detected in serum samples from the PBS or 1 YU groups at day 31. This analysis shows that a dose-dependent induction of serum antibodies directed against the heterologous HCV NS3-Core protein contained in GI-5005 occurs as a result of subcutaneous administration of this Tarmogen™ in rabbits.

The preliminary 97 day and 120 day clinical pathology and gross observation data are consistent with the findings from the 31 day cohort. Thirteen weekly administrations of GI-5005 at dose levels of 1, 10 and 100 YU to male and female rabbits did not result in any apparent systemic toxicity. Primary treatment related findings were limited to local site reactions with the incidence and severity generally dose related. However, in the 100 YU dose group more severe granulomatous changes, fibrosis, and necrosis were observed in the injection site reactions, and may represent a potential dose limiting effect in the clinical setting. Histopathological analysis of this 97 day cohort is not yet available. Treatment-related increases in leukocyte counts, reflecting increases in neutrophil counts, and increases in globulin values were also observed, with the onset and severity generally dose related for both effects. The increases tended to be progressive over time, with no indication of recovery.

Gross safety assessments from 331 C57BL/6 and BALB/c mice injected with GI-5000 Tarmogen™ series products and prototypes showed no treatment-related deaths and mild to moderate hair loss and inflammation with occasional ulceration consistent with delayed-type hypersensitivity at the site of injection in approximately 5% of animals. Injection site reactivity was limited to C57BL/6 mice that are typically more sensitive to skin trauma and may have been secondary to grooming behaviors resulting from group housing conditions. No other gross clinical abnormalities or adverse reactions were observed.

Table 5. Summary of safety studies performed with GI-5005 Tarmogen™s and prototypes

Study type	Species tested	Conclusions
Safety assessments	Mice	More than 300 mice have been injected with heat-inactivated intact yeast via the subcutaneous route. No adverse effects have been observed at the injection site, with the exception of mild to moderate skin reactivity noted in approximately 5%

		of C57BL/6 mice, and no harmful effects have been observed at any time in any mice at doses as high as 10 YU.
28-day GLP safety study	Rabbits	Weekly administration of a total of five doses of GI-5005 at dose levels of 1, 10, and 100 YU to male and female rabbits did not result in any apparent systemic toxicity. Adverse reactions were limited to mild to moderate injection site reactions. The study animals tolerated the treatment regimen well.
97-day GLP safety study	Rabbits	The preliminary 97 day clinical pathology and gross observation data are consistent with the findings from the 31 day cohort. No apparent systemic toxicity. Primary treatment related findings were limited to local site reactions with the incidence and severity generally dose related. Histopathological analysis of this 97 day cohort is not yet available. Treatment-related increases in leukocyte counts, reflecting increases in neutrophil counts, and increases in globulin values were also observed, with the onset and severity generally dose related for both effects.

Each publication described or cited herein is incorporated herein by reference in its entirety.

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While various embodiments of the present invention have been described in detail, it is apparent that modifications and adaptations of those embodiments will occur to those skilled in the art. It is to be expressly understood, however, that such modifications and adaptations are within the scope of the present invention, as set forth in the following claims.

What is Claimed is:

1. A vaccine comprising:

a) a yeast vehicle; and

b) an HCV fusion protein that is recombinantly expressed by the yeast vehicle, the HCV fusion protein comprising at least a portion of an HCV NS3 protease linked to at least a portion of an HCV Core sequence.

2. The vaccine of Claim 1, wherein the HCV NS3 protease lacks the catalytic domain of a natural HCV NS3 protease.

3. The vaccine of Claim 1, wherein the HCV NS3 protease consists essentially of the 262 amino acids of HCV NS3 following the initial N-terminal 88 amino acids of the full-length NS3 protein (positions 1115 to 1376 with respect to SEQ ID NO:20).

4. The vaccine of Claim 1, wherein the hydrophobic C-terminal sequence of the HCV Core is truncated.

5. The vaccine of Claim 5, wherein the HCV Core sequence consists essentially of amino acid positions 2 through 140 of the full-length HCV Core sequence (positions 2 to 140, with respect to SEQ ID NO:20).

6. The vaccine of Claim 1, wherein the HCV Core sequence has been appended to include two amino acids, glutamate and aspartate.

7. The vaccine of Claim 1, wherein the HCV Core sequence has been appended to include the amino acid sequence of G-G-G-H-H-H-H-H-H (SEQ ID NO:10).

