EXPANDER-BASED LNG PRODUCTION PROCESSES ENHANCED WITH LIQUID NITROGEN

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application 62/266,979, filed December 14, 2015 entitled EXPANDER-BASED LNG PRODUCTION PROCESSES ENHANCED WITH LIQUID NITROGEN, the entirety of which is incorporated by reference herein.

[0002] This application is related to U.S. Provisional Patent Application number 62/266,976 titled "Method and System for Separating Nitrogen from Liquefied Natural Gas Using Liquefied Nitrogen;" U.S. Provisional Patent Application No. 62/266,983 titled "Method of Natural Gas Liquefaction on LNG Carriers Storing Liquid Nitrogen;" and U.S. Provisional Patent Application No. 62/622,985 titled "Pre-Cooling of Natural Gas by High Pressure Compression and Expansion," all having common inventors and assignee and filed on an even date herewith, the disclosure of which is incorporated by reference herein in their entirety.

BACKGROUND

Field of Disclosure

[0003] The disclosure relates generally to the field of natural gas liquefaction to form liquefied natural gas (LNG). More specifically, the disclosure relates to the production and transfer of LNG from offshore and/or remote sources of natural gas.

Description of Related Art

[0004] This section is intended to introduce various aspects of the art, which may be associated with the present disclosure. This discussion is intended to provide a framework to facilitate a better understanding of particular aspects of the present disclosure. Accordingly, it should be understood that this section should be read in this light, and not necessarily as an admission of prior art.

[0005] LNG is a rapidly growing means to supply natural gas from locations with an abundant supply of natural gas to distant locations with a strong demand for natural gas. The conventional LNG cycle includes: a) initial treatments of the natural gas resource to remove contaminants such as water, sulfur compounds and carbon dioxide; b) the separation of some heavier hydrocarbon gases, such as propane, butane, pentane, etc. by a variety of possible methods including self-refrigeration, external refrigeration, lean oil, etc.; c) refrigeration of the

natural gas substantially by external refrigeration to form liquefied natural gas at or near atmospheric pressure and about -160 °C; d) transport of the LNG product in ships or tankers designed for this purpose to a market location; and e) re-pressurization and regasification of the LNG at a regasification plant to form a pressurized natural gas stream that may distributed to natural gas consumers. Step (c) of the conventional LNG cycle usually requires the use of large refrigeration compressors often powered by large gas turbine drivers that emit substantial carbon and other emissions. Large capital investments in the billions of US dollars and extensive infrastructure are required as part of the liquefaction plant. Step (e) of the conventional LNG cycle generally includes re-pressurizing the LNG to the required pressure using cryogenic pumps and then re-gasifying the LNG to form pressurized natural gas by exchanging heat through an intermediate fluid but ultimately with seawater or by combusting a portion of the natural gas to heat and vaporize the LNG. Generally, the available exergy of the cryogenic LNG is not utilized.

[0006] A relatively new technology for producing LNG is known as floating LNG (FLNG). FLNG technology involves the construction of the gas treating and liquefaction facility on a floating structure such as barge or a ship. FLNG is a technology solution for monetizing offshore stranded gas where it is not economically viable to construct a gas pipeline to shore. FLNG is also increasingly being considered for onshore and near-shore gas fields located in remote, environmentally sensitive and/or politically challenging regions. The technology has certain advantages over conventional onshore LNG in that it has a lower environmental footprint at the production site. The technology may also deliver projects faster and at a lower cost since the bulk of the LNG facility is constructed in shipyards with lower labor rates and reduced execution risk.

[0007] Although FLNG has several advantages over conventional onshore LNG, significant technical challenges remain in the application of the technology. For example, the FLNG structure must provide the same level of gas treating and liquefaction in an area that is often less than a quarter of what would be available for an onshore LNG plant. For this reason, there is a need to develop technology that reduces the footprint of the FLNG plant while maintaining the capacity of the liquefaction facility to reduce overall project cost. One promising means of reducing the footprint is to modify the liquefaction technology used in the FLNG plant. Known liquefaction technologies include a single mixed refrigerant (SMR) process, a dual mixed refrigerant (DMR) process, and expander-based (or expansion) process. The expander-based process has several advantages that make it well suited for FLNG projects.

The most significant advantage is that the technology offers liquefaction without the need for external hydrocarbon refrigerants. Removing liquid hydrocarbon refrigerant inventory, such as propane storage, significantly reduces safety concerns that are particularly acute on FLNG projects. An additional advantage of the expander-based process compared to a mixed refrigerant process is that the expander-based process is less sensitive to offshore motions since the main refrigerant mostly remains in the gas phase.

[0008] Although expander-based process has its advantages, the application of this technology to an FLNG project with LNG production of greater than 2 million tons per year (MTA) has proven to be less appealing than the use of the mixed refrigerant process. The capacity of known expander-based process trains is typically less than 1.5 MTA. In contrast, a mixed refrigerant process train, such as that of the propane-precooled process or the dual mixed refrigerant process, can have a train capacity of greater than 5 MTA. The size of the expander-based process train is limited since its refrigerant mostly remains in the vapor state throughout the entire process and the refrigerant absorbs energy through its sensible heat. For these reasons, the refrigerant volumetric flow rate is large throughout the process, and the size of the heat exchangers and piping are proportionately greater than those used in a mixed refrigerant process. Furthermore, the limitations in compander horsepower size results in parallel rotating machinery as the capacity of the expander-based process train increases. The production rate of an FLNG project using an expander-based process can be made to be greater than 2 MTA if multiple expander-based trains are allowed. For example, for a 6 MTA FLNG project, six or more parallel expander-based process trains may be sufficient to achieve the required production. However, the equipment count, complexity and cost all increase with multiple expander trains. Additionally, the assumed process simplicity of the expander-based process compared to a mixed refrigerant process begins to be questioned if multiple trains are required for the expander-based process while the mixed refrigerant process can obtain the required production rate with one or two trains. For these reasons, there is a need to develop an FLNG liquefaction process with the advantages of an expander-based process while achieving a high LNG production capacity. There is a further need to develop an FLNG technology solution that is better able to handle the challenges that vessel motion has on gas processing.

