CLAIMS

1. A method for liquefying a feed gas stream rich in methane using a system having first and second heat exchanger zones, wherein the first heat exchanger zone comprises a first and a second main heat exchanger, where the method comprises:

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

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

(c) cooling the compressed refrigerant stream by indirect heat exchange with an ambient temperature air or water, to produce a compressed, cooled refrigerant stream;

(d) directing the compressed, cooled refrigerant stream to the second heat exchanger zone to additionally cool the compressed, cooled refrigerant stream below ambient temperature to produce a compressed, additionally cooled refrigerant stream;

(e) expanding the compressed, additionally cooled refrigerant stream in at least one work producing expander, thereby producing an expanded, cooled refrigerant stream;

(f) passing the expanded, cooled refrigerant stream through a second main heat exchanger within the first heat exchanger zone to form a first warm refrigerant stream, wherein the first warm refrigerant stream has a temperature that is cooler, by at least 5 °F, than the highest fluid temperature within the first heat exchanger zone;

(g) passing the feed gas stream through the first heat exchanger zone to cool at least part of the feed gas stream by indirect heat exchange with the expanded, cooled refrigerant stream, thereby forming a liquefied gas stream;

(h) directing at least a portion of the first warm refrigerant stream to the second heat exchanger zone to cool by indirect heat exchange the compressed, cooled refrigerant stream, thereby forming a second warm refrigerant stream;

(i) passing a portion of the first warm refrigerant stream remaining within the first heat exchanger zone through the first main heat exchanger to further exchange heat within the first heat exchanger zone, thereby forming a third warm refrigerant stream;

(j) combining the second warm refrigerant stream with the third warm refrigerant stream to form a fourth warm refrigerant stream; and

(k) compressing the fourth warm refrigerant stream to produce the compressed refrigerant stream.

2. The method of claim 1, wherein the first warm refrigerant stream has a temperature that is cooler, by at least 10 °F, than the highest fluid temperature within the first heat exchanger

zone.

3. The method of claim 1 or 2, further comprising:

further cooling the liquefied gas stream within the first heat exchanger zone using a sub-cooling refrigeration cycle comprising a sub-cooling refrigerant, to thereby form a sub-cooled gas stream.

4. The method of claim 3, further comprising:

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

5. The method of claim 3, wherein the sub-cooling refrigeration cycle comprises a closed loop gas phase refrigeration cycle using nitrogen gas as a refrigerant.

6. The method of claim 4, wherein the sub-cooling refrigeration cycle 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 first heat exchanger zone as the sub-cooling refrigerant.

7. The method of claim 6, wherein the one or more reduced pressure gas streams comprise two or more reduced pressure gas streams having different pressures from each other.

8. The method of claim 6, further comprising:

compressing the sub-cooling refrigerant stream exiting the first heat exchanger zone; and

cooling the sub-cooling refrigerant stream by indirect heat exchange with an ambient temperature air or water and then adding the sub-cooling refrigerant to the gas stream.

9. The method of claim 4, 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.

10. The method of any one of claims 1-9, further comprising:

prior to directing the feed gas stream to the first heat exchanger zone, compressing the feed gas stream to a pressure no greater 1,600 psia, and then cooling it by indirect heat exchange with an ambient temperature air or water.

11. The method of any one of claims 1-10, wherein the feed gas stream is cooled to a temperature below an ambient temperature by indirect heat exchange within an external cooling unit prior to directing the feed gas stream to the first heat exchanger zone.

12. The method of any one of claims 1-11, wherein the compressed, cooled refrigerant stream is cooled to a temperature below the ambient temperature by indirect heat exchange within an external cooling unit prior to directing the compressed, cooled refrigerant stream to the second heat exchanger zone.

13. A system for liquefying a feed gas stream rich in methane, the system having first and second heat exchanger zones and comprising:

