CLAIMS

1. A process for liquefying hydrogen, the process comprising:

   cooling a hydrogen feed comprising ortho-hydrogen and para-hydrogen by indirect heat exchange to form a cold hydrogen stream;

   expanding at least a portion of the cold hydrogen stream to produce a partially vaporized intermediate-pressure hydrogen stream;

   separating the partially vaporized intermediate-pressure hydrogen stream to produce an intermediate-pressure hydrogen vapor stream and an intermediate-pressure hydrogen liquid stream;

   expanding at least a portion of the intermediate-pressure hydrogen liquid stream to produce a partially vaporized low-pressure hydrogen stream;

   warming by indirect heat exchange the partially vaporized low-pressure hydrogen stream or a stream derived from the partially vaporized low-pressure hydrogen stream to produce a warmed low-pressure hydrogen stream;

   warming by indirect heat exchange the intermediate-pressure hydrogen vapor stream to produce a warmed intermediate-pressure hydrogen stream;

   compressing and combining the warmed low-pressure hydrogen stream, the warmed intermediate-pressure hydrogen stream, and a warmed medium-pressure hydrogen stream to produce a recycle stream;

   cooling by indirect heat exchange the recycle stream to produce a cooled recycle stream;

   expanding at least a portion of the cooled recycle stream to produce a first cold medium-pressure hydrogen stream; and

   warming by indirect heat exchange the first cold medium-pressure hydrogen stream to produce the warmed medium-pressure hydrogen stream;

   wherein a cooling duty for cooling the hydrogen feed by indirect heat exchange is provided at least in part by the intermediate-pressure hydrogen vapor stream;

   wherein the warmed intermediate-pressure hydrogen stream is compressed prior to combining with the warmed medium-pressure hydrogen stream.

2. The process of claim 1, further comprising catalytically converting at least a portion of the ortho-hydrogen into para-hydrogen in the cold hydrogen stream.

3. The process of claim 2, wherein a pressure of the cold hydrogen stream is above the critical pressure and a temperature of the cold hydrogen stream is below the critical temperature.

4. The process of claim 1, further comprising warming by indirect heat exchange at least a portion of the intermediate-pressure hydrogen liquid stream to produce a second warmed intermediate-pressure hydrogen stream; and

   compressing and combining the second warmed intermediate-pressure hydrogen stream with the warmed low-pressure hydrogen stream, the warmed intermediate-pressure hydrogen stream, and the warmed medium-pressure hydrogen stream to produce the recycle stream.

5. The process of claim 1, further comprising dividing a portion of the intermediate-pressure hydrogen vapor stream and/or the warmed intermediate-pressure hydrogen stream to produce a purge gas stream;

   wherein the hydrogen feed and the purge gas stream comprise one or more light gases selected from a group consisting of helium and neon; and

   wherein the purge gas stream is enriched in the light gases relative to the hydrogen feed.

6. The process of claim 1, further comprising catalytically converting at least a portion of the ortho-hydrogen into para-hydrogen in the cooled recycle stream.

7. The process of claim 1, further comprising expanding at least a portion of the cold hydrogen stream to produce a second medium-pressure hydrogen stream; and

   warming by indirect heat exchange and combining the second medium-pressure hydrogen stream and the first cold medium-pressure hydrogen stream to produce the warmed medium-pressure hydrogen stream.

8. The process of claim 1, further comprising expanding at least a portion of the cooled recycle stream to produce a cold recycle stream; and

   combining the cold recycle stream with the cold hydrogen stream.

9. The process of claim 1, wherein the recycle stream comprises more than 90% para-hydrogen by volume.

10. The process of claim 1, further comprising the following steps:

    compressing at least a portion of a nitrogen stream by one or more stages of compression to produce a compressed nitrogen stream;

    cooling by indirect heat exchange the compressed nitrogen stream to produce a cooled compressed nitrogen stream;

    expanding at least a portion of the cooled compressed nitrogen stream to produce a partially condensed nitrogen stream;

    separating the partially condensed nitrogen stream to produce a nitrogen vapor stream and a nitrogen liquid stream; and

warming by indirect heat exchange and combining the nitrogen vapor stream and at least a portion of the nitrogen liquid stream to produce a nitrogen return stream;

wherein the nitrogen stream comprises the nitrogen return stream;

wherein the cooling duty for cooling the hydrogen feed by indirect heat exchange is provided at least in part by the nitrogen vapor stream and the at least the portion of the nitrogen liquid stream.

11. The process of claim 10, further comprising dividing at least a portion of the nitrogen liquid stream to produce a liquid nitrogen product.

12. The process of claim 10, further comprising the following steps:

cooling by indirect heat exchange and dividing a portion of the compressed nitrogen stream to produce a cold nitrogen expander feed;

expanding the cold nitrogen expander feed to produce a first cold medium-pressure nitrogen stream;

warming by indirect heat exchange the first cold medium-pressure nitrogen stream to produce a first medium-pressure nitrogen stream; and

feeding a medium-pressure nitrogen recycle stream to an interstage of the one or more stages of compression;

wherein the medium-pressure nitrogen recycle stream comprises the first medium-pressure nitrogen stream.

13. The process of claim 12, further comprising the following steps:

extracting a portion of the nitrogen stream from an interstage of the one or more stages of compression to produce a warm nitrogen expander feed;

expanding the warm nitrogen expander feed to produce a second cold medium-pressure nitrogen stream; and

warming by indirect heat exchange the second cold medium-pressure nitrogen stream to produce a second medium-pressure nitrogen recycle stream;

wherein the medium-pressure nitrogen recycle stream comprises the second medium-pressure nitrogen recycle stream.

14. The process of claim 13, further comprising the following steps:

expanding at least a portion of the cooled compressed nitrogen stream to produce a third cold medium-pressure nitrogen stream;

warming by indirect heat exchange the third cold medium-pressure nitrogen stream to produce a third medium-pressure nitrogen recycle stream;

wherein the medium-pressure nitrogen recycle stream comprises the third medium-pressure nitrogen recycle stream.

15. The process of claim 1, further comprising:

    separating the partially vaporized low-pressure hydrogen stream to produce a low-pressure hydrogen vapor stream and a low-pressure hydrogen liquid stream;

    dividing at least a portion of the low-pressure hydrogen liquid stream to form a low-pressure hydrogen return stream;

    warming by indirect heat exchange and combining the low-pressure hydrogen return stream with the low-pressure hydrogen vapor stream to produce the warmed low-pressure hydrogen stream.

16. The process of claim 1, further comprising catalytically converting at least a portion of the ortho-hydrogen into para-hydrogen in the hydrogen feed.