[0009] United States Patent No. 3,400,547 to Williams *et al.* discloses a process within an LNG production facility where liquid nitrogen (LIN) produced at a different location is used as a refrigerant to liquefy natural gas. The process uses propane chillers to cool the natural gas

prior to condensing the natural gas by indirect heat exchange with the vaporizing LIN. GB Patent No. 1,596,330 to Thompson discloses a process within an LNG production facility where LIN produced at a different location is used as the refrigerant to liquefy natural gas. The process uses propane and ethylene chillers in combination with the LIN to liquefy the natural gas into LNG. The processes disclosed by these two patents have the disadvantage of using a mechanical refrigeration system while still requiring a significant of amount of LIN to produce the LNG. Both processes estimate that for every ton of LNG produced, approximately one or more tons of LIN is required. In FLNG applications, space for storage of LIN either topside or in the hull of the floating structure may be limited. It would be advantageous to have an LNG production technology on an FLNG that uses LIN since it would significantly reduce the required topside space for the liquefaction process. Additionally, it would be advantageous to have an LNG production technology that uses less than 1 ton of LIN, or more preferably less than 0.75 ton of LIN, or more preferably less than 0.5 ton of LIN, for every ton of LNG produced.

[0010] United States Patent No. 6,412,302 to Foglietta describes a feed gas expander-based process where two independent closed refrigeration loops are used to cool the feed gas to form LNG. The first closed refrigeration loop uses the feed gas or components of the feed gas as the refrigerant. Nitrogen gas is used as the refrigerant for the second closed refrigeration loop. This technology has an advantage of requiring smaller equipment and topside space than a dual loop nitrogen expander-based process. For example, the volumetric flow rate of the refrigerant into the low pressure compressor can be 20 to 50% smaller for this technology compared to a dual loop nitrogen expander-based process. The technology, however, is still limited to a capacity of less than 1.5 MTA.

[0011] United States Patent No. 8,616,012 to Minta describes a feed gas expander-based process where feed gas is used as the refrigerant in a closed refrigeration loop. Within this closed refrigeration loop, the refrigerant is compressed to a pressure greater than or equal to 1500 psia, or more preferably greater than 2500 psia. The refrigerant is then cooled and expanded to achieve cryogenic temperatures. This cooled refrigerant is then used in a heat exchanger to cool the feed gas from warm temperatures to cryogenic temperatures. A subcooling refrigeration loop is then employed to further cool the feed gas to form LNG. In one embodiment, the subcooling refrigeration loop is a closed loop with flash gas used as the refrigerant. This feed gas expander-based process has the advantage of not being limited to a train capacity range of less than 1 MTA. A train size of approximately 6 MTA has been

considered. However, the technology has the disadvantage of a high equipment count and increased complexity due to its requirement for two independent refrigeration loops and the compression of the feed gas. Furthermore, the high pressure operation also means that the equipment and piping will be much heavier than that of other expander-based processes.

[0012] GB Patent No. 2,486,036 to Maunder *et al.* describes a feed gas expander-based process that is an open loop refrigeration cycle including a precooling expander loop and a liquefying expander loop, where the gas phase after expansion is used to liquefy the natural gas. According to Maunder, including a liquefying expander in the process significantly reduces the recycle gas rate and the overall required refrigeration power. This technology is simpler than the technologies described by Foglietta and Minta since only one type of refrigerant is used with a single compression string. However, the technology is still limited to capacity of less than 1.5 MTA and it requires the use of a liquefying expander, which is not standard equipment for LNG production. The technology has also been shown to be less efficient than the technologies described by Foglietta and Minta for the liquefaction of lean natural gas.

[0013] There remains a need to develop an LNG production process with the advantages of an expander-based process while having a high LNG production capacity with a reduced facility footprint. There is a further need to develop an LNG technology solution that is better able to handle the challenges that vessel motion has on gas processing. Such a high capacity expander-based liquefaction process would be particularly suitable for FLNG applications where the inherent safety and simplicity of expander-based liquefaction processes are greatly valued.

SUMMARY

[0014] The present disclosure provides a method for producing liquefied natural gas (LNG). A natural gas stream is directed to a mechanical refrigeration unit to liquefy the natural gas stream and form a pressurized liquefied natural gas (LNG) stream with a pressure greater than 50 psia (345 kPa) and less than 500 psia (3445 kPa). A liquid refrigerant subcooling unit is provided at a first location. Liquid refrigerant is produced at a second location that is geographically separate from the first location. The produced liquid refrigerant is transported to the first location. The pressurized LNG stream is subcooled in the liquid refrigerant subcooling unit by exchanging heat between the pressurized LNG stream and at least one stream of the liquid refrigerant to thereby produce an LNG stream.

[0015] The present disclosure also provides a system for producing liquefied natural gas (LNG). A mechanical refrigeration unit liquefies a natural gas stream using a feed gas expander-based process and forms a pressurized liquefied natural gas (LNG) stream with a pressure greater than 50 psia (345 kPa) and less than 500 psia (3445 kPa). A liquid nitrogen (LIN) subcooling unit is located in a first location. A liquid nitrogen (LIN) stream is produced at a second location that is geographically separate from the first location. The LIN stream is transported to the LIN subcooling unit. The LIN subcooling unit subcools the pressurized LNG stream by exchanging heat between the pressurized LNG stream and at least one stream of the LIN stream to thereby produce an LNG stream and at least one vaporized LIN stream.

[0016] The foregoing has broadly outlined the features of the present disclosure so that the detailed description that follows may be better understood. Additional features will also be described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] These and other features, aspects and advantages of the disclosure will become apparent from the following description, appending claims and the accompanying drawings, which are briefly described below.

[0018] Figure 1 is a graph showing a temperature cooling curve for an expander-based heat exchanger process.

[0019] Figure 2A is a simplified diagram of the value chain of known FLNG technology.

[0020] Figure 2B is a simplified diagram of the value chain of the disclosed aspects.

[0021] Figure 3 is a schematic diagram of a system according to a disclosed aspect.

[0022] Figure 4 is a schematic diagram of a mechanical refrigeration unit according to disclosed aspects.

[0023] Figure 5 is a schematic diagram of a liquid nitrogen (LIN) subcooling unit according to disclosed aspects.

[0024] Figure 6 is a schematic diagram of a LIN subcooling unit according to disclosed aspects.

[0025] Figure 7 is a flowchart showing a method according to disclosed aspects.

[0026] It should be noted that the figures are merely examples and no limitations on the scope of the present disclosure are intended thereby. Further, the figures are generally not

drawn to scale, but are drafted for purposes of convenience and clarity in illustrating various aspects of the disclosure.

DETAILED DESCRIPTION

[0027] To promote an understanding of the principles of the disclosure, reference will now be made to the features illustrated in the drawings and specific language will be used to describe the same. It will nevertheless be understood that no limitation of the scope of the disclosure is thereby intended. Any alterations and further modifications, and any further applications of the principles of the disclosure as described herein are contemplated as would normally occur to one skilled in the art to which the disclosure relates. For the sake clarity, some features not relevant to the present disclosure may not be shown in the drawings.

[0028] At the outset, for ease of reference, certain terms used in this application and their meanings as used in this context are set forth. To the extent a term used herein is not defined below, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent. Further, the present techniques are not limited by the usage of the terms shown below, as all equivalents, synonyms, new developments, and terms or techniques that serve the same or a similar purpose are considered to be within the scope of the present claims.