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

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

a cooler configured to cool the compressed refrigerant stream by indirect heat exchange with an ambient temperature air or water, to produce a compressed, cooled refrigerant stream;

at least one heat exchanger within the second heat exchanger zone, the compressed, cooled refrigerant stream being directed to the at least one heat exchanger within the second heat exchanger zone to additionally cool the compressed, cooled refrigerant stream below ambient temperature and thereby produce a compressed, additionally cooled refrigerant stream;

at least one work producing expander arranged to expand the compressed, additionally cooled refrigerant stream, thereby producing an expanded, cooled refrigerant stream;

at least a first and a second main heat exchanger within the first heat exchanger zone, the expanded, cooled refrigerant stream being passed through the second main heat exchanger in the first heat exchanger zone to form a first warm refrigerant stream, wherein the first warm refrigerant stream has a temperature that is cooler, by at least 5 °F, than the highest fluid temperature within the first heat exchanger zone;

wherein the feed gas stream is passed through the first heat exchanger zone to cool at least part of the feed gas stream by indirect heat exchange with the expanded, cooled refrigerant stream, thereby forming a liquefied gas stream;

wherein a portion of the first warm refrigerant stream is directed to the second heat exchanger zone to cool by indirect heat exchange the compressed, cooled refrigerant stream, thereby forming a second warm refrigerant stream;

wherein a portion of the first warm refrigerant stream remaining within the first heat exchanger zone further exchanges heat within the first main heat exchanger within the first heat exchanger zone to produce a third warm refrigerant stream;

wherein the second warm refrigerant stream is combined with the third warm refrigerant stream forming a fourth warm refrigerant; and

a compressor configured to compress the fourth warm refrigerant stream to produce the compressed refrigerant stream.

14. The system of claim 13, wherein the first warm refrigerant stream has a temperature that is cooler, by at least 10 °F, than the highest fluid temperature within the first heat exchanger zone.

15. The system of any one of claims 13-14, further comprising:

a sub-cooling refrigeration cycle comprising a sub-cooling refrigerant stream configured to further cool the liquefied gas stream within the first heat exchanger zone, to thereby form a sub-cooled gas stream.

16. The system of claim 15, further comprising:

an additional expander configured to expand the sub-cooled 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 gas stream, wherein the additional expander comprises a hydraulic turbine.

17. The system of claim 15, wherein the sub-cooling refrigeration cycle comprises a closed loop gas phase refrigeration cycle using nitrogen gas as the sub-cooling refrigerant.

18. The system of claim 16, further comprising:

a pressure reduction valve configured to reduce the pressure of a portion, not to exceed 50%, of the expanded, sub-cooled gas stream, to a range of about 30 to 300 psia, thereby producing one or more reduced pressure gas streams;

wherein the one or more reduced pressure gas streams is passed through the first heat exchanger zone as the sub-cooling refrigerant.

19. The system of claim 18, wherein the one or more reduced pressure gas streams comprise two or more reduced pressure gas streams having different pressures from each other.

20. The system of claim 15, further comprising:

a sub-cooling compressor configured to compress the sub-cooling refrigerant stream exiting the first heat exchanger zone; and

an external cooling unit configured to cool the sub-cooling refrigerant stream by indirect heat exchange with an ambient temperature air or water.

21. The system of claim 16, further comprising;

an additional expander configured to further expand at least a portion of the expanded, sub-cooled gas stream; and

a separation tank to which the expanded, sub-cooled gas stream is directed after passing through the additional expander.

22. The system of any one of claims 13-21, further comprising:

an additional compressor configured to compress, prior to directing the feed gas stream to the first heat exchanger zone, the feed gas stream to a pressure no greater 1,600 psia; and

an external cooling unit configured to cool the feed gas stream by indirect heat exchange with an ambient temperature air or water.

23. The system of any one of claims 13-22, further comprising:

a second external cooling unit configured to cool the feed gas stream to a temperature below an ambient temperature by indirect heat exchange within an external cooling unit prior to directing the feed gas stream to the first heat exchanger zone.

24. The system of any one of claims 13-23, further comprising:

a third external cooling unit configured to cool the compressed, cooled refrigerant stream to a temperature below the ambient temperature by indirect heat exchange therein prior to directing the compressed, cooled refrigerant stream to the second heat exchanger zone.

25. The system of claim 21, wherein refrigerant in the primary cooling loop is supplied from one or more of

the feed gas stream,

a flash gas stream, obtained by withdrawal of gaseous vapours from the separation tank, following direction of the expanded, sub-cooled gas stream to the separation tank; and

boil-off gas from liquid natural gas, obtained by withdrawal of liquid natural gas from the separation tank, following direction of the expanded, sub-cooled gas stream to the separation tank.

26. The system of any one of claims 13-25, wherein at least one of the first and second main heat exchanger within the first heat exchanger zone comprises a brazed aluminum heat exchanger.

27. The system of any one of claims 13-26, wherein at least one of the first and second main heat exchanger within the second heat exchanger zone comprises a printed circuit heat exchanger.