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(54) NATURAL GAS LIQUEFACTION CORE MODULES, PLANTS INCLUDING SAME AND RELATED METHODS

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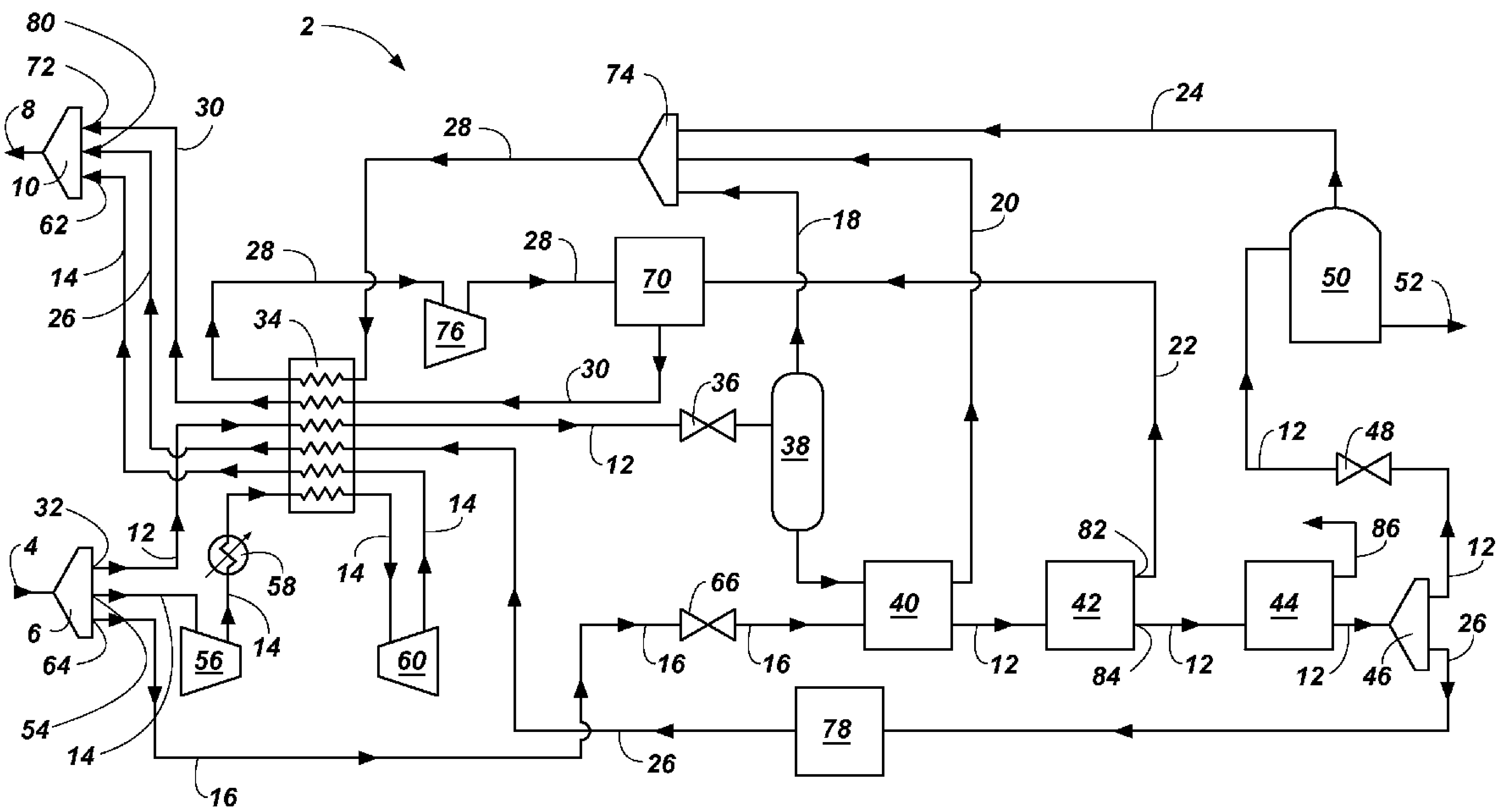
(57) **ABSTRACT**

A method of natural gas liquefaction may include liquefying natural gas from a first natural gas source with a first core module, and liquefying natural gas from at least a second natural gas source having a gas property different than a gas property of the first natural gas source with at least a second core module substantially identical to the first core module. Additionally, a method of designing a natural gas liquefaction plant may include utilizing a preconfigured core module design for a core module configured to receive source gas at site-independent predetermined input conditions, expel tail gas at site-independent predetermined outlet conditions, and liquefy natural gas. Furthermore, a method of distributing liquid natural gas may include providing a plurality of natural gas liquefaction plants comprising substantially identical core modules to a plurality of gaseous natural gas source locations. Finally, a modular natural gas liquefaction plant may include a preconfigured core module, and site-specific inlet and outlet modules.