[0029] As one of ordinary skill would appreciate, different persons may refer to the same feature or component by different names. This document does not intend to distinguish between components or features that differ in name only. The figures are not necessarily to scale. Certain features and components herein may be shown exaggerated in scale or in schematic form and some details of conventional elements may not be shown in the interest of clarity and conciseness. When referring to the figures described herein, the same reference numerals may be referenced in multiple figures for the sake of simplicity. In the following description and in the claims, the terms “including” and "comprising" are used in an open-ended fashion, and thus, should be interpreted to mean "including, but not limited to.”

[0030] The articles “the,” “a” and “an” are not necessarily limited to mean only one, but rather are inclusive and open ended so as to include, optionally, multiple such elements.

[0031] As used herein, the terms “approximately,” “about,” “substantially,” and similar terms are intended to have a broad meaning in harmony with the common and accepted usage by those of ordinary skill in the art to which the subject matter of this disclosure pertains. It should be understood by those of skill in the art who review this disclosure that these terms are

intended to allow a description of certain features described and claimed without restricting the scope of these features to the precise numeral ranges provided. Accordingly, these terms should be interpreted as indicating that insubstantial or inconsequential modifications or alterations of the subject matter described and are considered to be within the scope of the disclosure.

[0032] The term "heat exchanger" refers to a device designed to efficiently transfer or "exchange" heat from one matter to another. Exemplary heat exchanger types include a co-current or counter-current heat exchanger, an indirect heat exchanger (e.g. spiral wound heat exchanger, plate-fin heat exchanger such as a brazed aluminum plate fin type, shell-and-tube heat exchanger, etc.), direct contact heat exchanger, or some combination of these, and so on.

[0033] The term “dual purpose carrier” refers to a ship capable of (a) transporting LIN to an export terminal for natural gas and/or LNG and (b) transporting LNG to an LNG import terminal.

[0034] As previously described, the conventional LNG cycle includes: (a) initial treatments of the natural gas resource to remove contaminants such as water, sulfur compounds and carbon dioxide; (b) the separation of some heavier hydrocarbon gases, such as propane, butane, pentane, etc. by a variety of possible methods including self-refrigeration, external refrigeration, lean oil, etc.; (c) refrigeration of the natural gas substantially by external refrigeration to form LNG at or near atmospheric pressure and about -160 °C; (d) transport of the LNG product in ships or tankers designed for this purpose to a market location; and (e) re-pressurization and regasification of the LNG at a regasification plant to form a pressurized natural gas stream that may distributed to natural gas consumers. The present disclosure generally involves liquefying natural gas using liquid nitrogen (LIN). In general, using LIN to produce LNG is a non-conventional LNG cycle in which step (c) above is replaced by a natural gas liquefaction process that uses a significant amount of LIN as an open loop source of refrigeration, and in which step (e) above may be modified to use the exergy of the cryogenic LNG to facilitate the liquefaction of nitrogen gas to form LIN that may then be transported to the resource location and used as a source of refrigeration for the production of LNG. The disclosed LIN-to-LNG concept may further include the transport of LNG in a ship or tanker from the resource location (export terminal) to the market location (import terminal) and the reverse transport of LIN from the market location to the resource location.

[0035] Aspects disclosed herein provide a method for enhancing a mechanical refrigeration process for the production of LNG using liquid refrigerant produced at a different location to

subcool the liquefied natural gas coming from the mechanical refrigeration process. More specifically, a process is described in which treated natural gas may be directed to a mechanical refrigeration process. The natural gas may be completely liquefied within the mechanical refrigeration process to produce a pressurized LNG stream where the pressure of the pressurized LNG stream is greater than 50 psia (or 345 kPa) and less than 500 psia (or 3445 kPa), or more specifically greater than 100 psia (or 690 kPa) and less than 400 psia (or 2758 kPa), or more specifically greater than 200 psia (or 1379 kPa) and less than 300 psia (or 2068 kPa). The pressurized LNG stream may then be subcooled by exchanging heat with at least one liquid refrigerant stream to form an LNG stream. The liquid refrigerant stream is produced at a different geographic location than the location where the natural gas is liquefied, and may be 50 miles, or 100 miles, or 200 miles, or 500 miles, or 1,000 miles, or more than 1,000 miles from such location. The mechanical refrigeration process may be a single-mixed refrigerant process, a pure component cascade refrigerant process, a dual-mixed refrigerant process, an expander-based refrigeration process, or any other commonly known refrigeration process that can liquefy a natural gas stream to produce a pressurized LNG stream.

[0036] In an aspect, an expander-based process for the production of LNG may be enhanced by using LIN produced at a different location to subcool the pressurized LNG coming from the expander-based process. Natural gas may be treated to remove impurities, if present, such as water, heavy hydrocarbons, and sour gases, to make the natural gas suitable for liquefaction. The treated natural gas may be completely liquefied within the expander-based process to produce a pressurized LNG stream where the pressure of the pressurized LNG stream is greater than 50 psia (or 345 kPa) and less than 500 psia (or 3445 kPa), or more specifically greater than 100 psia (or 690 kPa) and less than 400 psia (or 2758 kPa), or more specifically greater than 200 psia (or 1379 kPa) and less than 300 psia (or 2068 kPa). The pressurized LNG stream may then be subcooled by exchanging heat with at least one LIN stream to form an LNG stream. The expander-based process may be a nitrogen gas expander-based process or may be a feed gas expander-based process.

[0037] Figure 1 shows a typical temperature cooling curve **100** for an expander-based liquefaction process. The higher temperature curve **104** is the temperature curve for the natural gas stream. The lower temperature curve **102** is the composite temperature curve of a cold cooling stream and a warm cooling stream. As illustrated, the cooling curve is marked by three temperature pinch-points. The lowest temperature pinch-point **106** occurs where the colder of the two cooling streams, typically the cold cooling stream, enters the heat exchanger. The

intermediate temperature pinch-point **108** occurs where the second cooling stream, typically the warm cooling stream, enters the heat exchanger. The warm temperature pinch-point **110** occurs where the cold and warm cooling streams exit the heat exchanger. The lowest temperature pinch-point **106** sets the required flow rate of the cold cooling stream. Since the cold cooling stream is first cooled by the warm cooling stream prior to being expanded to the low temperature, the flow rate of the cold cooling stream also impacts the required flow rate of the warm cooling stream. One way to increase the capacity of the expander-based process without significantly increasing equipment size and required power is to increase the temperature of lowest temperature pinch point. In such a case, to produce LNG additional refrigeration is needed to subcool the pressurized LNG coming from the expander-based process. It would not be advantageous nor efficient to subcool the pressurized LNG with another mechanical refrigeration cycle. For this reason, aspects described herein propose the use of a liquid refrigerant produced at a different location to subcool the pressurized LNG. The liquid refrigerant may be LIN.

