



- (51) **International Patent Classification:**
F25J 3/04 (2006.01)
- (21) **International Application Number:**
PCT/US2014/016712
- (22) **International Filing Date:**
17 February 2014 (17.02.2014)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
61/772,435 4 March 2013 (04.03.2013) US
- (71) **Applicant** (*for all designated States except US*): **EXXON-MOBIL UPSTREAM RESEARCH COMPANY** [US/US]; CORP-URC-SW359, P.O. Box 2189, Houston, TX 77252-2189 (US).
- (72) **Inventors; and**
- (71) **Applicants** (*for US only*): **BOHRA, Lalit, K.** [IN/US]; 6731 Honeycrest Lane, Spring, TX 77389 (US). **SITES, Angus, O.** [US/US]; 2410 Randal Point Court, Spring, TX 77388 (US). **DHANUKA, Sulabh, K.** [IN/US]; 2423 Haverhill Drive, Houston, TX 77008 (US).
- (74) **Agents:** **SULLIVAN, Jamie, L.** et al.; ExxonMobil Upstream Research Company, CORP-URC-SW359, P.O. Box 2189, Houston, TX 77252-2189 (US).
- (81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,

BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

- *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) **Title:** REGASIFICATION PLANT

(57) **Abstract:** Methods and system are provided for regasifying liquefied natural gas (LNG). An exemplary method disclosed includes flowing at least a portion of an LNG stream through an air separation unit (ASU) to form at least a portion of a natural gas (NG) stream. Heat is removed from an airflow in the ASU to separate an oxygen stream from the airflow. The oxygen stream and a fuel stream are combusted in a power plant.



REGASIFICATION PLANT

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of United States Patent Application
5 61/772,435 filed March 4, 2013 entitled REGASIFICATION PLANT, the entirety of which
is incorporated by reference herein.

FIELD OF THE INVENTION

[0002] Exemplary embodiments of the present techniques relate to a liquefied natural gas
terminal with flexible capability to provide pipelined natural gas, electricity to a grid, or both.

10 BACKGROUND

[0003] Large volumes of natural gas (i.e., primarily methane) are located in remote areas
of the world. This gas has significant value if it can be economically transported to market.
Where the gas reserves are located in reasonable proximity to a market and the terrain
between the two locations permits, the gas is typically produced and then transported to
15 market through submerged and/or land-based pipelines. However, when gas is produced in
locations where laying a pipeline is infeasible or economically prohibitive, other techniques
must be used for getting this gas to market.

[0004] A commonly used technique for non-pipeline transport of gas involves liquefying
the gas at or near the production site and then transporting the liquefied natural gas to market
20 in specially-designed storage tanks aboard transport vessels. The natural gas is cooled and
condensed to a liquid state to produce liquefied natural gas ("LNG"). LNG is often
transported at substantially atmospheric pressure and at temperatures of about -162 °C (-260
°F.), thereby significantly increasing the amount of gas which can be stored in a particular
storage tank on a transport vessel. Once a LNG transport vessel reaches its destination, the
25 LNG is typically off-loaded into other storage tanks from which the LNG can then be
revaporized as needed and transported as a gas to end users through pipelines or the like.
Natural gas is used for various purposes one of them being power generation. LNG has been
an increasingly popular transportation method to supply major energy-consuming nations
with natural gas.

30 [0005] During the regasification process, natural gas temperature changes from about -
162 °C to up to about 15 °C depending on sales specification. Required heat for

regasification is typically supplied by burning some of the product natural gas in fuel-fired vaporizers such as Submerged Combustion Vaporizers (SCVs) or Shell-and-Tube Vaporizers (STVs) with Fired Heaters. These fuel-fired vaporizers consume about 1.5 – 2.0% of product natural gas as the fuel. The fuel consumption not only results in large operating expenses by consuming some of the product itself but also in large environmental emissions in the form of CO₂ and NO_x. Using other sources of heat such as sea water and ambient air may reduce the terminal emissions but these have their own limitations. For example, use of sea water requires large capital investment and may adversely affect marine life due to the very large quantities of sea water required and the cold temperature of the discharge. At many locations, it is almost impossible to obtain permit to use sea water from regulatory authorities. Use of ambient air heat may be a viable option only in hot climates; even there benefit is greatly reduced by daily and seasonal variation in temperature and humidity.

[0006] The general methods discussed above utilize various heat sources to capture the cold contained in LNG, which could be used for reducing emissions, improving process efficiencies and economics of the LNG receiving terminal. Therefore, research efforts have focused on finding methods that not only reduce fuel consumption thereby reducing operating expenses and emissions associated with LNG regasification process, for example, by utilizing the LNG cold.

[0007] Several methods have been proposed in the prior art to address the issues of reducing emissions, and to use LNG cold to some advantage. One such method includes integrating LNG regasification with power generation. One efficient power generation method is the combined cycle power plant (CCGT). A CCGT plant includes gas turbine generator (GTG), which may further include compressors, combustors, gas turbines (GT), and the like. A heat recovery unit (HRU) can then be used to recover the exhaust heat from the gas turbine. An example of an HRU is a heat recovery steam generator (HRSG). The HRSG uses exhaust heat from the GTs for steam generation, and then sends the steam through a steam turbine generator (STG), and steam condenser. The steam condenser may use cooling from the LNG regasification for the condensation. Further, CCGT can include a cooling tower to provide coolant to a steam condenser.

[0008] The use of LNG cold to cool the inlet air in a gas turbine based power plant or condensing steam exiting steam turbine from a combined cycle power plant has been disclosed in the art. For example, U.S. Patent Application Publication No. 2008/0190106, by Mak, discloses power generation integrated with LNG regasification. The cold from the

LNG is used in a combined power plant to increase power output. In configurations, a first stage LNG cold provides cooling to an open or closed power cycle. A portion of the LNG is vaporized in the first stage. In a second stage, the cold from the LNG provides cooling for a heat transfer medium that is used to provide refrigeration for the cooling water to a steam power turbine and for an air intake chiller of a combustion turbine in the power plant.

[0009] U.S. Patent Application Publication No. 2005/0223712 by Briesch, et al., discloses using the vaporization of LNG to increase efficiency in power cycles. Inlet air chilling for a gas turbine is provided by the vaporization of the LNG. The cycle uses regeneration for preheating of combustor air. The process offers the potential efficiencies for the gas turbine cycle in excess of 60 %. The systems and methods permit the vaporization of LNG using ambient air, with the resulting super cooled air being easier to compress. In alternative embodiments, the vaporization of the LNG may be used as part of a bottoming cycle to increase the efficiencies of the gas turbine system.

[0010] U.S. Patent Application Publication No. 2003/0005698 by Keller discloses a process and system for LNG regasification. The system for vaporizing the LNG utilizes the residual cooling capacity of the LNG to condense the working fluid of a power producing cycle. The LNG can also chill liquids that are used in a direct-contact heat transfer system to cool air. The cold air is used to supply air to a combustion gas turbine operating in conjunction with a combined cycle power plant.

[0011] U.S. Patent No. 6,367,258 to Wen, et al., discloses vaporizing LNG in a combined cycle power plant. The efficiency of the combined cycle generation plant can be increased by using the vaporization of cold liquid including liquefied natural gas ("LNG") or liquefied petroleum gas (LPG). The vaporization is assisted by circulating a warm heat transfer fluid to transfer heat to a LNG/LPG vaporizer. The heat transfer fluid is chilled by LNG/LPG cold liquid vaporization and warmed by heat from a gas turbine. The heat transfer fluid absorbs heat from the air intake of a gas turbine and from a secondary heat transfer fluid circulating in a combined cycle power plant.