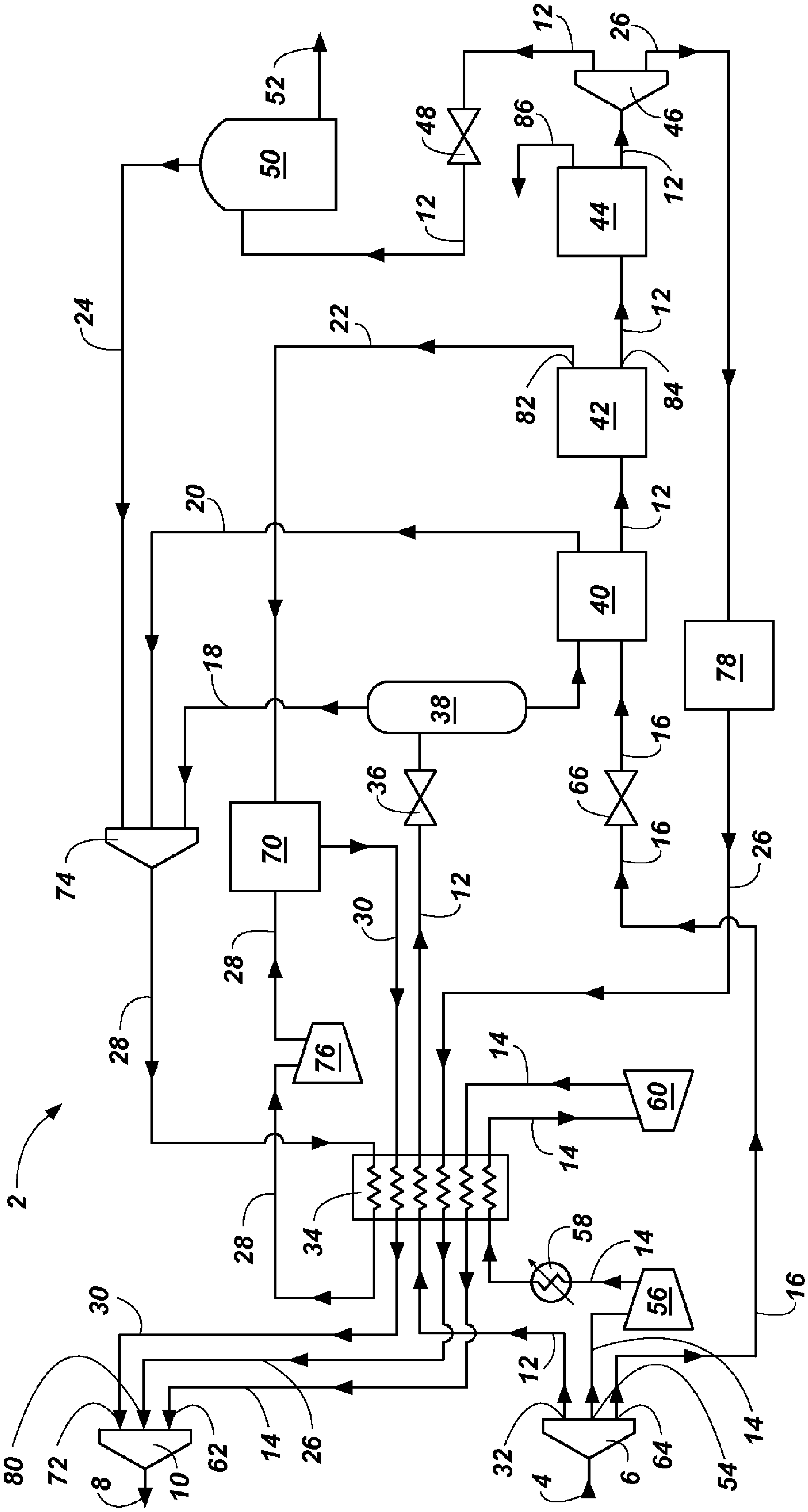


FIG. 1

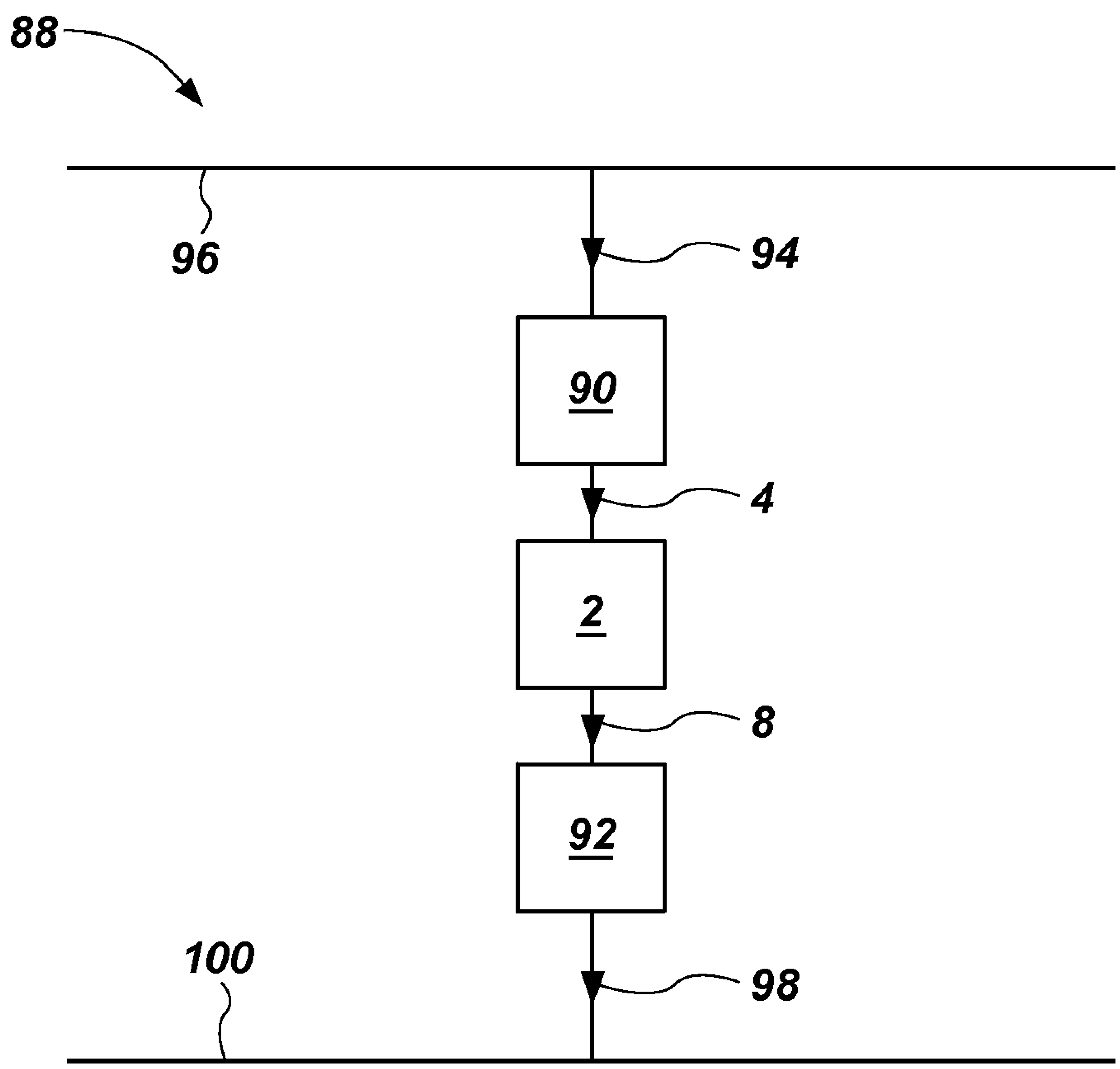


FIG. 2

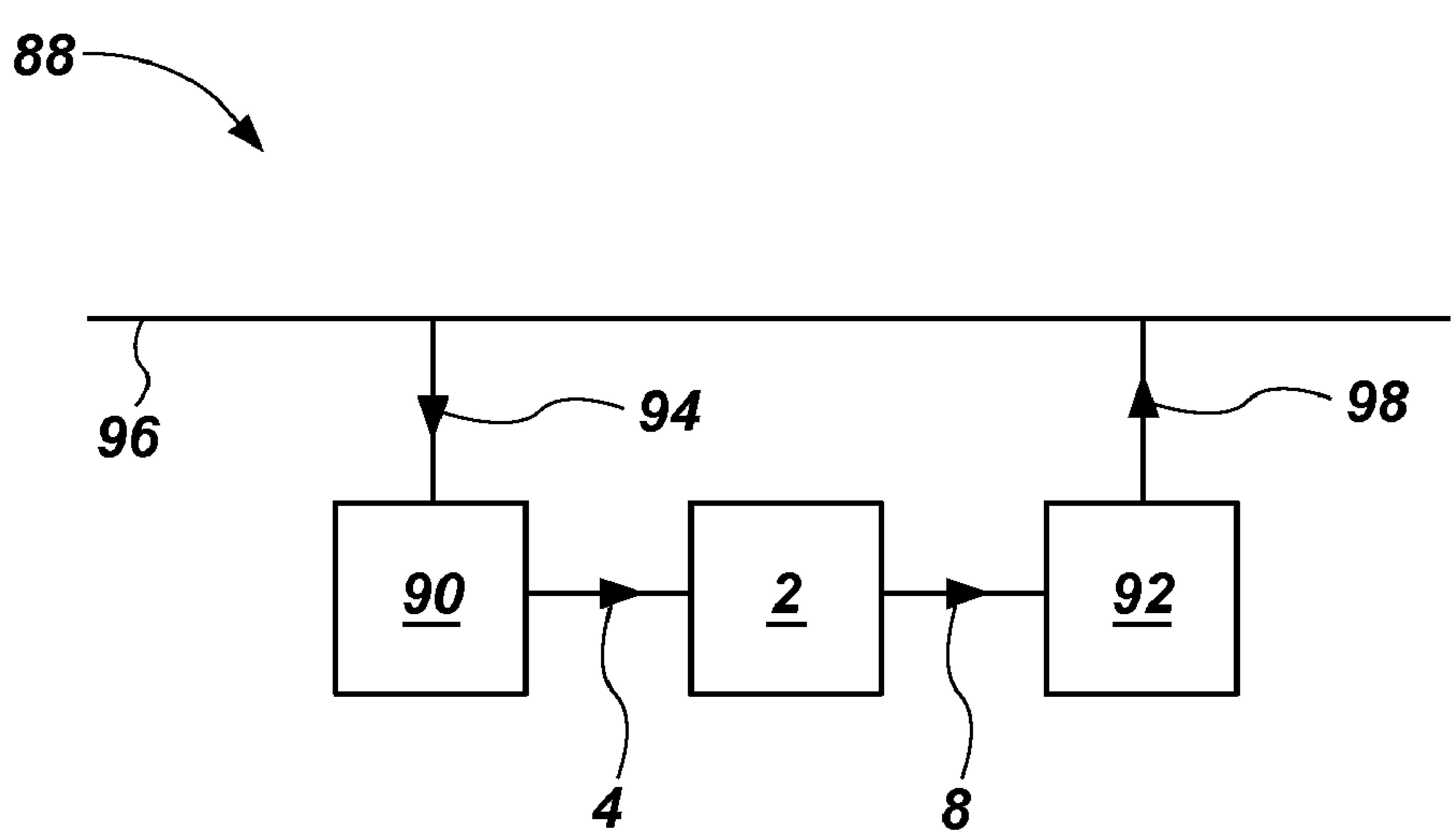


FIG. 3

NATURAL GAS LIQUEFACTION CORE MODULES, PLANTS INCLUDING SAME AND RELATED METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is related to U.S. patent application Ser. No. 09/643,420, filed Aug. 23, 2001, for APPARATUS AND PROCESS FOR THE REFRIGERATION, LIQUEFACTION AND SEPARATION OF GASES WITH VARYING LEVELS OF PURITY, now U.S. Pat. No. 6,425,263, issued Jul. 30, 2002, which is a continuation of U.S. patent application Ser. No. 09/212,490, filed Dec. 16, 1998, for APPARATUS AND PROCESS FOR THE REFRIGERATION, LIQUEFACTION AND SEPARATION OF GASES WITH VARYING LEVELS OF PURITY, now U.S. Pat. No. 6,105,390, issued Aug. 22, 2000, which claims the benefit of U.S. Provisional Patent Application Ser. No. 60/069,698 filed Dec. 16, 1997. This application is also related to U.S. patent application Ser. No. 11/381,904, filed May 5, 2006, for APPARATUS FOR THE LIQUEFACTION OF NATURAL GAS AND METHODS RELATING TO SAME; U.S. patent application Ser. No. 11/383,411, filed May 15, 2006, for APPARATUS FOR THE LIQUEFACTION OF NATURAL GAS AND METHODS RELATING TO SAME; U.S. patent application Ser. No. 11/560,682, filed Nov. 16, 2006, for APPARATUS FOR THE LIQUEFACTION OF GAS AND METHODS RELATING TO SAME; U.S. patent application Ser. No. 11/536,477, filed Sep. 28, 2006, for APPARATUS FOR THE LIQUEFACTION OF A GAS AND METHODS RELATING TO SAME; U.S. patent application Ser. No. 11/674,984, filed Feb. 14, 2007, for SYSTEMS AND METHODS FOR DELIVERING HYDROGEN AND SEPARATION OF HYDROGEN FROM A CARRIER MEDIUM, which is a continuation-in-part of U.S. patent application Ser. No. 11/124,589, filed May 5, 2005, for APPARATUS FOR THE LIQUEFACTION OF NATURAL GAS AND METHODS RELATING TO SAME, now U.S. Pat. No. 7,219,512, issued May 22, 2007, which is a continuation of U.S. patent application Ser. No. 10/414,991, filed Apr. 14, 2003, for APPARATUS FOR THE LIQUEFACTION OF NATURAL GAS AND METHODS RELATING TO SAME, now U.S. Pat. No. 6,962,061, issued Nov. 8, 2005, and U.S. patent application Ser. No. 10/414,883, filed Apr. 14, 2003, for APPARATUS FOR THE LIQUEFACTION OF NATURAL GAS AND METHODS RELATING TO SAME, now U.S. Pat. No. 6,886,362, issued May 3, 2005, which is a divisional of U.S. patent application Ser. No. 10/086,066, filed Feb. 27, 2002, for