It is claimed:

1. An immunogen, comprising:

a recombinant Mumps virus (MuV) F ectodomain trimer stabilized in a prefusion conformation by one or more amino acid substitutions in protomers of the trimer, the amino acid substitutions comprising cysteine substitutions that form a non-natural disulfide bond to stabilize the MuV F ectodomain trimer in the prefusion conformation,

wherein the cysteine substitutions are located at one or more of MuV F positions 86 and 215, positions 155 and 161, positions 165 and 231, positions 206 and 223, positions 209 and 214, and positions 221 and 255, according to a reference MuV F amino acid sequence set forth as SEQ ID NO: 1.

2. The immunogen of claim 1, wherein the cysteine substitutions are located at one or more of MuV F positions 86 and 215, positions 165 and 231, positions 206 and 223, and positions 209 and 214.

3. The immunogen of claim 1 or claim 2, wherein the cysteine substitutions are located at positions 206 and 223.

4. The immunogen of any one of the prior claims, wherein the cysteine substitutions at:

MuV F positions 86 and 215 are N86C and A215C substitutions;

MuV F positions 155 and 161 are K155C and L161C substitutions;

MuV F positions 165 and 231 are V165C and M231C substitutions;

MuV F positions 206 and 223 are V206C and A223C substitutions;

MuV F positions 209 and 214 are P209C and P214C substitutions; and

MuV F positions 221 and 255 are I221C and M255C substitutions.

5. The immunogen of any one of the prior claims, wherein the protomers of the recombinant MuV F ectodomain trimer comprise a F_2 protein comprising or consisting of MuV F positions 20-100 and a F_1 ectodomain comprising or consisting of MuV F positions 104-469, 104-476, or 104-483, according to a reference MuV F amino acid sequence set forth as SEQ ID NO: 1.

6. The immunogen of any one of the prior claims, wherein the protomers of the trimer further comprise a mutation to remove a F1/F2 furin cleavage site of the MuV F ectodomain and optionally a first residue of a fusion peptide of a F1 ectodomain.

7. The immunogen of claim 6, wherein the mutation to remove the F1/F2 furin cleavage site and the first residue of the fusion peptide comprise a deletion of MuV F positions 101-103 with positions 100 and 104 fused by a peptide linker.

8. The immunogen of claim 7, wherein the peptide linker is a Gly-Gly-Gly linker.

9. The immunogen of any one of the prior claims, wherein the protomers of the MuV F ectodomain trimer comprise the amino acid sequence set forth as:

residues 20-483 of any one of SEQ ID NOs: 3-8,

residues 20-476 of any one of SEQ ID NOs: 11-16, 26, or 51, or

residues 20-469 of any one of SEQ ID NOs: 19-24.

10. The immunogen of claim 9, wherein the protomers of the MuV F ectodomain trimer consist of the amino acid sequence set forth as:

residues 20-483 of any one of SEQ ID NOs: 3-8,

residues 20-476 of any one of SEQ ID NOs: 11-16, 26, or 51, or

residues 20-469 of any one of SEQ ID NOs: 19-24.

11. The immunogen of any one of the prior claims, wherein the protomers of the recombinant MuV F ectodomain trimer are fused C-terminally to a trimerization domain.

12. The immunogen of claim 11, wherein the trimerization domain comprises a GCN4 trimerization domain, a T4 fibritin trimerization domain, or both.

13. The immunogen of claim 12, wherein

the GCN4 trimerization domain comprises an amino acid sequence set forth as IEDKIEEILSKIYHIENEIARIKKLIGEAP (SEQ ID NO: 33);

the T4 fibritin trimerization domain comprises an amino acid sequence set forth as GYIPEAPRDGQAYVRKDGEWVLLSTFL (SEQ ID NO: 34); and/or

the trimerization domain comprising both the GCN4 and T4 fibritin trimerization domains comprises an amino acid sequence set forth as IEDKIEEILSKIYHIENEIARIKKLIGEAPGSGYIPEAPRDGQAYVRKDGEWVLLSTFL (SEQ ID NO: 35).