[0012] There is potential to eliminate fuel consumption associated with LNG regasification if a large enough power plant could be installed at the LNG regasification location. This scheme also improves efficiency of the power plant and the power output by cooling the turbine inlet air and providing a colder cooling medium to the steam turbine condenser. LNG cold may also be used in the intercoolers for the compressor of the GTG.

[0013] Another method to reduce emissions from a LNG terminal is use of ambient air heat for LNG regasification. Since use of ambient air heat reduces fuel consumption, the terminal economics may improve considerably. There are multiple types of ambient air vaporizers, including, for example, a direct type (both natural and forced draft), a fin-fan
5 (similar to air coolers), and a warming tower (also known as a “reverse cooling tower” or “heating tower”). The use of a warming tower has been described in prior art for LNG regasification.

[0014] For example, U.S. Patent No. 6,644,041, to Eyermann, discloses the vaporization of liquefied natural gas using a water tower. A temperature of a water stream may be
10 increased in the water tower. The warmed water can be passed through a first heat exchanger, and a circulating fluid may also be passed through the first heat exchanger so as to transfer heat from the warmed water into the circulating fluid. The LNG may be passed into a second heat exchanger, and the heated circulating fluid from the first heat exchanger may be passed through the second heat exchanger so as to transfer heat from the circulating fluid
15 to the LNG gas. The vaporized natural gas is discharged from the second heat exchanger.

[0015] Further, U.S. Patent No. 7,137,623 to Mockry, et al., discloses a heating tower that isolates outlet and inlet air. The heating tower may be used to heat a fluid by drawing an air stream into the heating tower through an inlet and passing the air stream over a fill medium. A fluid is passed over the fill medium along with discharging the air stream from
20 the heating tower through an outlet. The method further includes isolating the inlet air stream from the outlet air stream.

[0016] In the techniques discussed above, a power plant integrated with a LNG regasification process can decrease emissions and utilize LNG cold, while use of a warming tower for LNG regasification addresses only emissions issue. However, the size of a power
25 plant will be very large to fully utilize the cold from the LNG. For example, for 2 BCFD (billion cubic feet per day) of natural gas sales may require that the power plant be around 500 MW to utilize the cold. This size of plant would represent a very large capital expenditure. Further, a large market would be needed for the electricity produced by the plant.

30 [0017] Both the power plant and warming tower options become less attractive if there is not enough demand for natural gas, which may occur seasonally. Less demand for natural gas means there is less cold available from the LNG. Less available cold reduces the operational efficiency of installed equipment. The use of a warming tower can be further

constrained by prevailing ambient conditions, such as temperature and humidity. Therefore, both of the above mentioned techniques provide only partial solutions without any flexibility in utilizing LNG cold.

[0018] Related information may be found in U.S. Patent Nos. 5,295,350; 5,457,951; 5 6,324,867; 6,367,258; 6,374,591; 7,299,619; and 7,644,573. Further information may also be found in U.S. Patent Application Publication Nos. 2003/0005698, 2008/0307789, 2008/0034727, 2008/0047280, 2008/0178611, 2008/0190106, 2008/0250795, 2008/0276617, and 2008/0307789. Further information may also be found in Rosetta, M.J., and Himmelberger, "Integrating Ambient Air Vaporization Technology with Waste Heat 10 Recovery – A Fresh Approach to LNG Vaporization," presented at the 85th annual convention of the Gas Processors of America (GPA 2006), Grapevine, Texas, March 5-8, 2006; Cho, J.H.; Ebbert, D., Kotzot, H., and Durr, C., "Marrying LNG and Power Generation," *Energy Markets*; Oct/Nov 2005; 10, 8; ABI/INFORM Trade & Industry, p. 28; Rajeev Nanda and John Rizopoulos, "Utilizing Air Based Technologies as Heat Source for 15 LNG Vaporization," presented at the 86th Annual convention of the Gas Processors of America (GPA 2007), March 11-14, 2007, San Antonio, TX.

SUMMARY

[0019] An embodiment disclosed herein provides a method for regasifying liquefied natural gas (LNG). The method includes flowing at least a portion of an LNG stream through 20 an air separation unit (ASU) to form at least a portion of a natural gas (NG) stream. Heat is removed from an airflow in the ASU to separate an oxygen stream from the airflow. The oxygen stream and a fuel stream are combusted in a power plant.

[0020] Another embodiment provides a system for regasifying liquefied natural gas. The system includes an air separation unit configured to utilize cold from a portion of a stream of 25 liquefied natural gas (LNG) to cryogenically distill an air stream to produce an oxygen stream and a nitrogen stream, forming a natural gas (NG) stream. The system also includes a power plant configured to combust the oxygen stream with a fuel stream.

[0021] Another embodiment provides a method for cryogenically distilling a gas mixture. The method includes compressing the gas mixture and flowing the gas mixture through a 30 chiller to cool the gas mixture and liquefy at least a portion of the gas mixture. A liquefied natural gas is flowed through the chiller from the gas mixture to remove heat from the gas mixture. The cooled gas mixture is flowed into a cryogenic separation column. A product

gas mixture is removed from an upper section of the cryogenic separation column. A product liquid is removed from a lower section of the cryogenic separation column.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The advantages of the present techniques are better understood by referring to the following detailed description and the attached drawings, in which:

[0023] Fig. 1 is a block diagram of a LNG terminal that incorporates a power plant, illustrating the use of cold from the LNG to purify an air stream for use in the power plant;

[0024] Fig. 2 is a block diagram of another LNG terminal that incorporates a power plant, illustrating the use of cold from the LNG to liquefy product stream for sale;

[0025] Fig. 3 is a process flow diagram of a LNG regasification method that can be used in the systems discussed above;

[0026] Fig. 4 is a simplified process flow diagram of a combined plant having an ASU that provides LNG regasification and a power plant that combusts fuel with oxygen generated in the ASU;

[0027] Fig. 5 is a simplified process flow diagram of a combined plant having an ASU that provides LNG regasification and a power plant that combusts fuel with oxygen generated in the ASU;

[0028] Fig. 6 is a simplified process flow diagram of an air separation unit (ASU) that may be used in embodiments; and

[0029] Figs. 7A and 7B are a simplified process flow diagram of a power plant that can be used in embodiments.

DETAILED DESCRIPTION

[0030] In the following detailed description section, specific embodiments of the present techniques are described. However, to the extent that the following description is specific to a particular embodiment or a particular use of the present techniques, this is intended to be for exemplary purposes only and simply provides a description of the exemplary embodiments. Accordingly, the techniques are not limited to the specific embodiments described below, but rather, include all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

[0031] 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,
5 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.

[0032] A "combined cycle power plant" includes a gas turbine, a steam turbine, a generator, and a heat recovery steam generator (HRSG), and uses both steam and gas turbines to generate power. The gas turbine operates in an open Brayton cycle, and the steam turbine
10 operates in a Rankine cycle. Typically, combined cycle power plants utilize heat from the gas turbine exhaust to boil water in a heat recovery unit (HRU) to generate steam. The steam generated is utilized to power the steam turbine. After powering the steam turbine, the steam may be condensed and the resulting water returned to the HRU. The gas turbine and the steam turbine can be utilized to separately power independent generators, or in the
15 alternative, the steam turbine can be combined with the gas turbine to jointly drive a single generator via a common drive shaft. These combined cycle gas/steam power plants generally have higher energy conversion efficiency than gas or steam only plants. A combined cycle plant's efficiencies can be as high as 50 % to 60 %. The higher combined cycle efficiencies result from synergistic utilization of a combination of the gas turbine with the steam turbine.