APPARATUS FOR THE LIQUEFACTION OF NATURAL GAS AND METHODS RELATED TO SAME, now U.S. Pat. No. 6,581,409, issued Jun. 24, 2003, and which claims the benefit of U.S. Provisional Patent Application Ser. No. 60/288,985, filed May 4, 2001, for SMALL SCALE NATURAL GAS LIQUEFACTION PLANT. This application is also related to U.S. patent application Ser. No. 11/855,071, filed Sep. 13, 2007, for HEAT EXCHANGER AND ASSOCIATED METHODS; U.S. patent application Ser. No. ______, filed on even date herewith, for COMPLETE LIQUEFACTION METHODS AND APPARATUS (Attorney Docket No. 2939-9177US (BA-347)); and U.S. patent application Ser. No. ______, filed on even date herewith, for METHODS OF NATURAL GAS LIQUEFACTION AND NATURAL GAS LIQUEFACTION PLANTS UTILIZING MULTIPLE AND VARYING GAS STREAMS (Attorney Docket No. 2939-9179US (BA-350)). The disclosure of each of the foregoing documents is hereby incorporated by reference in its entirety.

GOVERNMENT RIGHTS

[0002] This invention was made with government support under Contract Number DE-AC07-05ID14517 awarded by the United States Department of Energy. The government has certain rights in the invention.

TECHNICAL FIELD

[0003] The present invention relates generally to the compression and liquefaction of gases and, more particularly, to the partial liquefaction of a gas, such as natural gas, by a modular natural gas liquefaction plant utilizing a core module.

BACKGROUND

[0004] Natural gas is a known alternative to combustion fuels such as gasoline and diesel. Much effort has gone into the development of natural gas as an alternative combustion fuel in order to combat various drawbacks of gasoline and diesel including production costs and the subsequent emissions created by the use thereof. As is known in the art, natural gas is a cleaner burning fuel than other combustion fuels. Additionally, natural gas is considered to be safer than gasoline or diesel as natural gas will rise in the air and dissipate, rather than settling.

[0005] To be used as an alternative combustion fuel, natural gas (also termed "feed gas" herein) is conventionally converted into compressed natural gas (CNG) or liquified (or liquid) natural gas (LNG) for purposes of storing and transporting the fuel prior to its use. Conventionally, two of the known basic cycles for the liquefaction of natural gases are referred to as the "cascade cycle" and the "expansion cycle."