[0038] Under certain circumstances, the liquid refrigerant can be produced with an amount of energy that makes the overall process of producing the pressurized LNG and liquefied refrigerant more thermodynamically efficient than a conventional LNG production process. For example, the refrigerant may be nitrogen produced from an air separation plant, where the nitrogen is liquefied using the cold available from the gasification of LNG. Typically during the gasification of LNG all the available exergy from gasifying the LNG is lost to the environment. Using this exergy can result in the production of LIN at a sufficiently low energy cost to make the overall energy requirement of the disclosed aspects comparable to or even less than the energy costs of a conventional LNG production process.

[0039] According to the disclosed aspects, the expander-based process may be a feed-gas expander-based process. The feed-gas expander-based process may be an open loop feed gas process where the recycling loop comprises a warm-end expander loop and a cold-end expander loop. The warm-end expander may discharge a first cooling stream and the cold-end expander may discharge the second cooling stream. The temperature of the first cooling stream may be higher than the temperature of the second cooling stream. The pressure of the first cooling stream may be the same or similar to the pressure of the second cooling stream. The cold-end expander may discharge a two-phase stream that is separated into a second cooling stream and a second pressurized LNG stream. Natural gas may be treated to remove impurities, if present, such as water, heavy hydrocarbons, and sour gases, to make the natural gas suitable

for liquefaction. The treated natural gas may be completely liquefied by indirect exchange of heat with the first cooling stream and the second cooling stream to produce a first pressurized LNG stream. The first pressurized LNG stream may be mixed with the second pressurized LNG stream to form a pressurized LNG stream. The pressure of the pressurized LNG stream is greater than 50 psia (or 345 kPa) and less than 500 psia (or 3445 kPa), or more specifically greater than 100 psia (or 690 kPa) and less than 400 psia (or 2758 kPa), or more specifically greater than 200 psia (or 1379 kPa) and less than 300 psia (or 2068 kPa). The pressurized LNG stream may be subcooled by exchanging heat with at least one LIN stream to form an LNG stream. The subcooling process may include the use of at least one heat exchanger to allow for indirect heat exchange between the vaporizing LIN stream and the pressurized LNG stream. The subcooling process may additionally comprise other equipment such as compressors, expanders, separators and/or other commonly known equipment, to facilitate the cooling of the pressurized LNG stream. The vaporized LIN stream, after heat exchange with the pressurized LNG stream, may be used to liquefy a second stream of treated natural gas to produce an additional pressurized LNG stream. The additional pressurized LNG stream may be mixed with the pressurized LNG stream prior to the subcooling of the pressurized LNG stream with LIN.

[0040] In one disclosed aspect, the produced LNG may be loaded onto an LNG carrier and/or a dual-purpose carrier at the LNG production location and is transported to an import terminal at a different location where LNG is offloaded and regasified. The cold energy from the gasification of the LNG may be used to liquefy nitrogen that is then loaded onto a LIN carrier and/or a dual-purpose carrier and transported back to the LNG production location, where the LIN is used to liquefy the treated natural gas.

[0041] Figures 2A and 2B are simplified diagrams highlighting a difference between the value chain of the aspects disclosed herein and the value chain of conventional FLNG technology, where an FLNG facility contains all or virtually all equipment necessary to process and liquefy natural gas. As shown in Figure 2A, an LNG cargo ship **200a** transports LNG from an FLNG facility **202** to a land-based import terminal **204** where the LNG is offloaded and regasified. The LNG cargo ship **200b**, now empty of cargo and ballast, returns to the FLNG facility **202** to be re-loaded with LNG. In contrast, the aspects disclosed herein and shown in Figure 2B provide a floating processing unit (FPU) **206** having a much smaller footprint than the FLNG facility **202** (Figure 2A). Referring to Figure 2B, a LIN cargo ship or a dual purpose ship **208a**, loaded with LIN at the import terminal **204**, arrives at the FPU **206** and offloads its

LIN cargo to storage tanks on and/or within the FPU **206**. On the FPU **206** a mechanical refrigeration unit cools the natural gas into a pressurized LNG stream. The pressurized LNG stream is then subcooled within an LIN subcooling unit on the FPU **206** to produce LNG. The produced LNG is transported to the LNG cargo ship or the dual purpose ship **208b**. The LNG cargo ship or dual purpose ship **208b**, now loaded with LNG, sails to the import terminal **204**, where the LNG may be offloaded and regasified. The cold energy from the regasification of the LNG is used to liquefy nitrogen at the import terminal **204**. Nitrogen that is liquefied at the import terminal **204** may be produced at an air separation unit **210**. The air separation unit **210** may be part of or within the import terminal **204**, or a separate facility from the import terminal **204**. The LIN may then be loaded into the LIN cargo ship or dual purpose ship, which returns to the FPU **206** to repeat the liquefaction process.

[0042] In another aspect, LIN may be used to liquefy LNG boil-off gas from the tanks during LNG production, transport and/or offloading. In another aspect, LIN and/or vaporized LIN from the subcooling process may be used to cool inlet air going into the gas turbines of the mechanical refrigeration process. In another aspect, LIN and/or LIN boil-off gas may be used to keep the liquefaction equipment cold during turndown or shutdown of the liquefaction process. In another aspect, nitrogen vapor may be used to derime the cryogenic heat exchangers during the periods between LNG production. The nitrogen vapor with contaminants may be vented to the atmosphere.

[0043] Figure 3 is a schematic diagram of a system **300** according to a disclosed aspect. Natural gas may be treated to remove impurities, if present, such as water, heavy hydrocarbons, and sour gases, to produce a treated natural gas stream **302** that is suitable for liquefaction. The treated natural gas stream **302** may be directed to a mechanical refrigeration unit **304** where the treated natural gas **302** is completely liquefied to produce a pressurized LNG stream **306**. The pressure of the pressurized LNG stream **306** may be greater than 50 psia (or 345 kPa) and less than 500 psia (or 3445 kPa), or more specifically greater than 100 psia (or 690 kPa) and less than 400 psia (or 2758 kPa), or more specifically greater than 200 psia (or 1379 kPa) and less than 300 psia (or 2068 kPa). The mechanical refrigeration unit **304** may comprise a single-mixed refrigeration process, a pure component cascade refrigeration process, a dual-mixed refrigeration process, an expander-based refrigeration process, or any other commonly known refrigeration process that can liquefy the treated natural gas stream **302** to a pressurized LNG stream **306**. The mechanical refrigeration unit **304** may comprise gas turbines that are used to provide the mechanical power to drive the compressors within the mechanical refrigeration