14. The immunogen of any one of claims 11-13, wherein the protomers of the MuV F ectodomain trimer fused to the trimerization domain comprise the amino acid sequence set forth as:

residues 20-513 of any one of SEQ ID NOs: 3-8,

residues 20-506 of any one of SEQ ID NOs: 11-16, 26, or 51, or

residues 20-499 of any one of SEQ ID NOs: 19-21, 23, or 24.

15. The immunogen of claim 14, wherein the protomers of the MuV F ectodomain trimer fused to the trimerization domain consist of the amino acid sequence set forth as:

residues 20-513 of any one of SEQ ID NOs: 3-8,

residues 20-506 of any one of SEQ ID NOs: 11-16, 26, or 51, or

residues 20-499 of any one of SEQ ID NOs: 19-21, 23, or 24.

16. The immunogen of any one of the prior claims, wherein the protomers of the recombinant MuV F ectodomain trimer are linked to a heterologous protein.

17. The immunogen of claim 16, wherein the heterologous protein is an ectodomain head or ectodomain stalk and head of a MeV H protein or a MuV HN protein.

18. The immunogen of claim 17, wherein the ectodomain head or ectodomain stalk and head of the MeV H protein or the MuV HN protein is fused C-terminally to a trimerization domain that is fused C-terminally to the protomer of the recombinant MuV F ectodomain trimer.

19. The immunogen of claim 18, wherein the protomers of the MuV F ectodomain trimer linked to the trimerization domain and the ectodomain of the MeV H protein or the ectodomain of a MuV HN protein comprise an amino acid sequence set forth as residues 20-

966 of SEQ ID NO: 27, residues 21-981 of SEQ ID NO: 28, or residues 20-1006 of SEQ ID NO: 29.

20. The immunogen of any one of the prior claims, wherein the protomers of the recombinant MuV F ectodomain trimer further comprise one or more conservative amino acid substitutions.

21. The immunogen of any one of the prior claims, conjugated to a heterologous carrier.

22. The immunogen of any one of the prior claims, wherein the immunogen is soluble.

23. The immunogen of any one of the prior claims, wherein the protomers of the recombinant MuV F ectodomain trimer comprise a full-length F_1 protein.

24. The immunogen of any one of the prior claims, wherein the protomers of the trimer are fused C-terminally to the trimerization domain at MuV F position 469, 476, or 483 according to a reference MuV F amino acid sequence set forth as SEQ ID NO: 1.

25. The immunogen of any one of the prior claims, wherein the protomers of the trimer are fused C-terminally to a transmembrane domain.

26. The immunogen of claim 25, wherein the transmembrane domain comprises a MuV F transmembrane domain.

27. The immunogen of claim 25 or 26, wherein the protomers of the recombinant MuV F ectodomain trimer are fused to the transmembrane domain by a peptide linker, or directly fused to the transmembrane domain.

28. A virus-like particle comprising the immunogen of any one of the prior claims.

29. A self-assembling protein nanoparticle comprising the immunogen of any one of the prior claims.

30. A nucleic acid molecule encoding the immunogen of any one of the prior claims.

31. The nucleic acid molecule of claim 30, operably linked to a promoter.

32. A vector comprising the nucleic acid molecule of claim 31.

33. The vector of claim 32, wherein the vector is an RNA vector.

34. A method of producing an immunogen, comprising:

expressing the nucleic acid molecule of claim 30 or 31, or the vector of claim 32 or 33, in a host cell; and

purifying the immunogen.

35. An immunogenic composition, comprising the immunogen of any one of claims 1-27, the nucleic acid molecule of claim 30 or 31, the vector of claim 32 or 33, the virus like particle of claim 28, or the self-assembling protein nanoparticle of claim 29, and a pharmaceutically acceptable carrier.

36. Use of the immunogenic composition of claim 35 in the manufacture of a medicament for eliciting an immune response to MuV F in a subject, wherein an effective amount of the immunogenic composition is to be administered to the subject to elicit the immune response.

37. The use of claim 36, wherein the immune response inhibits MuV infection in the subject.

38. The use of claim 36 or 37, wherein the subject is an adult who was previously immunized with a live attenuated vaccine to MuV and the administration boosts the immune response to the MuV.