8. The vaccine of Claim 1, wherein the HCV NS3 protease is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP).

9. The vaccine of Claim 1, wherein the fusion protein consists essentially of SEQ ID NO:2.

10. A vaccine comprising:

a) a yeast vehicle; and

b) an HCV fusion protein that is recombinantly expressed by the yeast vehicle, the HCV fusion protein comprising a full-length, inactivated HCV NS3 protein.

11. The vaccine of Claim 10, wherein the HCV NS3 protein comprises a mutation at residue 1165 of the HCV polyprotein sequence, with respect to SEQ ID NO:20, that results in inactivation of the proteolytic activity of the protein.

12. The vaccine of Claim 10, wherein the HCV NS3 protease is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP).

13. The vaccine of Claim 10, wherein the fusion protein consists essentially of SEQ ID NO:4.

14. A vaccine comprising:

a) a yeast vehicle; and

b) an HCV fusion protein that is recombinantly expressed by the yeast vehicle, the HCV fusion protein comprising a truncated HCV E1 protein fused to a truncated HCV E2 protein.

15. The vaccine of Claim 14, wherein the truncated HCV E1 protein consists essentially of amino acids 1 to 156 of HCV E1 (positions 192 to 347, with respect to SEQ ID NO:20).

16. The vaccine of Claim 14, wherein the truncated HCV E2 protein consists essentially of amino acids 1 to 334 of HCV E2 (positions 384 to 717, with respect to SEQ ID NO:20).

17. The vaccine of Claim 14, wherein the truncated HCV E1 protein is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP).

18. The vaccine of Claim 14, wherein the fusion protein consists essentially of SEQ ID NO:6.

19. A vaccine comprising:

a) a yeast vehicle; and

b) an HCV fusion protein that is recombinantly expressed by the yeast vehicle, the HCV fusion protein comprising a transmembrane domain-deleted HCV NS4b protein.

20. The vaccine of Claim 19, wherein the transmembrane domain-deleted HCV NS4b protein consists essentially of amino acids 1 to 69 of HCV NS4b (positions 1712 to 1780, with respect to SEQ ID NO:20) linked to amino acids 177 to 261 of HCV NS4b (positions 1888 to 1972, with respect to SEQ ID NO:20).

21. The vaccine of Claim 19, wherein the transmembrane domain-deleted HCV NS4b protein is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP).

22. The vaccine of Claim 19, wherein the fusion protein consists essentially of SEQ ID NO:8.

23. A vaccine comprising:

a) a yeast vehicle; and

b) an HCV fusion protein that is recombinantly expressed by the yeast vehicle, the HCV fusion protein comprising a full-length HCV Core protein fused to a full-length HCV E1 protein fused to a full-length HCV E2 protein.

24. The vaccine of Claim 23, wherein the full-length HCV Core protein is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP).

25. The vaccine of Claim 23, wherein the fusion protein consists essentially of SEQ ID NO:12.

26. A vaccine comprising:

a) a yeast vehicle; and

b) an HCV fusion protein that is recombinantly expressed by the yeast vehicle, the HCV fusion protein comprising a truncated HCV Core protein fused to an HCV E1 protein with deleted transmembrane domain and an HCVE2 protein with deleted transmembrane domain.

27. The vaccine of Claim 26, wherein the truncated HCV Core protein consists essentially of positions 2 to 140 of HCV Core protein (positions 2 to 140, with respect to SEQ ID NO:20).

28. The vaccine of Claim 26, wherein the HCV E1 protein with deleted transmembrane domain consists essentially of positions 1 to 156 of HCV E1 protein (positions 192 to 347, with respect to SEQ ID NO:20).

29. The vaccine of Claim 26, wherein the HCV E2 protein with deleted transmembrane domain consists essentially of positions 1 to 334 of HCV E2 protein (positions 384 to 717, with respect to SEQ ID NO:20).

30. The vaccine of Claim 26, wherein the truncated HCV Core protein is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP).

31. The vaccine of Claim 26, wherein the fusion protein consists essentially of SEQ ID NO:14.

32. A vaccine comprising:

a) a yeast vehicle; and

b) an HCV fusion protein that is recombinantly expressed by the yeast vehicle, the HCV fusion protein comprising HCV NS3 fused to HCV NS4a fused to

HCV NS4b, wherein the HCV NS3 protease is inactivated and the HCV NS4b lacks a transmembrane domain.