unit **304**. The pressurized LNG stream **306** may be directed to a liquid refrigerant subcooling unit **308** where the pressurized LNG stream **306** is subcooled by exchanging heat with a liquid refrigerant stream **310** to form an LNG stream **312**. The liquid refrigerant stream **310** is produced at a different location than the location of the mechanical refrigeration unit **304** and the liquid refrigerant subcooling unit **308**. The liquid refrigerant stream **310**, after being vaporized and warmed within the liquid refrigerant subcooling unit **308** exits the liquid refrigerant subcooling unit **308** as a refrigerant gas vent **314**. The liquid refrigerant subcooling unit **308** comprises at least one heat exchanger to allow for indirect heat exchange between the liquid refrigerant stream **310** and the pressurized LNG stream **306**. The liquid refrigerant subcooling unit **308** may additionally comprise other equipment such as compressors, expanders, separators and/or other commonly known equipment, to facilitate the cooling of the pressurized LNG stream **306**. The vaporized liquid refrigerant stream **310**, after heat exchange with the pressurized LNG stream **306**, may be used to liquefy a second stream of treated natural gas **316** to form an additional pressurized LNG stream. The additional pressurized LNG stream may be mixed with the pressurized LNG stream **306** prior to the subcooling of the pressurized LNG stream **306** with the liquid refrigerant stream **310** to form the LNG stream **312**.

[0044] Figure 4 is an illustration of a mechanical refrigeration unit **400** according to disclosed aspects. The mechanical refrigeration unit **400** includes a feed gas expander-based process. Natural gas to be liquefied by the mechanical refrigeration unit **400** may be treated to remove impurities, if present, such as water, heavy hydrocarbons, and sour gases, to produce a treated natural gas stream **402** that is suitable for liquefaction. The treated natural gas stream **402** is mixed with a recycled refrigerant stream **404** using a combining device **403**. The combined natural gas stream **405** may then be separated by one or more manifolds, splitters, or other types of separators **406**, **408**, **409** to produce a second treated natural gas stream **410**, a first refrigerant stream **412**, a second refrigerant stream **414**, and a small treated natural gas stream **415** to be liquefied using a liquid refrigerant, as will be explained herein. The first refrigerant stream **412** is expanded in a first expander **417** to produce a first cooling stream **416**. The first cooling stream **416** enters at least one heat exchanger **418** where it exchanges heat with the second treated natural gas stream **410** and the second refrigerant stream **414** to cool these two streams. The first cooling stream **416**, now heated, exits the at least one heat exchanger **418** as a first warm stream **420**. The second refrigerant stream **414**, after being cooled in the at least one heat exchanger **418**, is expanded in a second expander **422** to produce a two-phase stream **424**. The pressure of the two-phase stream **424** may be the same or near the same to the pressure of the first cooling stream **416**. The two-phase stream **424** may be

separated into its vapor component and its liquid component in a two-phase separator **426** to form a second cooling stream **428** and a second pressurized LNG stream **430**. The temperature of the first cooling stream **416** may be higher than the temperature of the second cooling stream **428**. The second pressurized LNG stream **430** may be pumped, using a pump **432**, to a higher pressure after it has exited the two-phase separator **426**. The second cooling stream **428** may enter the at least one heat exchanger **418** where it exchanges heat with the second treated natural gas stream **410** and the second refrigerant stream **414** to cool said streams. The heated second cooling stream exits the at least one heat exchanger **418** as a second warm stream **434**. The second treated natural gas stream **410** may exchange heat with the first cooling stream **416** and the second cooling stream **428** to produce a first pressurized LNG stream **436**. The first pressurized LNG stream **436** may be reduced in pressure in a hydraulic turbine **437** or other pressure-reducing device after the first pressurized LNG stream **436** has exited the at least one heat exchanger **418**. The first pressurized LNG stream **436** may be mixed with the second pressurized LNG stream **430** to form a combined pressurized LNG stream **438**. The pressure of the combined pressurized LNG stream **438** may be greater than 50 psia (or 345 kPa) and less than 500 psia (or 3445 kPa), or more specifically greater than 100 psia (or 690 kPa) and less than 400 psia (or 2758 kPa), or more specifically greater than 200 psia (or 1379 kPa) and less than 300 psia (or 2068 kPa). The pressurized LNG stream **438** may be directed to a LIN subcooling unit, as will be further described herein.

[0045] The first warm stream **420** may be combined with the second warm stream **434** in a combining apparatus **440** to form a combined warm refrigerant stream **442**. The combined warm refrigerant stream **442** may be compressed in multiple compressor stages to form the recycled refrigerant stream **404**. The compressor stages may include a first compressor stage **444**, a second compressor stage **446**, and a third compressor stage **448**. The first compressor stage **444** may be driven by a gas turbine (not shown). The second compressor stage **446** may be driven solely by the shaft power produced by the first expander **417**. The third compressor stage **448** may be driven solely by the shaft power produced by the second expander **422**. Coolers **450**, **452**, and **454** may cool the combined warm refrigerant stream **442** after the first, second, and third compressor stages **444**, **446**, **448**, respectively.

[0046] Figure 5 is a schematic diagram of a LIN subcooling unit **500** according to disclosed aspects. The LIN subcooling unit **500** may be used with the mechanical refrigeration unit **400** depicted in Figure 4. LIN produced at a different location than the location of the LIN subcooling unit **500** is transported to the location of the LIN subcooling unit **500** and directed

to at least one heat exchanger **502** as a LIN stream **504**. The LIN stream **504** is vaporized in the at least one heat exchanger **502** by subcooling a pressurized LNG stream **506** (which may be the same as the combined pressurized LNG stream **438** of Figure 4) to produce a vaporized nitrogen stream **508** and an LNG stream **510**. The vaporized nitrogen stream **508** may be directed to a secondary heat exchanger **512** to liquefy a treated natural gas stream **514**, which may be the same as the small treated natural gas stream **415**, to form an additional pressurized LNG stream **516**. The additional pressurized LNG stream **516** may be combined with the pressurized LNG stream **506** in a combining apparatus **518** prior to entering the at least one heat exchanger **502**. The additional pressurized LNG stream **516** may be reduced in pressure in a hydraulic turbine **520** or other pressure-reducing apparatus prior to being combined with the pressurized LNG stream **506**. The vaporized nitrogen stream **508** is heated by the treated natural gas stream **514** in the secondary heat exchanger **512** to form a nitrogen vent gas **522** that may be vented to the atmosphere or used in other areas of the gas processing facility in which the LIN subcooling unit **500** is located.