20 [0033] As used herein, a "cryogenic fluid" includes any fluid with a boiling point of less than about -130 °C at ambient pressure conditions. Such fluids may include liquefied natural gas (LNG), liquid nitrogen, liquid oxygen, liquid hydrogen, liquid helium, liquid carbon dioxide, and the like.

[0034] A "fuel" includes any number of hydrocarbons that may be combusted with an
25 oxidant to power a gas turbine. Such hydrocarbons may include natural gas, treated natural gas, kerosene, gasoline, or any number of other natural or synthetic hydrocarbons. In one embodiment, natural gas from an oil field is purified and used to power the turbine. In another embodiment, a reformed gas, for example, created by processing a hydrocarbon in a steam reforming process may be used to power the turbine.

30 [0035] The term "gas" is used interchangeably with "vapor," and means a substance or mixture of substances in the gaseous state as distinguished from the liquid or solid state. Likewise, the term "liquid" means a substance or mixture of substances in the liquid state as distinguished from the gas or solid state.

[0036] A “heat exchanger” broadly means any device capable of transferring heat from one media to another media, including particularly any structure, e.g., device commonly referred to as a heat exchanger. Heat exchangers include “direct heat exchangers” and “indirect heat exchangers.” Thus, a heat exchanger may be a plate-and-frame, shell-and-tube, spiral, hairpin, core, core-and-kettle, double-pipe, or any other type of known heat exchanger. “Heat exchanger” may also refer to any column, tower, unit or other arrangement adapted to allow the passage of one or more streams therethrough, and to affect direct or indirect heat exchange between one or more lines of refrigerant, and one or more feed streams.

[0037] A “hydrocarbon” is an organic compound that primarily includes the elements hydrogen and carbon although nitrogen, sulfur, oxygen, metals, or any number of other elements may be present in small amounts. As used herein, hydrocarbons generally refer to organic materials that are harvested from hydrocarbon containing sub-surface rock layers, termed reservoirs. For example, natural gas is a hydrocarbon.

[0038] “Liquefied natural gas” or “LNG” is cryogenic liquid form of natural gas generally known to include a high percentage of methane, but also other elements and/or compounds including, but not limited to, ethane, propane, butane, carbon dioxide, nitrogen, helium, hydrogen sulfide, or combinations thereof. The natural gas may have been processed to remove one or more components (for instance, helium) or impurities (for instance, water and/or heavy hydrocarbons) and then condensed into the liquid at almost atmospheric pressure by cooling.

[0039] The term “natural gas” refers to a multi-component gas obtained from a crude oil well (associated gas) or from a subterranean gas-bearing formation (non-associated gas). The composition and pressure of natural gas can vary significantly. A typical natural gas stream contains methane (C₁) as a significant component. Raw natural gas may also contain ethane (C₂), higher molecular weight hydrocarbons, acid gases (such as carbon dioxide, hydrogen sulfide, carbonyl sulfide, carbon disulfide, and mercaptans), and minor amounts of contaminants such as water, nitrogen, iron sulfide, wax, and crude oil. As used herein, natural gas includes gas resulting from the regasification of a liquefied natural gas, which has been purified prior to liquefaction to remove contaminants, such as water, acid gases, and most of the higher molecular weight hydrocarbons.

[0040] As used herein, a “Rankine power plant” includes a steam generator, a steam turbine, a steam condenser, and a recirculation pump. The steam generator is often a gas fired boiler that boils water to generate the steam. However, in embodiments, the steam

generator may be a heat recovery unit configured to boil water from the heat in an exhaust stream from a gas turbine engine. The steam is used to generate electricity in the steam turbine generator, and the reduced pressure steam is then condensed in the steam condenser. The resulting water is recirculated to the steam generator to complete the loop.

- 5 [0041] “Substantial” when used in reference to a quantity or amount of a material, or a specific characteristic thereof, refers to an amount that is sufficient to provide an effect that the material or characteristic was intended to provide. The exact degree of deviation allowable may in some cases depend on the specific context.

Overview

- 10 [0042] Embodiments described herein provide liquid natural gas (LNG) regasification techniques and systems that reduce emissions associated with fuel-fired vaporizers and improve the flexibility of utilizing LNG cold. In an embodiment, LNG is regasified using heat obtained from cooling an air flow in an air separation unit (ASU) to create an oxygen stream. The oxygen stream is used in a power plant to combust a fuel.
- 15 [0043] Fig. 1 is a block diagram of a LNG terminal **100** that incorporates a power plant, illustrating the use of cold from the LNG to purify an air stream for use in the power plant. In the LNG terminal **100**, purified air **102** is passed through an air separation unit (ASU) **104** to separate oxygen **106** and nitrogen **108** from the purified air **102**, as discussed with respect to Fig. 6. The ASU **104** utilizes a cryogenic distillation process. The cold is provided by a
- 20 stream of LNG **110**. As the LNG **110** removes heat energy from the air **102**, it is regasified into the product natural gas (NG) **112**. A portion of the NG **112** can be used as a fuel for the power plant **114**, adding to the efficiency of the process.

- [0044] The oxygen **106** is used to provide oxidant to the power plant **114**, which may be, for example, a combined cycle power plant utilizing a gas turbine generator and a heat
- 25 recovery steam generator (HRSG), as discussed with respect to Fig. 7. In some embodiments, the power plant **114** may be a Rankine cycle power plant using a standard boiler and steam generator configuration. The power plant **114** can be used to generate power **116** for the LNG terminal **100**. The power **116** may include mechanical energy, for example, to power compressors in the LNG terminal **100**. The power **116** may also include
- 30 electrical power, either consumed in the LNG terminal **100**, marketed through an electrical grid, or both. The exhaust from the power plant **114** can be purified to form carbon dioxide (CO₂) **118**, which can be used in enhanced oil recovery, sold as a product, or both. The

purification of the CO₂ **118** may be performed by passing the exhaust from the power plant **114** through a cooler to condense out water vapor formed in the combustion process. As the combustion is fed substantially pure oxygen, little, if any, nitrogen oxides, or other combustion by-products will be formed.

- 5 [0045] Fig. 2 is a block diagram of another LNG terminal **200** that incorporates a power plant, illustrating the use of cold from the LNG to liquefy product stream for sale. Like numbered items are as described with respect to Fig. 1. In embodiments, the CO₂ **118** can be liquefied using the LNG **110** as a heat sink in a CO₂ chiller **202**. This will also add to the amount of NG **112** available for sales. The liquefied CO₂ **204** can then be provided for sale.
- 10 Further, the N₂ **108** can be liquefied using the LNG **110** as a heat sink in an N₂ chiller **206**. The liquefied N₂ **208** can also be sold.

- [0046] Fig. 3 is a process flow diagram of a LNG regasification method **300** that can be used in the systems discussed above. The method begins at block **302**, with the use of LNG in an ASU to obtain O₂ and N₂ from a purified air stream. At block **304**, at least a portion of
- 15 the resulting NG can be sold, for example, to a pipeline. At block **306**, the N₂ can be sold or vented, depending on the economics of the N₂ as a product. In an embodiment, the cold from the LNG is used to condense the nitrogen for sales as a liquid product.

- [0047] If the nitrogen is vented, it may be passed through an expander to produce mechanical energy prior to venting. The mechanical energy can be used to drive a generator,
- 20 producing electricity. Further, after the expander, the nitrogen will be substantial cooler and may be used for cooling other units and processes.