[0006] Briefly, the cascade cycle consists of a series of heat exchanges with the feed gas, each exchange being at successively lower temperatures until liquefaction is accomplished. The levels of refrigeration are obtained with different refrigerants or with the same refrigerant at different evaporating pressures. The cascade cycle is considered to be very efficient at producing LNG as operating costs are relatively low. However, the efficiency in operation is often seen to be offset by the relatively high investment costs associated with the expensive heat exchange and the compression equipment associated with the refrigerant system. Additionally, a liquefaction plant incorporating such a system may be impractical where physical space is limited, as the physical components used in cascading systems are relatively large.

[0007] In an expansion cycle, gas is conventionally compressed to a selected pressure, cooled, and then allowed to expand through an expansion turbine, thereby producing work as well as reducing the temperature of the feed gas. The low temperature feed gas is then heat exchanged to effect liquefaction of the feed gas. Conventionally, such a cycle has been seen as being impracticable in the liquefaction of natural gas since there is no provision for handling some of the components present in natural gas which freeze at the temperatures encountered in the heat exchangers, for example, water and carbon dioxide.

[0008] Additionally, to make the operation of conventional systems cost effective, such systems are conventionally built on a large scale to handle large volumes of natural gas. As a result, fewer facilities are built, making it more difficult to provide the raw gas to the liquefaction plant or facility as well as making distribution of the liquefied product an issue. Another major problem with large-scale facilities is the capital and operating expenses associated therewith. For example, a conventional large-scale liquefaction plant, i.e., producing on the order of 70,000 gallons of LNG per day, may cost $16.3 million to $24.5 million, or more, in capital expenses.

[0009] An additional problem with large facilities is the cost associated with storing large amounts of fuel in anticipation of future use and/or transportation. Not only is there a cost associated with building large storage facilities, but there is also an efficiency issue related therewith as stored LNG will tend to warm and vaporize over time creating a loss of the LNG fuel product. Further, safety may become an issue when larger amounts of LNG fuel product are stored.

[0010] In confronting the foregoing issues, various systems have been devised which attempt to produce LNG or CNG from feed gas on a smaller scale, in an effort to eliminate long-term storage issues and to reduce the capital and operating expenses associated with the liquefaction and/or compression of natural gas.

[0011] For example, small scale LNG plants have been devised to produce LNG at a pressure letdown station, wherein gas from a relatively high pressure transmission line is utilized to produce LNG and tail gases from the liquefaction process are directed into a single lower pressure downstream transmission line. However, such plants may only be suitable for pressure let down stations having a relatively high pressure difference between upstream and downstream transmission lines, or may be inefficient at pressure let down stations having relatively low pressure drops. In view of this, the production of LNG at certain existing let down stations may be impractical using existing LNG plants. Furthermore, the costs to design, engineer, and manufacture LNG plants for a variety of natural gas source locations, which may each supply NG at different gas conditions, such as at various temperatures and pressures, may make it impractical to build an LNG plant for smaller markets.

[0012] Additionally, since many sources of natural gas, such as residential or industrial service gas, are considered to be relatively "dirty," the requirement of providing "clean" or "pre-purified" gas is actually a requirement of implementing expensive and often complex filtration and purification systems prior to the liquefaction process. This requirement simply adds expense and complexity to the construction and operation of such liquefaction plants or facilities.

[0013] In view of the shortcomings in the art, it would be advantageous to provide a process, and a plant for carrying out such a process, of efficiently producing liquefied natural gas, such as on a small scale. More particularly, it would be advantageous to provide a system for producing liquefied natural gas from a source of relatively "dirty" or "unpurified" natural gas at various levels of inlet pressure and inlet temperature and the return of natural gas from the plant. Such a system or process may include various clean-up cycles which are integrated with the liquefaction cycle for purposes of efficiency. Further, it would be advantageous for the process and plant to be readily transportable using available sources of transportation over public roads and highways to other geographic locations. It would be advantageous for the process and plant be capable of being operated in a variety of geographical locations without substantially changing the process and apparatus of the plant.

[0014] It would be additionally advantageous to provide a plant for the liquefaction of natural gas which is relatively inexpensive to build and operate, and which desirably requires little or no operator oversight.

[0015] It would be advantageous to provide a plant for the liquefaction of natural gas which having a core module of substantially standardized components operably coupled in a substantially standardized manner and suitable for use in a wide variety of site conditions with minimal or no internal modification being required of the core module.

[0016] It would be additionally advantageous to provide such a plant which is easily transportable and which may be located and operated at existing sources of natural gas which are within or near populated communities, thus providing easy access for consumers of LNG fuel.

BRIEF SUMMARY

[0017] In some embodiments, a method of natural gas liquefaction may include liquefying natural gas from a first natural gas source with a first core module, and liquefying natural gas from at least a second natural gas source having a gas property different than a gas property of the first natural gas source with at least a second core module substantially identical to the first core module.

[0018] In additional embodiments, a method of designing a natural gas liquefaction plant may include utilizing a preconfigured core module design for a core module configured to receive source gas at site-independent predetermined input conditions, expel tail gas at site-independent predetermined outlet conditions, and liquefy natural gas. The method may further include designing a site-specific inlet module configured to provide source gas from a specific natural gas source to the core module at the fixed predetermined input conditions, and designing a site-specific outlet module configured to convey tail gas from the core module at the predetermined tail gas outlet conditions to a specific tail gas stream.

[0019] In further embodiments, a method of distributing liquid natural gas may include providing a plurality of substantially identical core modules to a plurality of gaseous natural gas source locations. The method may further include liquefying at least a portion of the gaseous natural gas from each of the plurality of gaseous natural gas sources with the plurality of substantially identical core modules to provide liquid natural gas at each of the plurality of gaseous natural gas source locations.

[0020] In additional embodiments, methods of natural gas liquefaction may comprise liquefying gaseous natural gas with a plurality of substantially identical core modules at a single site.

[0021] In yet further embodiments, a modular natural gas liquefaction plant may include a core module, an inlet module and an outlet module. The core module may include a processed natural gas inlet configured to receive gaseous natural gas at a site-independent predetermined pressure and temperature, a liquid natural gas outlet, and a tail gas outlet configured to expel a tail gas at a site-independent predetermined pressure and temperature. The inlet module may include a natural gas source inlet configured to receive gaseous natural gas at a temperature and pressure of a site-specific natural gas source; and a processed natural gas outlet configured to deliver gaseous natural gas to the processed natural gas inlet of the core module at the site-independent predetermined pressure and temperature. Finally, the outlet module may include a tail gas inlet configured to receive a tail gas from the tail gas outlet of the core module at the site-independent predetermined pressure and temperature; and a processed tail gas outlet configured to deliver the tail gas to a site-specific location at a site-specific pressure and temperature.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0022] The foregoing and other advantages of the invention will become apparent upon reading the following detailed description and upon reference to the drawings.

[0023] FIG. **1** is a schematic overview of a core module for a liquefaction plant according to an embodiment of the present invention.

[0024] FIG. **2** is a flow diagram depicting a site having a gas supply pipeline and a tail gas pipeline for a modular type liquefaction plant according to embodiments of the present invention.

[0025] FIG. **3** is a flow diagram depicting another site having a single gas supply pipeline that may be utilized to supply gas to and receive tail gas from a modular type liquefaction plant according to embodiments of the present invention.