[0047] Figure 6 is a schematic diagram of a LIN subcooling unit **600** according to disclosed aspects. The LIN subcooling unit **600** may be used with the mechanical refrigeration unit **400** depicted in Figure 4. LIN produced at a different location than the location of the LIN subcooling unit **600** is transported from the different location and directed to the LIN subcooling unit **600** as a LIN stream **602**. A pump **604** may pump the LIN stream **602** to a pressure greater than 400 psi to form a high pressure LIN stream **606**. The high pressure LIN stream **606** exchanges heat with a pressurized LNG stream **608** (which may be the same as the combined pressurized LNG stream **438** of Figure 4) in at least one heat exchanger **610** to form a first warmed nitrogen gas stream **612**. The first warmed nitrogen gas stream **612** may be expanded in a first expander **614** to produce a first additionally cooled nitrogen gas stream **616**. The first additionally cooled nitrogen gas stream **616** exchanges heat with the pressurized LNG stream **608** in the at least one heat exchanger **610** to form a second warmed nitrogen gas stream **618.**

[0048] The second warmed nitrogen gas stream **618** may indirectly exchange heat with other process streams, for example in a secondary heat exchanger **619**, prior to the second warmed nitrogen gas stream **618** being compressed in one or more compressor stages to form a compressed nitrogen gas stream **620**. As shown in Figure 6, the one or more compressor stages may comprise two compressor stages, including a first compressor stage **622** and a second compressor stage **624**. The second compressor stage **624** may be driven solely by the

shaft power produced by the first expander **614**. The first compressor stage **622** may be driven solely by the shaft power produced by a second expander **626**. After each compression stage, the compressed nitrogen gas stream **620** may be cooled by indirect heat exchange with the environment in coolers **628**, **630**, respectively. The compressed nitrogen gas stream **620** may be expanded in the second expander **626** to produce a second additionally cooled nitrogen gas stream **632**. The second additionally cooled nitrogen gas stream **632** exchanges heat with the pressurized LNG stream **608** in the at least one heat exchanger **610** to form a third warmed nitrogen gas stream **634**. The pressurized LNG stream **608** is subcooled by exchanging heat with the high pressure LIN stream **606**, the first additionally cooled nitrogen gas stream **616**, and the second additionally cooled nitrogen gas stream **632** to form an LNG stream **636**. The third warmed nitrogen gas stream **634** may be directed to a tertiary heat exchanger **638** to liquefy a treated natural gas stream **640**, which may be the same as the small treated natural gas stream **415** in Figure 4, to form an additional pressurized LNG stream **642**. The additional pressurized LNG stream **642** may be combined with the pressurized LNG stream **608** in a combining apparatus **644** prior to the subcooling of the pressurized LNG stream **608** in the at least one heat exchanger **610**. The additional pressurized LNG stream **642** may be reduced in pressure in a hydraulic turbine **646** prior to being combined with the pressurized LNG stream **608**. The third warmed nitrogen gas stream **634** may be heated by the treated natural gas stream **640** to form a nitrogen vent gas **648** that may be vented to the atmosphere or used in other areas of the gas processing facility in which the LIN subcooling unit **600** is located. The LIN subcooling unit **600** illustrated in Figure 6 reduces the LIN requirement for subcooling a pressurized LNG stream by approximately 20 to 25% compared to the LIN subcooling unit **500** illustrated in Figure 5. However, the choice of subcooling units may depend on criteria such as cost of LIN and available topside space for LIN storage and/or the LIN subcooling unit itself.

[0049] Figure 7 is a flowchart of a method **700** for producing liquefied natural gas (LNG). At block **702** a natural gas stream is directed to a mechanical refrigeration unit to liquefy the natural gas stream and form a pressurized liquefied natural gas (LNG) stream with a pressure greater than 50 psia (345 kPa) and less than 500 psia (3445 kPa). At block **704** a liquid refrigerant subcooling unit is provided at a first location. At block **706** liquid refrigerant is produced at a second location that is geographically separate from the first location. At block **708** the produced liquid refrigerant is transported to the first location. At block **710** the pressurized LNG stream is subcooled in the liquid refrigerant subcooling unit by exchanging heat between the pressurized LNG stream and at least one stream of the liquid refrigerant to thereby produce an LNG stream.

[0050] The steps depicted in Figure 7 are provided for illustrative purposes only and a particular step may not be required to perform the disclosed methodology. Moreover, Figure 7 may not illustrate all the steps that may be performed. The claims, and only the claims, define the disclosed system and methodology.

[0051] The aspects described herein have several advantages over known technologies. For example, the described aspects may significantly increase the capacity of a conventional mechanical refrigeration process without significantly increasing required power and footprint of the mechanical refrigeration process. For example, compared to known feed gas expander-based processes, the feed gas expander-based process coupled with LIN subcooling described herein can produced approximately 50% more LNG at an equivalent mechanical refrigeration power. The amount of LIN needed is approximately 0.26 ton of LIN for every ton of LNG produced. The reduced amount of LIN makes this technology particularly suitable for FLNG applications. Using the disclosed aspects, the 50% extra throughput through the feed gas expander-based process only increases the required volumetric flow to the low pressure compressor and the cryogenic heat exchanger load by approximately 10% respectively compared to known feed gas expander technologies.

[0052] Disclosed aspects may include any combinations of the methods and systems shown in the following numbered paragraphs. This is not to be considered a complete listing of all possible aspects, as any number of variations can be envisioned from the description above.

1. A method for producing liquefied natural gas (LNG), comprising:

directing a natural gas stream to a mechanical refrigeration unit to liquefy the natural gas stream and form a pressurized liquefied natural gas (LNG) stream with a pressure greater than 50 psia (345 kPa) and less than 500 psia (3445 kPa);

providing a liquid refrigerant subcooling unit at a first location;

producing liquid refrigerant at a second location that is geographically separate from the first location;

transporting the produced liquid refrigerant to the first location; and

subcooling the pressurized LNG stream in the liquid refrigerant subcooling unit by exchanging heat between the pressurized LNG stream and at least one stream of the liquid refrigerant to thereby produce an LNG stream.

2. The method of paragraph 1, wherein the mechanical refrigeration unit includes an

expander-based refrigeration process.

3. The method of paragraph 2, wherein the expander-based refrigeration process is a feed gas expander-based process.

4. The method of paragraph 3, wherein the feed gas expander-based process is an open loop feed gas expander-based process.

5. The method of paragraph 3, wherein the feed gas expander-based process is a closed loop feed gas expander-based process.

6. The method of paragraph 3, wherein the feed gas expander-based process comprises:

discharging a first cooling stream from a warm-end expander; and

discharging a two-phase stream from a cold-end expander;

wherein a temperature of the first cooling stream is higher than a temperature of the two-phase stream.

7. The method of paragraph 3, wherein the pressurized LNG stream is a first pressurized LNG stream, and further comprising separating the two-phase stream into a second cooling stream and a second pressurized LNG stream.