33. The vaccine of Claim 32, wherein the HCV NS3 protein consists essentially of positions 1 to 631 of HCV HS3 (positions 1027 to 1657, with respect to SEQ ID NO:20), wherein the serine at position 1165 with respect to SEQ ID NO:20 has been substituted with alanine, to inactivate the protease.

34. The vaccine of Claim 32, wherein the HCV NS4a protein consists essentially of positions 1 to 54 of the HCV NS4a protein (positions 635 to 691, with respect to SEQ ID NO:20).

35. The vaccine of Claim 32, wherein the HCV NS4b protein consists essentially of positions 1 to 69 of HCV NS4b (positions 1712 to 1780, with respect to SEQ ID NO:20) fused to positions 177 to 261 of HCV NS4b (positions 1888 to 1972, with respect to SEQ ID NO:20).

36. The vaccine of Claim 32, wherein the HCV NS3 protein is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP).

37. The vaccine of Claim 32, wherein the fusion protein consists essentially of SEQ ID NO:16.

38. A vaccine comprising:

a) a yeast vehicle; and

b) an HCV fusion protein that is recombinantly expressed by the yeast vehicle, the HCV fusion protein comprising an HCV NS5a protein fused to an HCV NS5b protein, wherein the NS5b protein contains an inactivating deletion of NS5b C-terminus.

39. The vaccine of Claim 38, wherein the HCV NS5a protein consists essentially of 1 to 448 of HCV NS5a (positions 1973 to 2420, with respect to SEQ ID NO:20).

40. The vaccine of Claim 38, wherein the HCV NS5b protein consists essentially of positions 1 to 539 of HCV NS5b (positions 2421 to 2959, with respect to SEQ ID NO:20).

41. The vaccine of Claim 38, wherein the HCV NS5a protein is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP).

42. The vaccine of Claim 38, wherein the fusion protein consists essentially of SEQ ID NO:18.

43. The vaccine of any one of Claims 1 to 42, wherein the expression of the fusion protein is under the control of an inducible promoter.

44. The vaccine of Claim 43, wherein the inducible promoter is *CUP1*.

45. The vaccine of any one of Claims 1 to 42, wherein the vaccine further comprises a dendritic cell, wherein the dendritic cell has been loaded intracellularly with the yeast vehicle that recombinantly expresses the HCV fusion protein.

46. The vaccine of any one of Claims 1 to 45, further comprising at least one biological response modifier.

47. The vaccine of Claim 46, wherein the biological response modifier is selected from the group consisting of: a cytokine, a hormone, a lipidic derivative, and a small molecule drug.

48. The vaccine of Claim 46, wherein the biological response modifier is selected from the group consisting of: anti-CTLA-4, anti-CD137, anti-CD28, anti-CD40, alemtuzumab, denileukin diftitox, anti-CD4, anti-CD25, anti-PD1, anti-PD-L1, anti-PD-L2, FOXP3-blocking agents, Flt-3 ligand, imiquimod, granulocyte-macrophage colony-stimulating factor (GM-CSF), sargramostim, Toll-like receptor (TLR)-7 agonists, and TLR-9 agonists.

49. Use of the vaccine of any one of Claims 1 to 48 in a formulation for protecting an animal against HCV infection.

50. Use of the vaccine of any one of Claims 1 to 48 in a formulation for eliciting an antigen-specific, cell-mediated immune response against an HCV antigen.

51. Use of the vaccine of any one of Claims 1 to 48 in a formulation for treating or preventing a disease or condition.

52. Use of the vaccine of any one of Claims 1 to 48 in a formulation for immunizing a population of individuals at risk for becoming infected with HCV.

53. Use of the vaccine of any one of Claims 1 to 48 in a formulation for treating a population of individuals that are infected with HCV.

54. A method to protect an animal against hepatitis C virus (HCV) infection, comprising administering to an animal that has been infected with HCV or is at risk of being infected with HCV, a vaccine according to any one of Claims 1 to 48, wherein administration of the vaccine to the animal reduces or prevents HCV infection or at least one symptom resulting from HCV infection in the animal.

55. A method to elicit an antigen-specific, cell-mediated immune response against an HCV antigen, comprising administering to an animal a vaccine according to any one of Claims 1 to 48.

56. A method to elicit an antigen-specific, cell-mediated immune response against an HCV antigen in a population of individuals who have been infected with HCV, comprising administering to said population of individuals a vaccine according to any one of Claims 1 to 48.