DETAILED DESCRIPTION

[0026] A modular type liquefaction plant having a core module designed so that it may be used for a variety of site conditions, may be readily transported to site locations, and may be readily manufactured using common, substantially standardized components therein so as to be capable of use at a wide variety of site locations and conditions substantially without modification.

[0027] Illustrated in FIG. **1** is a schematic overview of a core module **2** for natural gas (NG) liquefaction according to an embodiment of the present invention. The core module **2** may include a primary gas inlet **4** coupled to a splitter **6**, and a primary gas outlet **8** coupled to a mixer **10**. A process stream **12**, a cooling stream **14**, and a transfer motive gas stream **16** may originate from the splitter **6** of the primary gas inlet **4** and the cooing stream **14**, as well as tail streams **26**, **30**, may be combined in the mixer **10** and directed out of the core module **2** through the primary gas outlet **8**.

[0028] As shown in FIG. **1**, the process stream **12** may be directed through a NG inlet **32** from the splitter **6**, and then directed through a primary heat exchanger **34** and an expansion valve **36**. The process stream **12** may then be directed though a gas-liquid separation tank **38**, a transfer tank **40**, a hydrocyclone **42** and a filter **44**. Finally, the process stream **12** may be directed through a splitter **46**, a valve **48**, a storage tank **50** and a liquid natural gas (LNG) outlet **52**.

[0029] As further shown in FIG. **1**, the cooling stream **14** may be directed through a cooling fluid inlet **54** from the splitter **6**, and then directed through a turbo compressor **56**, an ambient heat exchanger **58**, the primary heat exchanger **34**, a turbo expander **60**, and finally, through a cooling fluid outlet **62** and into the mixer **10**. Additionally, the transfer motive gas stream **16** may be directed through a transfer fluid inlet **64** from the splitter **6**, and then through an expansion valve **66** to the transfer tank **40**. In additional embodiments, the transfer motive gas stream **16** may originate from other suitable locations of the core module **2**. Optionally, the transfer motive gas stream **16** may also be directed through the primary heat exchanger **34**.

[0030] A first tail gas stream **30** may include a combination of streams from the core module **2**. For example, as shown in FIG. **1**, the first tail gas stream **30** may include a carbon dioxide management stream **22**, a separation chamber vent stream **18**, a transfer tank vent stream **20**, and a storage tank vent stream **24**. The carbon dioxide management stream **22** may be directed from an underflow outlet **82** of the hydrocyclone **42**, and then may be directed through a sublimation chamber **70**, the primary heat exchanger **34** and finally through a first tail gas outlet **72** into the mixer **10**. Additionally, the separation chamber vent stream **18** may be directed from a gas outlet of the gas liquid separation tank **38**, the transfer tank vent stream **20** may be directed from the transfer tank **40**, and a storage tank vent stream **24** may be directed from the storage tank **50**. The separation chamber vent stream **18**, the transfer tank vent stream **20**, and the storage tank vent stream **24** may then be directed through a mixer **74**, the heat exchanger **34**, a compressor **76**, and into the sublimation chamber **70** to be mixed with the carbon dioxide management stream **22** to form the first tail gas stream **30**.

[0031] Finally, as shown in FIG. **1**, a second tail gas stream **26** may be directed from an outlet of the splitter **46**. The second tail gas stream **26** may then be directed through a pump **78**, the heat exchanger **34**, and finally, through a second tail gas outlet **80** into the mixer **10**. In additional embodiments, the pump **78** may not be required and may not be included in the plant **10**. For example, sufficient pressure may be imparted to the process stream **12** within the transfer tank **40** by the transfer motive gas stream **16** such that the pump **78** may not be required and may not be included in the core module **2**.

[0032] In operation, a gaseous NG may be provided to the core module **2** through the primary gas inlet **4**, which may be divided by the splitter **6** into the cooling stream **14**, the process stream **12**, and the transfer motive stream **16**. The cooling stream **14** may be directed from the splitter **6** through the cooling fluid inlet **54** and then directed into the turbo compressor **56** to be compressed. The compressed cooling stream **14** may then exit the turbo compressor **56** and be directed into the ambient heat exchanger **58**, which may transfer heat from the cooling stream **14** to ambient air. Additionally, the cooling stream **14** may be directed through a first channel of the primary heat exchanger **34**, where it may be further cooled.

[0033] In some embodiments, the primary heat exchanger **34** may comprise a high performance aluminum multi-pass plate and fin type heat exchanger, such as may be purchased from Chart Industries Inc., 1 Infinity Corporate Centre Drive, Suite 300, Garfield, Heights, Ohio 44125, or other well known manufacturers of such equipment.

[0034] After passing through the primary heat exchanger **34**, the cooling stream **14** may be expanded and cooled in the turbo expander **60**. For example, the turbo expander **60** may comprise a turbo expander having a specific design for a mass flow rate, pressure level of gas, and temperature of gas to the inlet, such as may be purchased from GE Oil and Gas, 1333 West Loop South, Houston, Tex. 77027-9116, USA, or other well known manufacturers of such equipment. Additionally, the energy required to drive the turbo compressor **56** may be provided by the turbo expander **60**, such as by the turbo expander **60** being directly connected to the turbo compressor **56** or by the turbo expander **60** driving an electrical generator (not shown) to produce electrical energy to drive an electrical motor (not shown) that may be connected to the turbo compressor **56**. The cooled cooling stream **14** may then be directed through a second channel of the primary heat exchanger **34** and then through the cooling fluid outlet **62** into the mixer **10** to be directed out of the core module **2** through the primary gas outlet **8**.

[0035] Meanwhile, a gaseous NG stream may be directed from the splitter **6** into the NG inlet **32** to provide the process stream **12** to the core module **2** and the process stream **12** may then be directed through a third channel of the primary heat exchanger **34**. Heat from the process stream **12** may be transferred to the cooling stream **14** within the primary heat exchanger **34** and the process stream **12** may exit the primary heat exchanger **34** in a cooled gaseous state. The process stream **12** may then be directed through the expansion valve **36**, such as a Joule-Thomson expansion valve, wherein the process stream **12** may be expanded and cooled to form a liquid natural gas (LNG) portion and a gaseous NG portion. Additionally, carbon dioxide (CO_2) that may be contained within the process stream **12** may become solidified and suspended within the LNG portion, as carbon dioxide has a higher freezing temperature than methane (CH_4), which is the primary component of NG. The LNG portion and the gaseous portion may be directed into the gas-liquid separation tank **38**, and the LNG portion may be directed out of the separation tank **38** as a LNG process stream **12**, which may then be directed into the transfer tank **40**. A transfer motive gas stream **16** may then be directed through the transfer motive gas inlet **64** from the splitter **6** through the valve **66**, which may be utilized to regulate the pressure of the transfer motive gas stream **16** prior to being directed into the transfer tank **40**. The transfer motive gas stream **16** may facilitate the transfer of the liquid NG process stream **12** through the hydrocyclone **42**, such as may be available, for example, from Krebs Engineering of Tucson, Ariz., wherein the solid CO_2 may be separated from the liquid NG process stream **12**.