- [0048] At block **308**, the oxygen from the ASU is provided to the combustors, or burners, in a power plant. Substantially simultaneously, at block **310**, a fuel is provided to the combustors or burners in the power plant. The fuel may be a portion of the NG generated
- 25 from the regasification of the LNG. However, the power plant is not limited to using the NG as the fuel. For example, if the LNG terminal is built in proximity to an existing power plant, substantial synergies can be obtained by providing oxygen to the power plant, decreasing emissions from the combustion of the fuel without changing the configuration of the power plant to use the natural gas.

- 30 [0049] At block **312**, the fuel and oxygen are combusted in the power plant, producing power at block **314**. The power can be mechanical power, for example, used to power compressors or an electrical generator. At block **316**, at least a portion of the electrical power

generated may be marketed. This may be in addition to any power that is used in the plant itself.

[0050] At block 318, the CO₂ from the exhaust stream may be condensed to a liquid. At block 320, the NG produced may be marketed, for example, being combined with the NG streams produced from the ASU and any nitrogen condenser used. At block 322, the CO₂ is marketed or used, for example, for enhanced oil recovery. In some embodiments, the CO₂ may be disposed, or sequestered, by injection into subterranean formations. Other sequestration sinks may include injection of the CO₂ into a seabed at a temperature and pressure that is sufficient to keep the CO₂ in liquid form.

10 Examples of combined LNG terminal and power plant equipment

[0051] Fig. 4 is a simplified process flow diagram of a combined plant 400 having an ASU that provides LNG regasification and a power plant that combusts fuel with oxygen generated in the ASU. Like numbered items are as described with respect to Figs. 1 and 2. In the combined plant 400, an LNG high pressure pump 402 boosts the pressure of the LNG 110 to the pipeline pressure for marketing the NG 112, prior to the use of the high pressure LNG 403 in the ASU 104 and other chillers, such as the CO₂ chiller 202.

[0052] To purify the CO₂ for condensation, the exhaust 404 from the power plant 114 is passed through a cooler 406. In the cooler 406, the exhaust 404 may be cooled or chilled by a heat exchange solution 408, such as water, a glycol/water mixture, ammonia, and the like. The heat exchange solution 408 may be cooled by exchanging heat with a portion of the high pressure LNG 403, or may be cooled by a standard refrigeration procedure. The chilled exhaust stream 410 is flowed into a separator in which the water 414 settles out from the bottom, and the dry CO₂ 118 flows out the top. After drying, the CO₂ 118 may have a dewpoint of -10 °C, -20 °C, -40 °C, or lower. If a lower dewpoint is desired, the CO₂ 118 may be flowed through a second heat exchanger, which may be chilled by a portion of the high pressure LNG stream 403. After drying, the CO₂ 118 is flowed into a compressor 416 to boost the pressure to a point at which liquid CO₂ 118 will form, e.g., greater than about 517 kPa. The high pressure CO₂ 418 is then flowed into the CO₂ chiller 202 to be cooled against the high pressure LNG 403.

30 [0053] In the CO₂ chiller 202, the high pressure CO₂ 418 is liquefied. The liquefied CO₂ 204 can then be used, sold, or disposed of, for example, by injection into a subterranean formation.

[0054] Fig. 5 is a simplified process flow diagram of a combined plant **500** having an ASU that provides LNG regasification and a power plant that combusts fuel with oxygen generated in the ASU. Like number items are as described with respect to previous figures. As noted herein, the N₂ **108** may be liquefied for marketing. In the combined plant **500**, the N₂ **108** is passed through an N₂ liquefier **502** to perform this function. The N₂ liquefier **502** can include a compressor to increase the pressure of the N₂ **108**, followed by a chiller to liquefy the high pressure nitrogen. In other embodiments, the N₂ can be flowed directly through a chiller to be condensed into the liquid N₂ **208**. The liquid N₂ **208** can then be marketed.

10 [0055] Fig. 6 is a simplified process flow diagram of an air separation unit (ASU) **600** that may be used in embodiments. Like numbered items are as discussed with respect to the previous figures. The ASU **600** can be used, for example, as the ASU **104** discussed with respect to Fig. 1. In the ASU **600**, purified air **102** is passed through a compressor **602** to increase the pressure for processing. The compressed air **604** is flowed through a pre-cooler **606** to remove the heat of compression and reduce the temperature for the distillation process. The pre-cooler **606** may be chilled with a stream of LNG **110**, which can add to the amount of NG **112** formed in the regasification plant. The chilled air stream **608** can be flowed through a purification unit **610**, which can be used to remove any remaining CO₂, water, or both from the air prior to the cryogenic distillation.

20 [0056] The process feed stream **612** is sent through a main heat exchanger **614** for initial chilling to cryogenic temperatures, e.g., less than the boiling point for oxygen (about -183 °C, at atmospheric pressure) and greater than the boiling point for nitrogen (about -195.8 °C, at atmospheric pressure). It will be understood that these temperatures will increase at higher pressures. However, the temperature of the oxygen liquefaction increases at a higher rate than the nitrogen, broadening the operating range for the cryogenic distillation at higher pressures.

[0057] In an embodiment, the main heat exchanger **614** is chilled by a stream of LNG **110**. As the LNG **110** vaporizes in the main heat exchanger, NG **112** is formed. This decreases or eliminates the need to provide extra cooling to the main heat exchanger **614**, and increases the overall efficiency of the process. The main heat exchanger can be an aluminum fin type generally used in cryogenic cold boxes. However, other types may be used, such as shell/tube heat exchangers, plate type heat exchangers, and plate-fin heat exchangers, among others.

[0058] A portion of the feed stream **612** may be sent through a boost compressor **615** to further increase the pressure. The high pressure stream **616** from the boost compressor **614** is flowed through the main heat exchanger **614** for chilling. The chilled high-pressure stream **618** is passed through an expander **620** which further removes energy, forming a mixed phase stream **622**. The mixed phase stream **622** is passed through a subcooler **624**, and then injected into a low pressure distillation column **626**.

[0059] Another portion of the feed stream **612** is passed directly through the main heat exchanger **614** for chilling. The chilled feed stream **628** is injected into a high pressure distillation column **630**. The low pressure distillation column **626** and the high pressure distillation column **630** may be different regions of a single column, for example, with a plate **632** that isolates the two pressure regions.

[0060] A liquid bottoms stream **634** is taken from the bottom of the high pressure distillation column **630** and passed through the sub-cooler **624**. The liquid bottoms stream **634** is flashed across a valve **636** before being injected into the low pressure distillation column **626**. The flashing of the liquid bottoms stream **634** further decreases the temperature of the stream and allowing separation of liquid and gas phases in the low pressure distillation column **626**. A gas top stream **638** is removed from the top of the high pressure distillation column **630**, and is passed through the sub-cooler **624**, before being injected into the low pressure distillation column **626**.

[0061] A liquid oxygen stream **640** is taken from the bottom of the low pressure distillation column **626**. The liquid oxygen stream **640** can be pumped through the main heat exchanger **614** to be regasified to oxygen **106**, prior to being sent on to the power plant. A gas nitrogen stream **642** can be taken from the top of the low pressure distillation column **626**. The nitrogen stream **642** can be disposed, for example, by passing the gas through an expander to remove energy and then venting. In an embodiment, the nitrogen is liquefied using the cold from a stream of LNG **110**, further increasing the amount of NG **112** that can be produced.