57. A method to immunize against HCV a population of individuals that is at risk of becoming infected with HCV, comprising administering to said population of individuals a vaccine according to any one of Claims 1 to 48.

58. The method of any one of Claims 53 to 57, wherein the vaccine is administered as a booster to a vaccine comprising a viral vector encoding an HCV antigen.

59. The method of any one of Claims 53 to 57, wherein the vaccine is administered to prime the immune system prior to boosting with a different HCV vaccine.

60. An isolated HCV fusion protein comprising at least a portion of an HCV NS3 protease linked to at least a portion of an HCV Core sequence, wherein the HCV NS3 protease lacks the catalytic domain of a natural HCV NS3 protease.

61. The isolated fusion protein of Claim 60, wherein the HCV NS3 protease consists essentially of the 262 amino acids of HCV NS3 following the initial N-terminal 88 amino acids of the full-length NS3 protein (positions 1115 to 1376 with respect to SEQ ID NO:20).

62. The isolated fusion protein of Claim 60, wherein the hydrophobic C-terminal sequence of the HCV Core is truncated.

63. The isolated fusion protein of Claim 62, wherein the HCV Core sequence consists essentially of amino acid positions 2 through 140 of the full-length HCV Core sequence (positions 2 to 140, with respect to SEQ ID NO:20).

64. The isolated fusion protein of Claim 60, wherein the HCV Core sequence has been appended to include two amino acids, glutamate and aspartate.

65. The isolated fusion protein of Claim 60, wherein the HCV Core sequence has been appended to include the amino acid sequence of G-G-G-H-H-H-H-H-H (SEQ ID NO:10).

66. The isolated fusion protein of Claim 60, wherein the HCV NS3 protease is linked at its N-terminus to the amino acid sequence represented by SEQ ID NO:9 (MADEAP).

67. The isolated fusion protein of Claim 60, wherein the fusion protein consists essentially of SEQ ID NO:2.

68. An isolated fusion protein encoded by a nucleic acid sequence consisting essentially of a nucleic acid sequence selected from the group consisting of: SEQ ID NO:4, SEQ ID NO:6, SEQ ID NO:8, SEQ ID NO:12, SEQ ID NO:14, SEQ ID NO:16 and SEQ ID NO:18.

69. An isolated nucleic acid molecule comprising a nucleic acid sequence encoding the fusion protein of any one of Claims 60 to 68.

70. A recombinant nucleic acid molecule comprising the isolated nucleic acid molecule of Claim 69.

71. A recombinant nucleic acid molecule according to Claim 70, which is a viral vector.

72. A recombinant cell that has been transfected with the recombinant nucleic acid molecule of Claim 71.

73. The recombinant cell of Claim 72, wherein the cell is a tumor cell.

74. The recombinant cell of Claim 72, wherein the cell is a yeast cell.

75. A vaccine comprising:

a) an HCV fusion protein according to any one of Claims 60 to 68; and

b) a pharmaceutically acceptable carrier.

76. A vaccine comprising an isolated nucleic acid molecule encoding an HCV fusion protein according to any one of Claims 60 to 68.

77. Use of the vaccine of any one of Claims 60 to 68 in a formulation for protecting an animal against HCV infection.

78. Use of the vaccine of any one of Claims 60 to 68 in a formulation for eliciting an antigen-specific, cell-mediated immune response against an HCV antigen.

79. Use of the vaccine of any one of Claims 60 to 68 in a formulation for immunizing a population of individuals at risk for becoming infected with HCV.

80. Use of the vaccine of any one of Claims 60 to 68 in a formulation for treating a population of individuals that are infected with HCV.

81. A method to protect an animal against hepatitis C virus (HCV) infection, comprising administering to an animal that has been infected with HCV or is at risk of being infected with HCV, a vaccine according to any one of Claims 60 to 68, wherein administration of the vaccine to the animal reduces or prevents HCV infection or at least one symptom resulting from HCV infection in the animal.

82. A method to elicit an antigen-specific, cell-mediated immune response against an HCV antigen, comprising administering to an animal a vaccine according to any one of Claims 60 to 68.

83. A method to elicit an antigen-specific, cell-mediated immune response against an HCV antigen in a population of individuals who have been infected with HCV, comprising administering to said population of individuals a vaccine according to any one of Claims 60 to 68.

84. A method to immunize against HCV a population of individuals that is at risk of becoming infected with HCV, comprising administering to said population of individuals a vaccine according to any one of Claims 60 to 68.