[0036] Optionally, a separate transfer tank **40** may not be used and instead a portion of the separation tank **38** may be utilized as a transfer tank to transfer the process stream **12** into the hydrocyclone **42**. In additional embodiments, a pump may be utilized to transfer the process stream from the separation tank **38** into the hydrocyclone. A pump may provide certain advantages, as it may provide a constant system flow, when compared to a batch process utilizing a transfer tank. However, a transfer tank configuration, such as shown in FIG. **1**, may provide a more reliable process stream **12** flow. In yet further embodiments, a plurality of transfer tanks **40** may be utilized; optionally, a plurality of hydrocyclones **42** may also be utilized. Such a configuration may improve flow regularity of the process stream **12** through the core module **2** while maintaining a reliable flow of the process stream **12**. Additionally, an accumulator (not shown) may be provided and the transfer motive gas stream **16** may be accumulated in the accumulator prior to being directed into the transfer tank **40** to facilitate an expedient transfer of the process stream **12** out of the transfer tank **40** and through the hydrocyclone **42**.

[0037] In the hydrocyclone **42**, a slurry including the solid CO_2 from the LNG process stream **12** may be directed through an underflow outlet **82** and the LNG process stream **12** may be directed through an overflow outlet **84**. The LNG process stream **12** may then be directed through the filter **44**, which may remove any remaining CO_2 or other impurities, which may be removed from the system through a filter outlet **86**, such as during a cleaning process. In some embodiments, the filter **44** may comprise one screen filter or a plurality of screen filters that are placed in parallel. A substantially pure LNG process stream **12**, such as substantially pure liquid CH4, may then exit the filter **44** and be directed into a LNG process stream **12** and a secondary LNG stream that may form the second tail stream **26**. The LNG process stream **12** may be directed through the valve **48** and into the storage tank **50**, wherein it may be withdrawn for use through the LNG outlet **52**, such as to a vehicle which is powered by LNG or into a transport vehicle.

[0038] Additionally, the CO_2 slurry in the hydrocyclone **42** may be directed through the underflow outlet **82** to form the CO_2 management stream **22** and be directed to the CO_2 sublimation chamber **70** to sublimate the solid CO_2 for removal from the core module **2**. Additionally, the separation chamber vent stream **18**, the transfer tank vent stream **20** and the storage tank vent stream **24** may be combined in the mixer **74** to provide a gas stream **28** that may be used to sublimate the CO_2 management stream **22**. The gas stream **28** may be relatively cool upon exiting the mixer **74** and may be directed through a fourth channel of the primary heat exchanger **34** to extract heat from the process stream **12** in the third channel of the primary heat exchanger **34**. The gas stream **28** may then be directed through the compressor **76** to further pressurize and warm the gas stream **28** prior to directing the gas stream **28** into the CO_2 sublimation chamber **70** to sublimate the CO_2 of the CO_2 management stream **22** from the underflow outlet **82** of the hydrocyclone **42**. In some embodiments, a heat exchanger, such as described in application Ser. No. 11/855,071, filed Sep. 13, 2007, titled Heat Exchanger and Associated Method, owned by the assignee of the present invention, the disclosure thereof previously incorporated by reference in its entirely herein, may be utilized as the sublimation chamber **70**. In further embodiments, a portion of the gas stream **28**, such as an excess flow portion, may be directed through a tee (not shown) and into the mixer **10**, rather than being directed into the CO_2 sublimation chamber **70**.

[0039] The combined gaseous CO_2 from the CO_2 management stream **22** and the gases from the stream **28** may then exit the sublimation chamber **70** as the first tail gas stream **30**, which may be relatively cool. For example, the first tail gas stream **30** may be just above the CO_2 sublimation temperature upon exiting the sublimation chamber **70**. The first tail gas stream **30** may then be directed through a fifth channel of the primary heat exchanger **34** to extract heat from the process stream **12** in the third channel prior to entering the mixer **8** through the first tail gas outlet **72** and being directed out of the core module **2** through the primary gas outlet **8**.

[0040] Finally, the second tail gas stream **26**, which may initially comprise a secondary substantially pure LNG stream from the splitter **46**, may be directed through the pump **78**. In additional embodiments, the pump **78** may not be required and may not be included in the core module **2**. For example, sufficient pressure may be imparted to the process stream **12** within the transfer tank **40** by the transfer motive gas stream **16** such that the pump **78** may not be required and may not be included in the core module **2**. The second tail gas stream **26** may then be directed through a sixth channel of the primary heat exchanger **34**, where it may extract heat from the process stream **12** in the third channel, and may become vaporized to form gaseous NG. The second tail stream **26** may then be directed into the mixer **10** via the second tail gas outlet **80** and out of the core module **2** through the primary gas outlet **8**.

[0041] In some embodiments, as the process stream **12** progresses through the primary heat exchanger **34**, the process stream **12** may be cooled first by the cooling stream **14**, which may extract about two-thirds (⅔) of the heat to be removed from the process stream **12** within the heat exchanger **34**. Remaining cooling of the process stream **12** within the primary heat exchanger **34** may then be accomplished by the transfer of heat from the process stream **12** to the second tail gas stream **26**. In view of this, the amount of flow that is directed into the second tail gas stream **26** may be regulated to achieve a particular amount of heat extraction from the process stream **12** within the heat exchanger **34**.

[0042] In some embodiments, the core module **2** may be configured to utilize a desired site-independent predetermined inlet gas condition, such as a desired site-independent predetermined inlet pressure level and a desired site-independent predetermined inlet temperature level, for the source gas directed into the primary gas inlet **4**. In other words, the core module **2** may be configured to receive a gas into the primary gas inlet **4** at a pressure and temperature level that may each be selected independent of a specific source gas pressure and temperature at a site at which the core module **2** is to be utilized. Additionally, the core module **2** may be configured to utilize a desired site-independent predetermined outlet gas condition, such as a desired site-independent predetermined outlet pressure level and a desired site-independent predetermined outlet temperature level, for the tail gas directed out of the primary gas outlet **8**.

[0043] As the core module **2** may be designed and manufactured independent of a specific site **88**, a modular type natural gas liquefaction plant for a specific site **88** may include a customized inlet module **90** and a customized outlet module **92** in addition to the preconfigured core module **2**, as shown in FIGS. **2** and **3**. The inlet module **90** may include an inlet **94** to receive a source gas, such as gaseous NG, from the specific site **88**, such as from a NG supply pipeline **96**, into the inlet module **90**. Upon entering the inlet module **90** the source gas may be processed, such as by one or more of compression, expansion, cooling, heating, dehydration, and filtration using conventional methods and devices, to meet the site-independent predetermined inlet gas conditions for the core module **2**. The source gas may then be directed into the primary gas inlet **4** of the core module **2** at the site-independent predetermined inlet conditions, such as a site-independent predetermined temperature and pressure.

[0044] Additionally, the outlet module **92** may be configured to receive the tail gas stream, including the combined first tail gas stream **30**, second tail gas stream **26**, and cooling stream **14**, directed out of the primary gas outlet **8** of the core module **2**. Upon entering the outlet module **92** the tail gas stream may be processed, such as by one or more of compression, expansion, cooling, and heating using conventional methods and devices, to meet the site **88** specific tail gas requirements. The tail gas may then be directed out of an outlet **98** of the outlet module **92** to a site-specific location at a site-specific pressure and temperature. For example, a site-specific location for the tail gas may be a relatively low pressure NG pipeline **100**, such as shown in FIG. **2**, and the tail gas may be processed to an appropriate relatively low pressure. For another example, the site-specific location for the tail gas may be the same NG supply pipeline **96** that provides the NG source gas, such as shown in FIG. **3**, and the tail gases may require compression within the outlet module to provide the tail gas to the supply pipeline **96** at an appropriate pressure.