[0062] The ASU **600** is not limited to the configuration shown. Any number of other configurations, including, for example, single columns, high pressure chilling, and the like may be used for cryogenic distillation in embodiments.

[0063] Figs. 7A and 7B are a simplified process flow diagram of a power plant **700** that can be used in embodiments. The power plant **700** illustrated is a combined cycle power

plant using a gas turbine engine **702** and a heat recovery steam generator (HRSG) **704**. An ASU **104** using LNG to provide cooling may be used to provide oxygen **116** to the gas turbine engine **702**, as described herein. It can be noted that the present techniques are not limited to combined cycle power plants, but may also be used with power plants based on other power generation cycles, such as a steam power plant based on a Rankine cycle.

[0064] The gas turbine engine **702** may have a compressor **706** and a turbine expander **708** on a single shaft **710**. The gas turbine engine **702** is not limited to a single shaft arrangement, as multiple shafts could be used, generally with mechanical linkages or transmissions between shafts. The gas turbine engine **702** may also have a number of combustors **712** that feed hot exhaust gas **714** to the turbine expander **708**. For example, the gas turbine engine **702** may have 2, 4, 6, 14, 18, or even more combustors **712**, depending on the size of the gas turbine engine **702**.

[0065] The combustors **712** are used to burn a fuel **716**, for example, a portion of the NG **112** stream regasified from an LNG **110**, as discussed with respect to Fig. 1. Oxygen **116** from an ASU **104** may be provided to each of the combustors **712**. Recycled exhaust gas **718** may be compressed in the compressor **706** and then provided to the combustors **712** for cooling and dilution of the fuel and oxygen mixture.

[0066] The exhaust gas **714** from the combustors **712** expands in the turbine expander **708**, creating mechanical energy. The mechanical energy may power the compressor **706** through the shaft **710**. Further, a portion of the mechanical energy may be used to power an electrical generator **720** or additional compressors. The oxygen **116** flow can be individually metered to each of the combustors **712** to control an equivalence ratio in that combustor **712**.

[0067] It will be apparent to one of skill in the art that a stoichiometric burn, *e.g.*, at an equivalence ratio of 1, will be hotter than a non-stoichiometric burn. Therefore, cooling with a high pressure recycle gas **718** can prevent damage to the combustors **712** or the turbine expander **708** from the extreme heat. Sensors can be placed in an expander exhaust section **722** of the gas turbine engine **702** to control flow of the oxygen and fuel.

[0068] A control system, such as a distributed control system (DCS), a programmable logic controller (PLC), a direct digital controller (DDC), or any other appropriate control system, may be used to control the operation of the LNG terminal and power plant. For example, the control system may automatically adjust parameters, such as the amount of LNG that can be regasified at a particular operating rate.

[0069] In the embodiment shown in Fig. 7, the compressor **706** is used to compress a recycled exhaust stream **724** to form the high pressure recycle gas **718**. The oxygen **116** does not have to be separately injected, but may be mixed with the recycled exhaust stream **724**.

[0070] In the combined cycle power plant **700**, the hot exhaust gases **726** from the expander exhaust section **722** are passed through a heat recovery unit (HRU) **728**. In the HRU **728**, the hot exhaust gases **726** are used to boil a stream of water **730**, forming steam **732**. The steam **732** is used to turn a steam turbine (ST) **734**, which may be used to power a generator **736**, compressors, or other units. The low pressure steam **738** from the steam generator **734** is condensed back to water **730** in a heat exchanger **740**, completing a Rankine cycle.

[0071] The hot exhaust gases **726** are cooled in the HRU **728**, forming a cooled exhaust stream **742**. The cooled exhaust stream **742**, which includes primarily CO₂ and water vapor from the combustion, is passed through a cooler **744**, which chills the stream and condenses out most of the water **746**, forming the recycled exhaust stream **724**.

[0072] The gas turbine engine **702** of the combined cycle power plant **700** can be described as operating in a semi-closed Brayton cycle. The gas turbine engine **702** cannot operate in a fully closed Brayton cycle since mass is introduced from the fuel and oxygen. This mass is removed as the condensed water **746**, and as an exhaust stream **748**, for example, from the high pressure recycle gas **718**. The exhaust stream **748** can be provided to a chiller to form a liquid CO₂ stream, as described with respect to Figs. 1 and 2.

[0073] The cooler **744** may be a non-contact heat exchanger, or any number of other types described herein. For example, in an embodiment, the cooler **744** may be a tube in shell heat exchanger, in which a water stream is flowed through tubes inside a shell, while the cooled exhaust stream **742** is flowed around the tubes. As the cooled exhaust stream **742** contact the tubes, it is further cooled, and water **746** condenses out. The water **746** can then be removed from the shell of the cooler **744**, for example, through a weir, allowing the recycled exhaust stream **724** to flow out separately. In this embodiment, the recycled exhaust stream **724** from the cooler **744** may then be recycled to the inlet of the compressor **706**.

[0074] In summary, embodiments described herein provide benefits over fuel-fired vaporizers, including, for example, more efficient use of installed equipment, such as power plants. Further, the techniques provide increased flexibility to use cold contained in LNG **110** and lower the amount of fuel used to vaporize LNG **110** and, thus, increase the sales and

revenue of natural gas **110** from an LNG terminal **100**. The elimination or reduction of fuel-fired vaporizers and the use of oxygen from an ASU **104**, may also decrease the associated capital expenditures and operating expenditures, and provide a reduction in the emissions, such as CO₂ and NO_x, associated with the fuel consumption of a vaporizer in a terminal. The

5 use of the cold from the LNG **110** also provides an increase in power plant efficiency and power output.

CLAIMS

What is claimed is:

1. A method for regasifying liquefied natural gas (LNG), comprising:
flowing at least a portion of an LNG stream through an air separation unit (ASU) to form at least a portion of a natural gas (NG) stream;
removing heat from an airflow in the ASU to separate an oxygen stream from the airflow; and
combusting the oxygen stream and a fuel stream in a power plant.
2. The method of claim 1, comprising:
flowing a portion of the LNG stream through a gaseous carbon dioxide (CO₂) chiller to form a portion of the NG stream; and
forming a liquefied CO₂ stream in the CO₂ chiller.
3. The method of claim 1 or claim 2, comprising:
flowing a portion of the LNG stream through a nitrogen (N₂) chiller to form a portion of the NG stream; and
forming a liquefied N₂ stream in the N₂ chiller.
4. The method of any one of claims 1-3, comprising providing the NG stream to a market.
5. The method any one of claims 1-4, comprising:
generating electrical power in the power plant; and
providing the electrical power to a market.
6. The method of any one of claim 2, claim 4 or claim 5, comprising providing the liquefied CO₂ stream to a market.
7. The method of any one of claim 2, claim 4, claim 5 or claim 6, comprising injecting the CO₂ stream into a subterranean formation.
8. The method of any one of claim 2, claim 4, claim 5 or claim 6 or claim 7, comprising injecting the CO₂ stream proximate to a seabed.
9. The method of any one of claims 1-8, comprising venting a nitrogen stream to the

atmosphere.

10. The method of any one of claims 1-9, comprising chilling the oxygen stream with LNG prior to the power plant.

11. A system for regasifying liquefied natural gas, comprising:

an air separation unit configured to utilize cold from a portion of a stream of liquefied natural gas (LNG) to cryogenically distill an air stream to produce an oxygen stream and a nitrogen stream, forming a natural gas (NG) stream; and

a power plant configured to combust the oxygen stream with a fuel stream.

