CLAIMS

1. A method for liquefying a feed gas stream comprising natural gas, the method comprising:

providing the feed gas stream at a pressure less than 1,200 psia;

providing a compressed refrigerant stream with a pressure greater than or equal to 1,500 psia;

cooling the compressed refrigerant stream by indirect heat exchange with a cooling medium, thereby producing a compressed, cooled refrigerant stream;

expanding the compressed, cooled refrigerant stream in a first expander to an intermediate pressure to further cool the compressed, cooled refrigerant stream, thereby producing a first expanded, cooled refrigerant stream, wherein the first expander is mechanically coupled to a first coupled compressor to together form a first turboexpander-compressor;

expanding the first expanded, cooled refrigerant stream in a second expander to further cool the first expanded, cooled refrigerant stream, thereby producing a second expanded, cooled refrigerant stream, wherein the second expander is mechanically coupled to a second coupled compressor to together form a second turboexpander-compressor;

passing the second expanded, cooled refrigerant stream through one or more heat exchangers, thereby forming a warm refrigerant stream;

passing the feed gas stream through the one or more heat exchangers to cool at least part of the feed gas stream by indirect heat exchange with the second expanded, cooled refrigerant stream, thereby forming a cool feed gas stream;

using the second coupled compressor and a first driven compressor, compressing the warm refrigerant stream to a discharge pressure within 300 psia of the intermediate pressure, thereby forming a first compressed refrigerant stream;

compressing the first compressed refrigerant stream using the first coupled compressor, thereby forming a second compressed refrigerant stream; and

compressing the second compressed refrigerant stream to provide the compressed refrigerant stream.

2. The method of claim 1, further comprising driving the first driven compressor using at least one of a reciprocating engine, a steam turbine, a gas turbine, and a motor.

3. The method claim 1 or claim 2, wherein cooling the compressed refrigerant stream comprises cooling the compressed refrigerant stream via indirect heat exchange with a cooling medium.

4. The method of any one of claims 1-3, wherein cooling the compressed refrigerant stream comprises cooling the compressed refrigerant stream by indirect heat exchange with a cooling medium having a temperature lower than ambient conditions.

5. The method of any one of claims 1-4, further comprising:

cooling the warm refrigerant stream by indirect heat exchange with a cooling medium after being compressed in the second coupled compressor and prior to being compressed in the first driven compressor.

6. The method of any one of claims 1-5, further comprising:

cooling the first compressed refrigerant stream prior to being compressed in the first coupled compressor.

7. The method of any one of claims 1-6, further comprising:

cooling the second compressed refrigerant stream via indirect heat exchange with a cooling medium prior to being compressed to provide the compressed refrigerant stream.

8. The method of any one of claims 1-7, wherein the compressed refrigerant stream has a pressure of approximately 3,000 psia.

9. The method of any one of claims 1-8, wherein the intermediate pressure is less than 1,500 psia and greater than 1,000 psia.

10. The method of any one of claims 1-9, wherein compressing the second compressed refrigerant stream is accomplished using a second driven compressor.

11. The method of claim 10, further comprising:

driving the second driven compressor using at least one of a reciprocating engine, a steam turbine, a gas turbine, and a motor.

12. The method of claim 10 or claim 11, wherein the first driven compressor and the second driven compressor share a common driver.

13. The method of any one of claims 10-12, wherein the first driven compressor and the second driven compressor are within a single compressor casing.

14. The method of any one of claims 1-13, further comprising:

using a sub-cooling loop, further cooling the cool feed gas stream to form a sub-cooled feed gas stream.

15. The method of claim 14, further comprising:

expanding the sub-cooled feed gas stream to a pressure greater than or equal to 50 psia and less than or equal to 450 psia, to produce an expanded, sub-cooled feed gas stream.

16. The method of claim 14 or claim 15, wherein the sub-cooled feed gas stream is expanded within a hydraulic turbine.

17. The method of any one of claims 14-16, wherein the sub-cooling loop is a closed loop gas phase refrigeration cycle where nitrogen gas is the refrigerant.

18. The method of claim 14, wherein the sub-cooling loop comprises:

withdrawing a portion not to exceed 50% of the expanded, sub-cooled gas stream and reducing its pressure in a pressure reduction valve to a range of about 30 to 300 psia to produce one or more reduced pressure gas streams; and

passing the one or more reduced pressure gas streams through the one or more heat exchangers as the sub-cooling refrigerant stream.

19. The method of claim 18, wherein more than one reduced pressure gas stream is produced and the one or more reduced pressure gas streams are at different pressures from each other.

20. The method of claim 18 or claim 19, wherein the sub-cooling refrigerant stream exiting the one or more heat exchangers is compressed to a pressure approximate to that of the feed gas stream and is cooled by indirect heat exchange with a cooling medium before mixing the sub-cooling refrigerant stream with the feed gas stream.

21. The method of claim 15, wherein at least a portion of the expanded, sub-cooled gas stream is further expanded and then directed to a separation tank from which liquid natural gas is withdrawn and remaining gaseous vapors are withdrawn as a flash gas stream.