8. The method of paragraph 3, wherein the feed gas expander-based process comprises:

discharging a first cooling stream from a warm-end expander; and

discharging a second cooling stream from a cool-end expander;

wherein a temperature of the first cooling stream is higher than a temperature of the second cooling stream.

9. The method of paragraphs 7 or 8, wherein a pressure of the first cooling stream is the same or substantially the same as a pressure of the second cooling stream.

10. The method of paragraph 9, further comprising mixing the second pressurized LNG stream with the first pressurized LNG stream prior to directing the pressurized LNG stream to the liquid refrigerant subcooling unit.

11. The method of any of paragraphs 1-10, wherein the liquid refrigerant subcooling unit comprises at least one heat exchanger.

12. The method of any of paragraphs 1-11, wherein the liquid refrigerant subcooling unit comprises at least one compressor and/or expander.

13. The method of any of paragraphs 1-12, wherein the vaporized liquid refrigerant stream is used to liquefy a second treated natural gas stream to produce an additional pressurized LNG stream.

14. The method of paragraph 13, wherein the additional pressurized LNG stream is mixed with the pressurized LNG stream prior to the subcooling of the pressurized LNG stream with the liquid refrigerant.

15. The method of any of paragraphs 1-14, further comprising locating the mechanical refrigeration unit and the liquid refrigerant subcooling unit on a floating LNG facility.

16. The method of any of paragraphs 1-15, further comprising re-liquefying LNG boil-off gas using the liquid refrigerant.

17. The method of any of paragraphs 1-16, wherein the liquid refrigerant and/or a liquid refrigerant boil-off gas is used to keep the mechanical refrigeration unit and/or liquid refrigerant subcooling unit equipment cold during turndown and/or shutdown periods of the mechanical refrigeration unit.

18. The method of any of paragraphs 1-17, wherein warm liquid refrigerant vapor is used to derime heat exchangers used to exchange heat.

19. The method of any of paragraphs 1-18, further comprising:

transporting the LNG stream from the first location to the second location in a dual-purpose carrier; and

after the LNG stream has been offloaded from the dual-purpose carrier, transporting the liquid refrigerant from the second location to the first location in the dual purpose carrier.

20. The method of any of paragraphs 1-19, wherein the mechanical refrigeration unit includes one of a single-mixed refrigerant process, a pure component cascade refrigerant process, or a dual-mixed refrigerant process.

21. The method of any of paragraphs 1-20, wherein the pressurized LNG stream has a pressure greater than 100 psia (690 kPa) and less than 400 psia (2758 kPa).

22. The method of any of paragraphs 1-21, wherein the pressurized LNG stream has a pressure greater than 200 psia (1379 kPa) and less than 300 psia (2068 kPa).

23. The method of any of paragraphs 1-22, wherein the liquid refrigerant comprises liquid nitrogen (LIN).

24. The method of paragraph 23, further comprising producing the LIN by exchanging heat with LNG during LNG regasification.

25. The method of paragraph 23, further comprising pressurizing the LIN to a pressure greater than 400 psia (2758 kPa) to form a high pressure liquid nitrogen stream.

26. The method of paragraph 25, further comprising exchanging heat between the high pressure liquid nitrogen stream and the pressurized LNG stream to form a warm nitrogen gas stream.

27. The method of paragraph 23, further comprising:

reducing, in the liquid refrigerant subcooling unit, a pressure of at least one warmed natural gas stream in at least one expander service, to reduce the pressure of the at least one warmed nitrogen gas stream, and to thereby produce at least one additionally cooled nitrogen gas stream.

28. The method of paragraph 27, wherein the at least one additionally cooled nitrogen gas stream exchanges heat with the pressurized LNG stream to form warmed nitrogen gas streams.

29. The method of paragraph 27, further comprising:

coupling the at least one expander service with at least one generator to generate electrical power.

30. The method of paragraph 27, further comprising:

coupling the at least one expander service with at least one compressor that is used to compress warmed nitrogen gas streams.

31. The method of any of paragraphs 1-30, further comprising:

directing pressurized LNG streams from a plurality of mechanical refrigeration units to the liquid refrigerant subcooling unit to produce at least one LNG stream.

32. A system for producing liquefied natural gas (LNG), comprising:

a mechanical refrigeration unit configured to liquefy a natural gas stream using a feed gas expander-based process and form a pressurized liquefied natural gas (LNG) stream with a pressure greater than 50 psia (345 kPa) and less than 500 psia (3445 kPa);

a liquid nitrogen (LIN) subcooling unit located in a first location;

a liquid nitrogen (LIN) stream produced at a second location that is geographically separate from the first location and transported to the LIN subcooling unit;

wherein the LIN subcooling unit is configured to subcool the pressurized LNG stream by exchanging heat between the pressurized LNG stream and at least one stream of the LIN stream to thereby produce an LNG stream and at least one vaporized LIN stream.

33. The system of paragraph 32, wherein the mechanical refrigeration unit comprises:

a warm-end expander configured to discharge a first cooling stream therefrom; and

a cold-end expander configured to discharge a two-phase stream therefrom;

wherein a temperature of the first cooling stream is higher than a temperature of the two-phase stream;

wherein the pressurized LNG stream is a first pressurized LNG stream, and

wherein the two-phase stream is configured to be split into a second cooling stream and a second pressurized LNG stream.

34. The system of paragraph 32, wherein the mechanical refrigeration unit comprises:

A warm-end expander configured to discharge a first cooling stream therefrom; and

discharging a second cooling stream from a cool-end expander;

wherein a temperature of the first cooling stream is higher than a temperature of the second cooling stream.

35. The system of paragraphs 33 or 34, wherein a pressure of the first cooling stream is the same or substantially the same as a pressure of the second cooling stream.

36. The system of paragraph 35, wherein the second pressurized LNG stream is mixed with the first pressurized LNG stream prior to directing the pressurized LNG stream to the LIN subcooling unit.

37. The system of any of paragraphs 32-35, wherein the at least one vaporized liquid refrigerant stream is used to liquefy a second treated natural gas stream to produce an additional pressurized LNG stream.

38. The system of any of paragraphs 32-36, wherein the mechanical refrigeration unit and the liquid refrigerant subcooling unit are located on a floating LNG facility.

39. The system of any of paragraphs 32-37, further comprising:

[0053] A dual-purpose carrier configured to transport the LNG stream from the first location to the second location and transport the liquid refrigerant from the second location to

the first location in the dual purpose carrier after the subcooled LNG stream has been offloaded from the dual-purpose carrier.