12. The system of claim 11, comprising a cold box configured to condense liquid CO₂ from an exhaust stream of the power plant by transferring heat to a portion of the stream of LNG.

13. The system of claim 11 or claim 12, wherein the power plant comprises a combined cycle power plant, comprising a gas turbine generator and a heat recovery steam generator.

14. The system of any one of claims 11-13, further comprising an inlet air cooler on a gas turbine engine configured to transfer heat from an oxygen stream to an LNG stream.

15. The system of any one of claims 11-14, comprising an electrical generator.

16. The system of any one of claims 11-15, wherein the power plant comprises a steam generator, a steam turbine generator, a steam condenser, and a recirculation pump.

17. A method for cryogenically distilling a gas mixture, comprising:

compressing the gas mixture;

flowing the gas mixture through a chiller to cool the gas mixture and liquefy at least a portion of the gas mixture;

flowing a liquefied natural gas through the chiller from the gas mixture to remove heat from the gas mixture;

flowing the cooled gas mixture into a cryogenic separation column;

removing a product gas mixture from an upper section of the cryogenic separation column; and

removing a product liquid from a lower section of the cryogenic separation column.

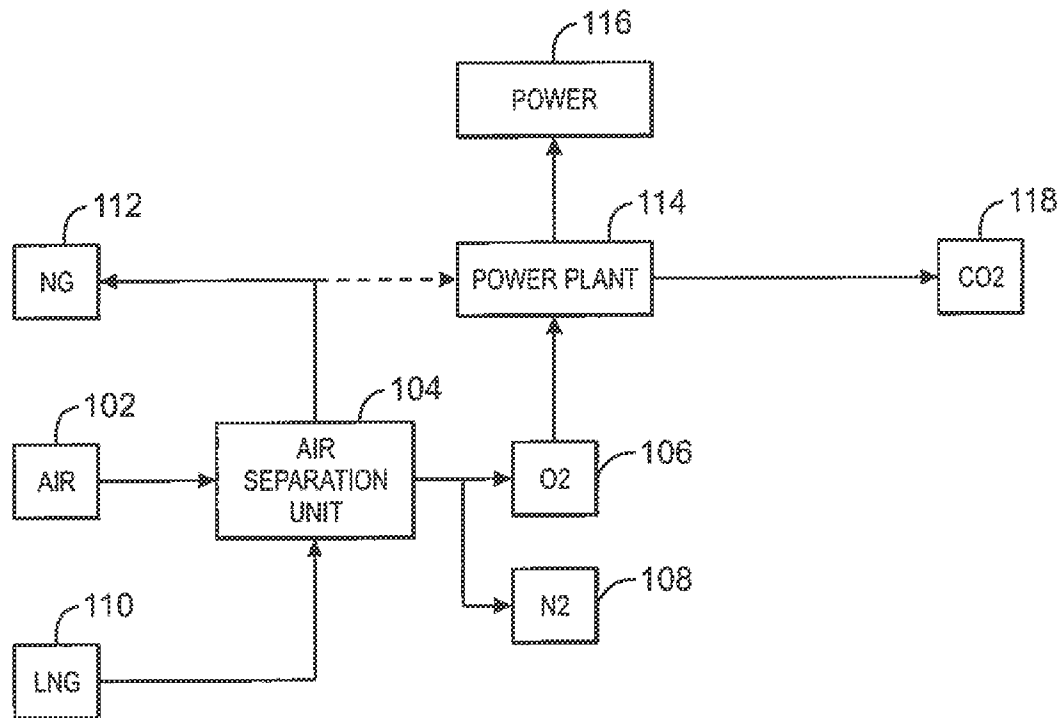
18. The method of claim 17, comprising purifying the gas mixture after compression to

remove carbon dioxide and water vapor.

19. The method of claim 17 or claim 18, comprising liquefying the product gas.
20. The method of any one of claims 17-19, comprising regasifying the product liquid.