22. The method of claim 21, wherein the compressed refrigerant stream comprises boil off gas of the liquid natural gas.

23. The method of any one of claims 1-22, further comprising:

adjusting one or more of

a discharge pressure of one or more of the compressors, and

an inlet pressure of one or more of the expanders,

to thereby maintain a fixed differential pressure between the discharge pressure and the inlet pressure.

24. The method of claim 23, wherein the fixed differential pressure is obtained through control algorithms using one or more of compressor speed of one or more of the compressors, inlet guide vanes of one ore more of the expanders, recycle valves of one or more of the compressors, and bypass valves of one or more of the expanders.

25. A natural gas liquefaction system comprising:

a first heat exchanger configured to cool a compressed refrigerant stream by indirect heat exchange with a cooling medium, thereby producing a compressed, cooled refrigerant stream, wherein the compressed refrigerant stream is provided to the first heat exchanger at a pressure of at least 1,500 psia;

a first expander configured to expand the compressed, cooled refrigerant stream to an intermediate pressure, to further cool the compressed, cooled refrigerant stream, thereby producing a first expanded, cooled refrigerant stream;

a first coupled compressor mechanically coupled to the first expander to together form a first turboexpander-compressor;

a second expander configured to expand the first expanded, cooled refrigerant stream to further cool the first expanded, cooled refrigerant stream, thereby producing a second expanded, cooled refrigerant stream;

a second coupled compressor mechanically coupled to the second expander to together form a second turboexpander-compressor;

one or more heat exchangers arranged to permit the second expanded, cooled refrigerant stream and a feed gas stream to pass therethrough and exchange heat therein through indirect heat exchange, thereby forming a warm refrigerant stream and a cool feed gas stream, wherein the feed gas stream comprises natural gas and is supplied to the one or more heat exchangers at a pressure of less than 1,200 psia;

a first driven compressor configured to, along with the second coupled compressor, compress the warm refrigerant stream to a discharge pressure within 300 psia of the intermediate pressure, thereby forming a first compressed refrigerant stream;

wherein the first compressed refrigerant stream is further compressed using the first

coupled compressor, thereby forming a second compressed refrigerant stream; and

wherein the second compressed refrigerant stream is compressed to provide the compressed refrigerant stream.

26. The system of claim 25, further comprising a driving element configured to drive the first driven compressor, wherein the driving element comprises at least one of a reciprocating engine, a steam turbine, a gas turbine, and a motor.

27. The system of claim 25 or claim 26, further comprising:

a first cooler configured to cool the compressed refrigerant stream via indirect heat exchange with a cooling medium.

28. The system of claim 27, wherein the cooling medium has a temperature lower than ambient conditions.

29. The system of any one of claims 25-28, further comprising:

a second cooler configured to cool the warm refrigerant stream by indirect heat exchange with a cooling medium after being compressed in the second coupled compressor and prior to being compressed in the first driven compressor;

a third cooler configured to cool the first compressed refrigerant stream prior to being compressed in the first coupled compressor; and

a fourth cooler configured to cool the second compressed refrigerant stream via indirect heat exchange with a cooling medium prior to being compressed, to thereby provide the compressed refrigerant stream.

30. The system of any one of claims 25-29, wherein the compressed refrigerant stream has a pressure of approximately 3,000 psia.

31. The system of any one of claims 25-30, wherein the intermediate pressure is less than 1,500 psia and greater than 1,000 psia.

32. The system of any one of claims 25-31, further comprising:

a second driven compressor configured to compress the second compressed refrigerant stream.

33. The system of claim 32, further comprising:

a driving element configured to drive the second driven compressor, wherein the driving element comprises at least one of a reciprocating engine, a steam turbine, a gas

turbine, and a motor.

34. The system of claim 32 or claim 33, wherein the first driven compressor and the second driven compressor share a common driver.

35. The system of any one of claims 31-33, wherein the first driven compressor and the second driven compressor are within a single compressor casing.

36. The system of any one of claims 25-32, further comprising a sub-cooling loop configured to further cool the cool feed gas stream to form a sub-cooled feed gas stream.

37. The system of claim 36, further comprising:

a hydraulic turbine configured to expand the sub-cooled feed gas stream to a pressure greater than or equal to 50 psia and less than or equal to 450 psia, to thereby produce an expanded, sub-cooled feed gas stream.

38. The system of claim 36 or claim 37, wherein the sub-cooling loop is a closed loop gas phase refrigeration cycle where nitrogen gas is the refrigerant.

39. The method of claim 1, further comprising:

using a sub-cooling loop, further cooling the cool feed gas stream to form a sub-cooled feed gas stream having a liquid portion;

cooling the warm refrigerant stream by indirect heat exchange with a second cooling medium after being compressed in the second coupled compressor and prior to being compressed in the first driven compressor;

cooling the first compressed refrigerant stream via heat exchange with a third cooling medium;

cooling the second compressed refrigerant stream via heat exchange with a fourth cooling medium

in particular wherein at least of the first cooling medium, the second cooling medium, the third cooling medium, and the fourth cooling medium comprises air or water.