[0054] It should be understood that the numerous changes, modifications, and alternatives to the preceding disclosure can be made without departing from the scope of the disclosure. The preceding description, therefore, is not meant to limit the scope of the disclosure. Rather, the scope of the disclosure is to be determined only by the appended claims and their equivalents. It is also contemplated that structures and features in the present examples can be altered, rearranged, substituted, deleted, duplicated, combined, or added to each other.

CLAIMS

1. A method for producing liquefied natural gas (LNG), comprising:

directing a first natural gas stream to a mechanical refrigeration unit to liquefy the first natural gas stream and form a pressurized liquefied natural gas (LNG) stream with a pressure greater than 50 psia (345 kPa) and less than 500 psia (3445 kPa), wherein the mechanical refrigeration unit includes an expander-based refrigeration process without using nitrogen as a coolant;

providing a liquid nitrogen (LIN) subcooling unit at a first location;

producing LIN at a second location that is geographically separate from the first location;

transporting the produced LIN to the first location;

subcooling the pressurized LNG stream in the LIN subcooling unit by exchanging heat between the pressurized LNG stream and at least one stream of the LIN to thereby produce an LNG stream and a vaporized LIN stream;

using the vaporized LIN stream to liquefy a second natural gas stream to produce an additional pressurized LNG stream; and

mixing the additional pressurized LNG stream with the pressurized LNG stream prior to the subcooling of the pressurized LNG stream with the LIN.

2. The method of claim 1, wherein the expander based refrigeration process is a feed gas expander-based process that comprises:

discharging a first cooling stream from a warm-end expander; and

discharging a two-phase stream from a cold-end expander;

wherein a temperature of the first cooling stream is higher than a temperature of the two-phase stream;

wherein the pressurized LNG stream is a first pressurized LNG stream, and further comprising separating the two-phase stream into a second cooling stream and a second pressurized LNG stream; or

wherein the expander-based refrigeration process is a feed gas expander-based process that comprises:

discharging a first cooling stream from a warm-end expander; and

discharging a second cooling stream from a cool-end expander;

wherein a temperature of the first cooling stream is higher than a temperature of the second cooling stream.

3. The method of claim 2, wherein a pressure of the first cooling stream is the same or substantially the same as a pressure of the second cooling stream, and further comprising:

mixing the second pressurized LNG stream with the first pressurized LNG stream prior to directing the pressurized LNG stream to the LIN subcooling unit.

4. The method of any one of claims 1-3, wherein the LIN subcooling unit comprises:

at least one heat exchanger, or

at least one compressor and/or expander.

5. The method of any one of claims 1-4, further comprising locating the mechanical refrigeration unit and the LIN subcooling unit on a floating LNG facility.

6. The method of any one of claims 1-5, further comprising re-liquefying LNG boil-off gas using the LIN.

7. The method of any one of claims 1-6, wherein the LIN and/or a LIN boil-off gas is used to keep the mechanical refrigeration unit and/or the LIN subcooling unit equipment cold during turndown and/or shutdown periods of the mechanical refrigeration unit.

8. The method of any one of claims 1-7, wherein warm nitrogen vapor is used to derime heat exchangers used to exchange heat.

9. The method of any one of claims 1-8, further comprising:

transporting the LNG stream from the first location to the second location in a dual-purpose carrier; and

after the LNG stream has been offloaded from the dual-purpose carrier, transporting the LIN from the second location to the first location in the dual purpose carrier.

10. The method of any one of claims 1-9, wherein the mechanical refrigeration unit includes one of a single-mixed refrigerant process, a pure component cascade refrigerant process, or a dual-mixed refrigerant process.

11. The method of any one of claims 1-10, wherein the pressurized LNG stream has a pressure greater than 100 psia (690 kPa) and less than 400 psia (2758 kPa).

12. The method of any one of claims 1-11, wherein the pressurized LNG stream has a pressure greater than 200 psia (1379 kPa) and less than 300 psia (2068 kPa).

13. The method of any one of claims 1-12, further comprising producing the LIN by exchanging heat with LNG during LNG regasification.

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

pressurizing the LIN to a pressure greater than 400 psia (2758 kPa) to form a high pressure LIN stream;

exchanging heat between the high pressure LIN stream and the pressurized LNG stream to form a warm nitrogen gas stream; and

reducing, in the LIN subcooling unit, a pressure of at least one warmed natural gas stream in at least one expander service, to reduce the pressure of the at least one warmed nitrogen gas stream, and to thereby produce at

least one additionally cooled nitrogen gas stream; and further comprising:

coupling the at least one expander service with

at least one generator to generate electrical power, or

at least one compressor that is used to compress warmed nitrogen gas streams.

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

directing pressurized LNG streams from a plurality of mechanical refrigeration units to the LIN subcooling unit to produce at least one LNG stream.

16. A system for producing liquefied natural gas (LNG), comprising:

a mechanical refrigeration unit configured to liquefy a natural gas stream using a feed gas expander-based process without using nitrogen as a coolant and form a pressurized liquefied natural gas (LNG) stream with a pressure greater than 50 psia (345 kPa) and less than 500 psia (3445 kPa);

a liquid nitrogen (LIN) subcooling unit located in a first location;

a liquid nitrogen (LIN) stream produced at a second location that is geographically separate from the first location and transported to the LIN subcooling unit;

wherein the LIN subcooling unit is configured to subcool the pressurized LNG stream by exchanging heat between the pressurized LNG stream and at least one stream of the LIN stream to thereby produce an LNG stream and at least one vaporized LIN stream;

a heat exchanger configured to exchange heat between

at least one of the at least one vaporized LIN streams; and

a second natural gas stream

such that the second natural gas stream is liquefied to form an additional pressurized LNG stream that is mixed with the pressurized LNG stream prior to the subcooling of the pressurized LNG stream with the LIN.

17. The system of claim 16, wherein the mechanical refrigeration unit comprises:

a warm-end expander configured to discharge a first cooling stream therefrom; and

a cold-end expander configured to discharge a two-phase stream therefrom;

wherein a temperature of the first cooling stream is higher than a temperature of the two-phase stream;

wherein the pressurized LNG stream is a first pressurized LNG stream; and

wherein the two-phase stream is configured to be split into a second cooling stream and a second pressurized LNG stream; or

wherein the mechanical refrigeration unit comprises:

a warm-end expander configured to discharge a first cooling stream therefrom; and

a cool-end expander configured to discharge a second cooling stream therefrom;

wherein a temperature of the first cooling stream is higher than a temperature of the second cooling stream.

18. The system of claim 16 or claim 17, wherein the mechanical refrigeration unit and the LIN subcooling unit are located on a floating LNG facility.

19. The system of any one of claims 16-18, further comprising:

a dual-purpose carrier configured to transport the LNG stream from the first location to the second location and transport the LIN from the second location to the first location in the dual purpose carrier after the subcooled LNG stream has been offloaded from the dual-purpose carrier.