2013EM028

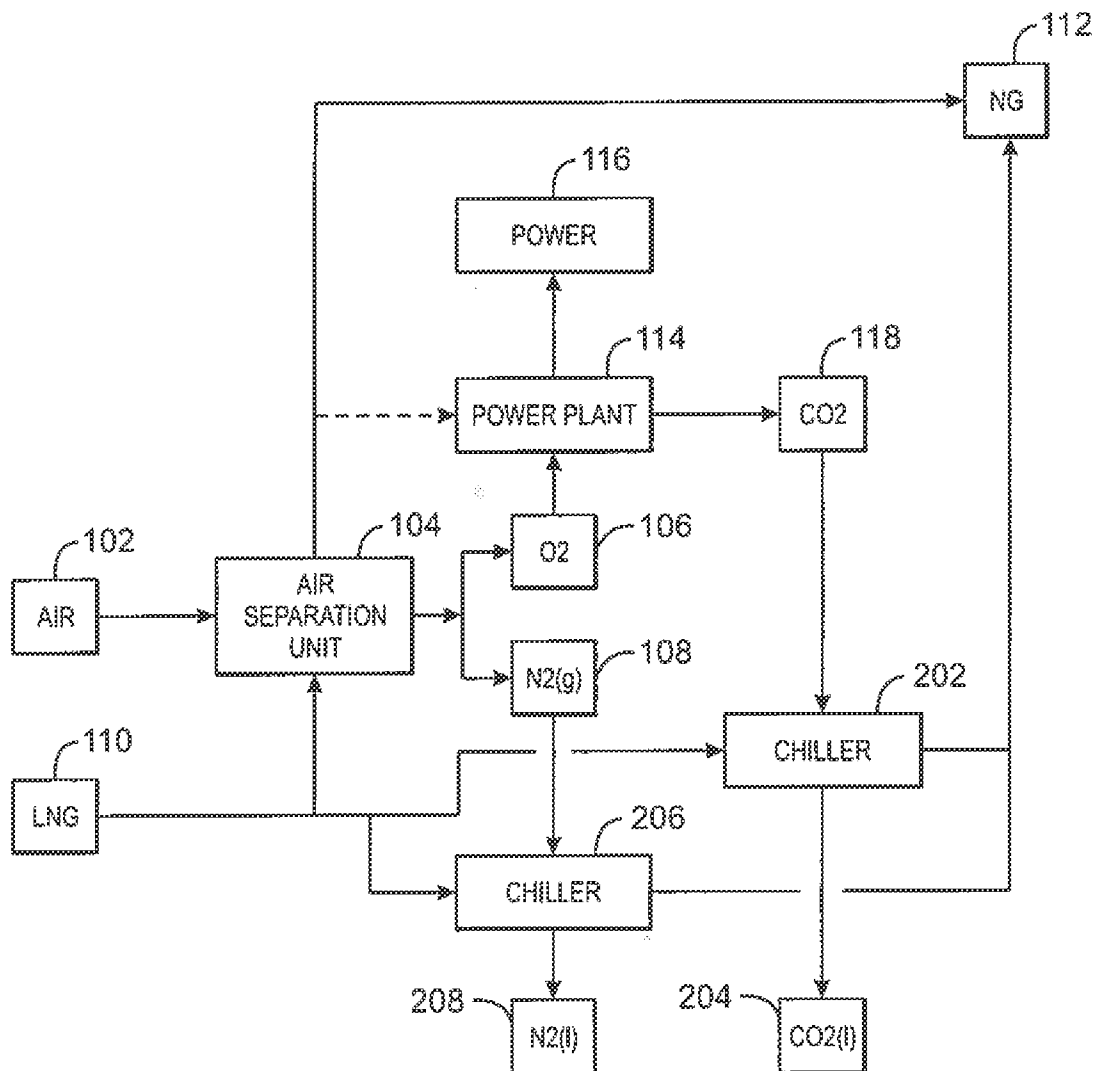
1/8



100
FIG. 1

2013EM028

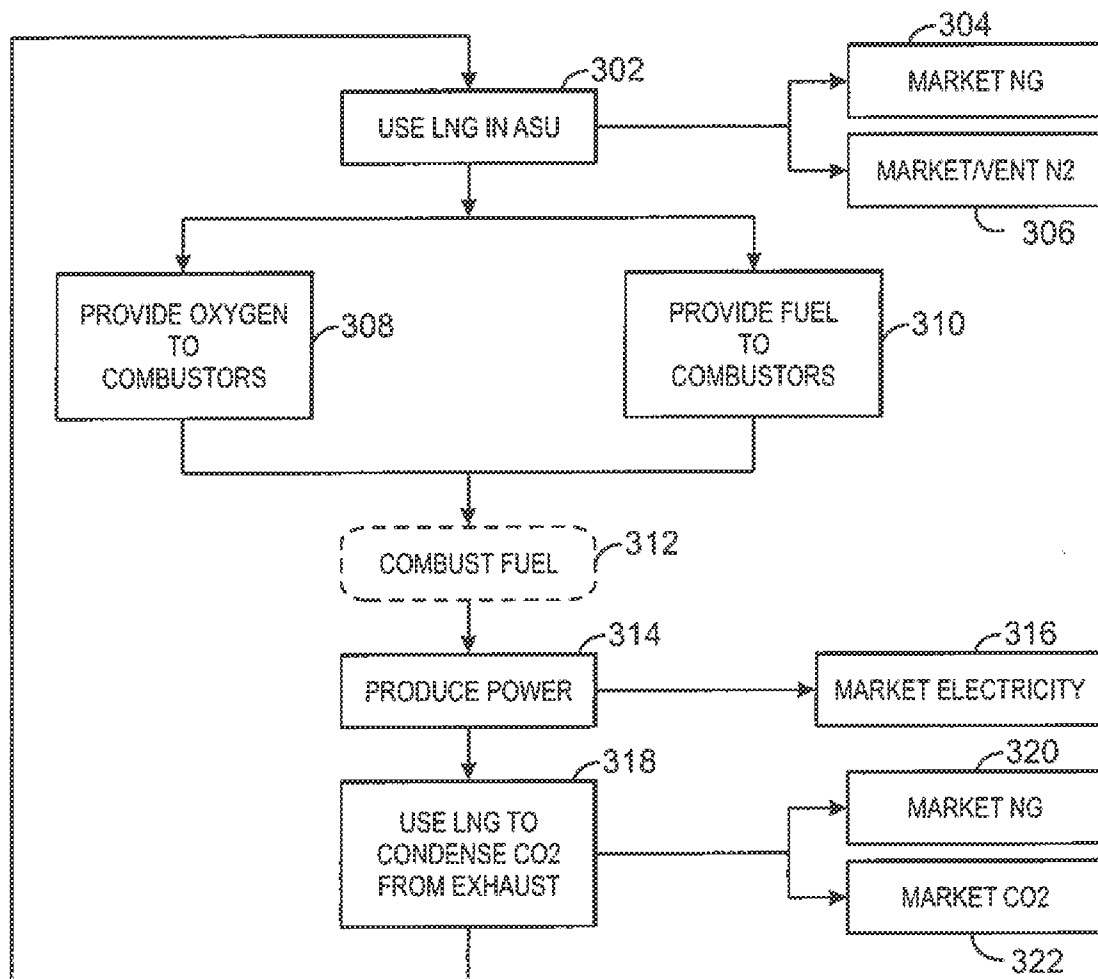
2/8



200
FIG. 2

2013EM028

3/8



300
FIG. 3

2013EM028

4/8

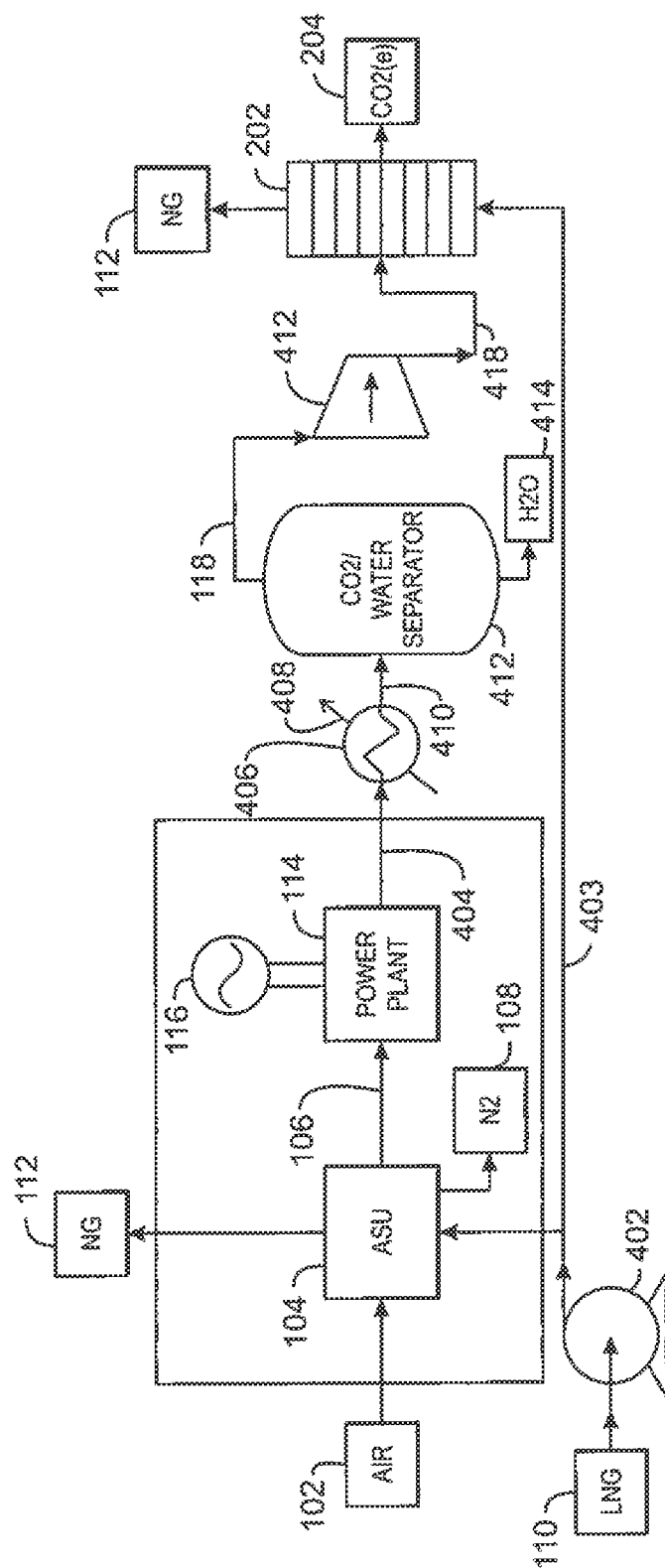
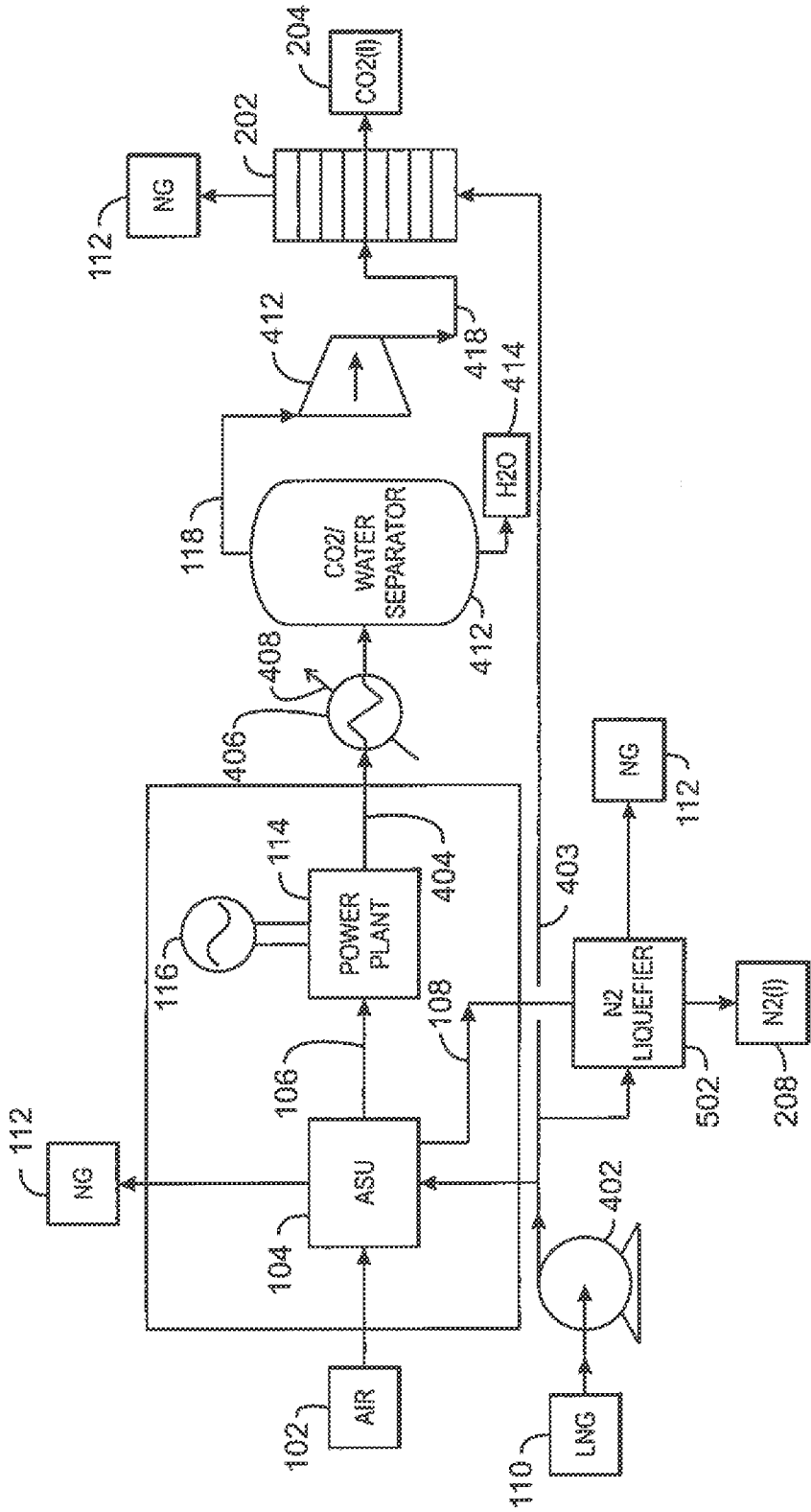