[0045] In view of this approach to plant design and configuration, the inlet module **90** and the outlet module **92** may be configured to enable a preconfigured core module **2** to operate at any number of specific sites, which may each provide a source gas having different properties, such as gas composition, gas pressure, and gas temperature, and may have unique tail gas requirements. In some cases, one or more of the source gas conditions and the required tail gas conditions for a specific site may coincidentally meet one or more of the site-independent predetermined gas conditions for the primary gas inlet **4** and primary gas outlet **8** of the core module **2**. In such a case, one or more of the inlet module **90** and the outlet module **92** may simply be configured as a gas conduit.

[0046] The inlet module **90** and the outlet module **92**, allow a specific site **88** to be adapted to the core module **2**, and the core module **2** may be utilized at any number of sites **88** with minimal or no internal modifications required. In view of the foregoing, a core module **2** may be mass produced and then delivered to numerous sites.

[0047] Although a common design between numerous core modules **2** may not necessarily provide the most energy efficient system at every site, when compared to custom site-specific plants, a common design for core module **2** may result in other efficiencies, improved safety, a reduction in engineering and design cost, a reduction in maintenance cost, improved reliability and a reduction in initial investment cost that may outweigh any inefficiencies that may exist at an individual site.

[0048] The core module **2** may be configured with some flexibility in its mechanical design, such as shown in FIG. **1**, to allow accommodation of somewhat varying input and output temperatures and pressures without necessitating a replacement of any of the physical components of the core module **2**. However, the plant may be designed and configured for specific site-independent predetermined gas conditions for the primary gas inlet **4** and the primary gas outlet **5** selected for efficiency.

[0049] Provided for example and not limitation, the core module **2** may be configured to utilize an inlet pressure level of about 800 psia and a inlet temperature level of about 50° F. to about 120° F. Extensive modeling has suggested that approximately 800 psia may be the most efficient incoming pressure. Additionally, for example and not limitation, the desired predetermined specified outlet pressure level of the core module **2** may be about 100 psia. In general, the lower the outlet pressure level, the higher the production rate. However, from studying location data the inventors of the present invention have discovered that ideal low pressure lines with enough available flow to accommodate tail gas from the core module **2** are few and may be difficult to access. In view of this, as the designed tail gas outlet pressure of the core module **2** is increased, more potential natural gas liquefaction plant sites become available. It is believed at the present time that selection of a 100 psia outlet pressure may be a good compromise between the relatively few sites with available lower pressure pipelines and the more readily available sites with available higher pressure pipelines. This may also be a good outlet pressure to provide to an outlet module **92** having a compressor to increase the gas pressure for a higher pressure pipeline, as it may result in a relatively low compression ratio. Lower compression ratios require less power and may be more economical. Furthermore, an outlet or exit pressure of about 100 psia may provide efficiencies for the cooling stream **14** of the core module **2**, since a higher gas pressure may result in a lower critical temperature for certain components of the gas, such as CO_2, which may allow the cooling stream **14** to reach a lower temperature.

[0050] While these may be desired pressure levels and temperature levels for the core module **2**, such may vary without substantially impacting the operation of the core module **2** because the core module **2** described herein has the flexibility to accommodate such varying conditions of inlet gas pressure level and temperature level as well as outlet gas pressure level therefrom.

[0051] In additional embodiments, the core module **2** may not include the primary gas inlet **4**, the splitter **6**, the primary gas outlet **8** and the mixer **10**. Instead, the inlet gas streams **12**, **14**, **16** may be maintained separately and the outlet gas streams **14**, **26**, **30** may also be maintained separately, which may provide a more flexible core module **2**, such as described in U.S. patent application Ser. No. ______, filed on even date herewith, for METHODS OF NATURAL GAS LIQUEFACTION AND NATURAL GAS LIQUEFACTION PLANTS UTILIZING MULTIPLE AND VARYING GAS STREAMS (Attorney Docket No. 2939-9179US (BA-350)), previously incorporated by reference herein in its entirety.

[0052] The core module **2** may have a relatively small physical size and may be readily transported from one geographic location to another. Such a compact design may allow core modules **2** to be mass produced at one or more locations and transported to various sites, such as by conventional rail and roadway transport. Furthermore, the mass production of core modules **2** may allow components to be purchased and manufactured in relatively high numbers, which may reduce the cost of components and may make it economically feasible to design unique and especially efficient components for the core module **2**. Mass production may result in replacement components being relatively inexpensive, resulting in lower maintenance cost. Furthermore, if a core module **2** at a site became damaged and required extensive repair or replacement, the damaged core module **2** could be replaced with another substantially identical core module **2** that is operable relatively quickly and cost effectively. Additional and various other advantages may also result from the mass production of substantially identical core modules **2**.

[0053] Modular LNG plants utilizing substantially identical core modules **2** may also be utilized to more efficiently and cost effectively distribute LNG. It may be relatively expensive to ship LNG from a large plant, such as by truck, to each point-of-use location where it is required. It may also be relatively expensive and difficult to provide infrastructure, such as a LNG pipeline, to transport LNG from a large plant to various distant locations. However, a plurality of modular LNG plants utilizing substantially identical core modules **2** may be located at or near various LNG point-of-use locations, such as LNG vehicle fueling stations, having existing gaseous NG sources, which may have various and different pressures and temperatures, and produce LNG from the gaseous NG sources at or near the LNG point-of-use locations. In view of this, existing gaseous NG infrastructure may be utilized with core modules **2** according to the present invention to distribute LNG in a relatively efficient and cost effective manner.

[0054] In some embodiments, the core module **2** may be configured as a "small-scale" natural gas liquefaction core module **2** which is coupled to a source of natural gas such as a pipeline **96**, although other sources, such as a well head, are contemplated as being equally suitable. The term "small-scale" is used to differentiate from a larger-scale plant having the capacity of producing, for example 70,000 gallons of LNG or more per day. In comparison, the presently disclosed liquefaction plant may have a capacity of producing, for example, approximately 30,000 gallons of LNG a day but may be scaled for a different output as needed and is not limited to small-scale operations or plants. Additionally, the liquefaction core module **2** of the present invention may be considerably smaller in size than a large-scale plant and may be transported from one site to another, as previously described herein. However, the core module **2** may also be configured as a large-scale plant if desired. A core module **2** may also be relatively inexpensive to build and operate, and may be configured to require little or no operator oversight.

[0055] In further embodiments, a plurality of core modules **2** may be utilized at a single site, such as at sites that have a relatively large LNG demand, sites having variable demand or at critical demand sites. In some embodiments, a site having a relatively high LNG demand may include a plurality of core modules **2**, each producing LNG simultaneously to meet the demand. Provided for example and not limitation, a site having a LNG demand of about 120,000 gallons a day may utilize four substantially identical core modules **2**, each configured to produce about 30,000 gallons of LNG a day. Additionally, the site may include one or more additional substantially identical core modules **2**, which may be rotated into use at the site, which may allow individual core modules **2** to be shut down for cleaning, servicing or repairs while backup core modules **2** are utilized to make up for the lost LNG production, thus allowing the LNG demand to be met at all times. If a site has a particularly critical LNG demand, a greater redundancy in core modules **2**, and thus backup LNG production capacity, may be provided. Additionally, if a site has variable demand, as demand increases additional core modules **2** at the site may be activated and utilized to meet the increased demand, likewise, the additional core modules **2** may be deactivated as demand decreases.

[0056] In additional embodiments, core modules **2** may be designed in several sizes or capacities, and core modules having different sizes and capacities may be combined in various combinations to meet any particular sites LNG demand.

[0057] The core module **2** and methods illustrated and described herein may include the use of any well known apparatus and methods, such as within the inlet module **90**, to remove carbon dioxide, nitrogen, oxygen, ethane, etc. from the natural gas supply before entry into the core module **2**. Additionally, if the source of natural gas has little carbon dioxide, nitrogen, oxygen, ethane, etc., the use of hydrocyclones and carbon dioxide sublimation in the liquefaction process and core module **2** may not be needed and may not be included.

[0058] While the invention may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention includes all modifications, equivalents, and alternatives falling within the scope of the invention as defined by the following appended claims.

1. A method of natural gas liquefaction, the method comprising:

liquefying natural gas from a first natural gas source with a first core module; and liquefying natural gas from at least a second natural gas source having a gas property different than a gas property of the first natural gas source with at least a second core module substantially identical to the first core module.

2. The method of claim **1**, wherein liquefying natural gas from at least a second natural gas source having a gas property different than a gas property of the first natural gas source comprises liquefying natural gas from at least a second natural gas source having a gas pressure level different than a gas pressure level of the first natural gas source.

3. The method of claim **1**, further comprising increasing the gas pressure level of the natural gas from the at least a second natural gas source with an inlet module prior to directing the natural gas from the at least a second natural gas source into the at least a second core module for liquefaction.

4. The method of claim **3**, further comprising directing the natural gas from the first natural gas source into the first core module and directing the natural gas from the at least a second natural gas source into the at least a second core module at substantially the same pressure.

5. The method of claim **4**, further comprising directing the natural gas from the first natural gas source into the first core module and directing the natural gas from the at least a second natural gas source into the at least a second core module at about 800 psia.

6. The method of claim **1**, wherein liquefying natural gas from at least a second natural gas source having a gas property different than a gas property of the first natural gas source comprises liquefying natural gas from at least a second natural gas source having a gas temperature different than a gas temperature of the first natural gas source.

7. The method of claim **6**, further comprising decreasing the gas temperature level of the natural gas from the at least a second natural gas source with an inlet module prior to directing the natural gas from the at least a second natural gas source into the at least a second core module for liquefaction.

8. The method of claim **6**, further comprising increasing the gas temperature level of the natural gas from the at least a second natural gas source with an inlet module prior to directing the natural gas from the at least a second natural gas source into the at least a second core module for liquefaction.

9. The method of claim **8**, further comprising directing the natural gas from the first natural gas source into the first core module and directing the natural gas from the at least a second natural gas source into the at least a second core module at substantially the same temperature.

10. The method of claim **9**, further comprising directing the natural gas from the first natural gas source into the first core module and directing the natural gas from the at least a second natural gas source into the at least a second core module at a temperature level between about 50° F. and about 120° F.

11. The method of claim **1**, further comprising:

processing a first tail gas expelled from the first core module with a first outlet module to change at least one of the pressure level and the temperature level of the first tail gas; and

processing a second tail gas expelled from the at least a second core module with a second outlet module to change at least one of the pressure level and the temperature level of the second tail gas.

12. The method of claim **11**, further comprising expelling the first tail from the first core module and the second tail gas from the at least a second core module at substantially the same temperature and pressure.

13. The method of claim **12**, further comprising expelling the first tail from the first core module and the second tail gas from the at least a second core module at a pressure level of about 100 psia.

14. The method of claim **1**, further comprising:

expelling a first tail gas comprising carbon dioxide out of the first core module; and

expelling a second tail gas comprising carbon dioxide out of the at least a second core module.

15. A method of designing a natural gas liquefaction plant, the method comprising:

utilizing a preconfigured core module design for a core module configured to receive source gas at site-independent predetermined input conditions, expel tail gas at site-independent predetermined outlet conditions, and liquefy natural gas;

designing a site-specific inlet module configured to provide source gas from a specific natural gas source to the core module at the fixed predetermined input conditions; and

designing a site-specific outlet module configured to convey tail gas from the core module at the predetermined tail gas outlet conditions to a specific tail gas stream.

16. The method of claim **15**, wherein designing a site-specific inlet module configured to provide source gas from a specific natural gas source to the core module at the fixed predetermined input conditions further comprises designing a site-specific inlet module configured to provide source gas from a specific natural gas source to the core module at a pressure level of about 800 psia and at a temperature level of about 50° F. and about 120° F.

17. The method of claim **15**, wherein designing a site-specific outlet module configured to convey tail gas from the core module at the predetermined tail gas outlet conditions to a specific tail gas stream further comprises designing a site-specific outlet module configured to convey tail gas from the core module at a pressure level of about 100 psia.

18. The method of claim **15**, wherein utilizing a preconfigured core module design for a core module configured to liquefy natural gas further comprises utilizing a preconfigured core module design for a core module configured to liquefy natural gas by:

cooling a gaseous natural gas process stream by transferring heat from a gaseous natural gas process stream to a cooling stream; and

expanding the cooled gaseous natural gas process stream to form a liquid natural gas process stream.

19. A method of distributing liquid natural gas, the method comprising:

providing a plurality of natural gas liquefaction plants comprising substantially identical core modules to a plurality of gaseous natural gas source locations; and

liquefying at least a portion of the gaseous natural gas from each of the plurality of gaseous natural gas sources with the plurality of natural gas liquefaction plants to provide liquid natural gas at each of the plurality of gaseous natural gas source locations.

20. The method of claim **19**, wherein providing a plurality of natural gas liquefaction plants comprising substantially identical core modules to a plurality of gaseous natural gas source locations further comprises providing a plurality of natural gas liquefaction plants comprising substantially identical core modules to a plurality of gaseous natural gas sources comprising gaseous natural gas sources having various gas properties.

21. The method of claim **19**, further comprising locating the plurality of natural gas liquefaction plants comprising substantially identical core modules at a plurality of liquid natural gas point-of-use locations.

22. A modular natural gas liquefaction plant comprising:

a core module comprising:

a processed natural gas inlet configured to receive gaseous natural gas at a site-independent predetermined pressure and temperature;

a liquid natural gas outlet; and

a tail gas outlet configured to expel a tail gas at a site-independent predetermined pressure and temperature;

an inlet module comprising:

a natural gas source inlet configured to receive gaseous natural gas at a temperature and pressure of a site-specific natural gas source; and

a processed natural gas outlet configured to deliver gaseous natural gas to the processed natural gas inlet of the core module at the site-independent predetermined pressure and temperature; and

an outlet module comprising:

a tail gas inlet configured to receive a tail gas from the tail gas outlet of the core module at the site-independent predetermined pressure and temperature; and

a processed tail gas outlet configured to deliver the tail gas to a site-specific location at a site-specific pressure and temperature.

23. A method of natural gas liquefaction, comprising liquefying gaseous natural gas with a plurality of substantially identical core modules at a single site.

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