FIG. 4

2013EM028

5/8



500
FIG. 5

2013EM028

6/8

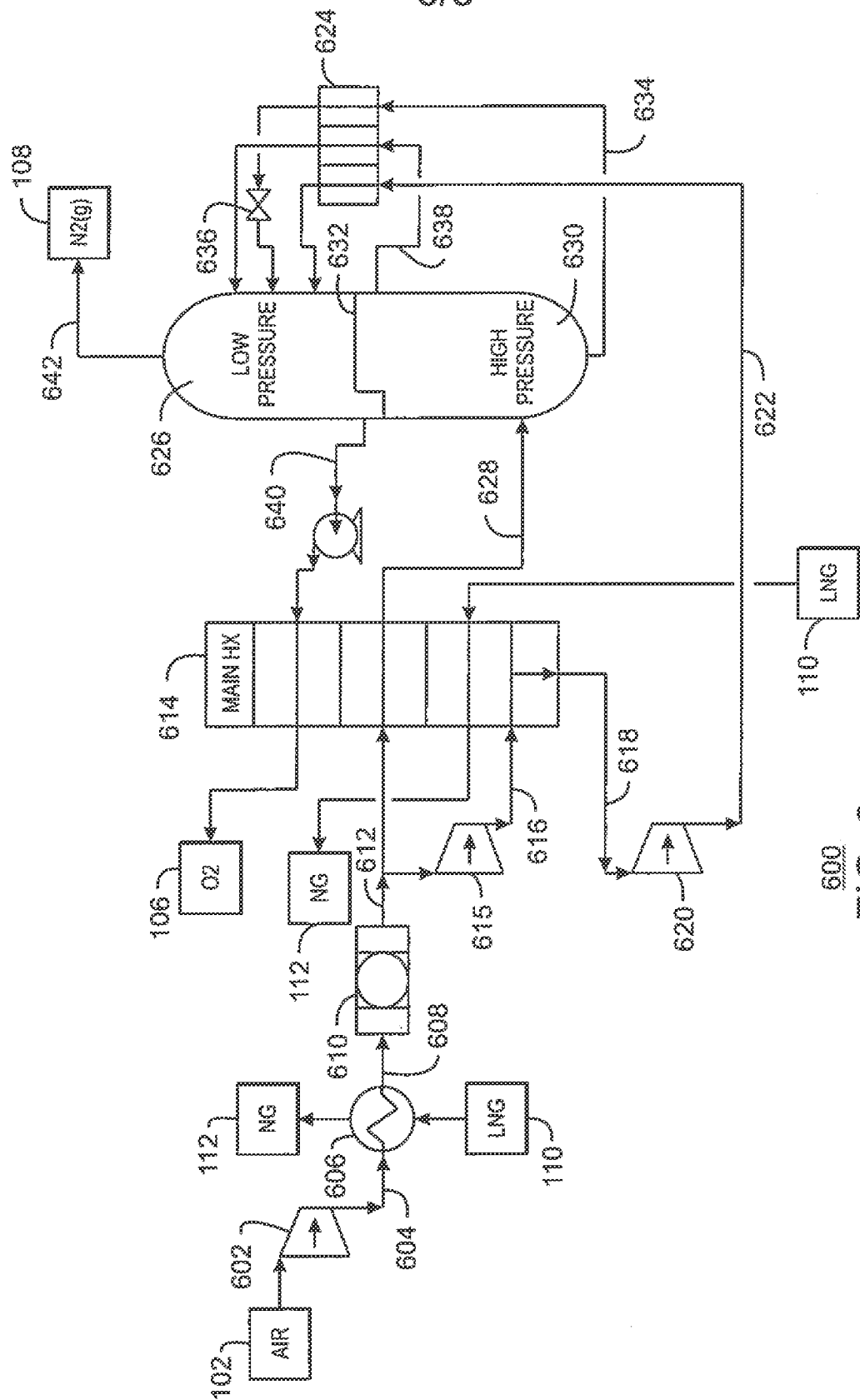
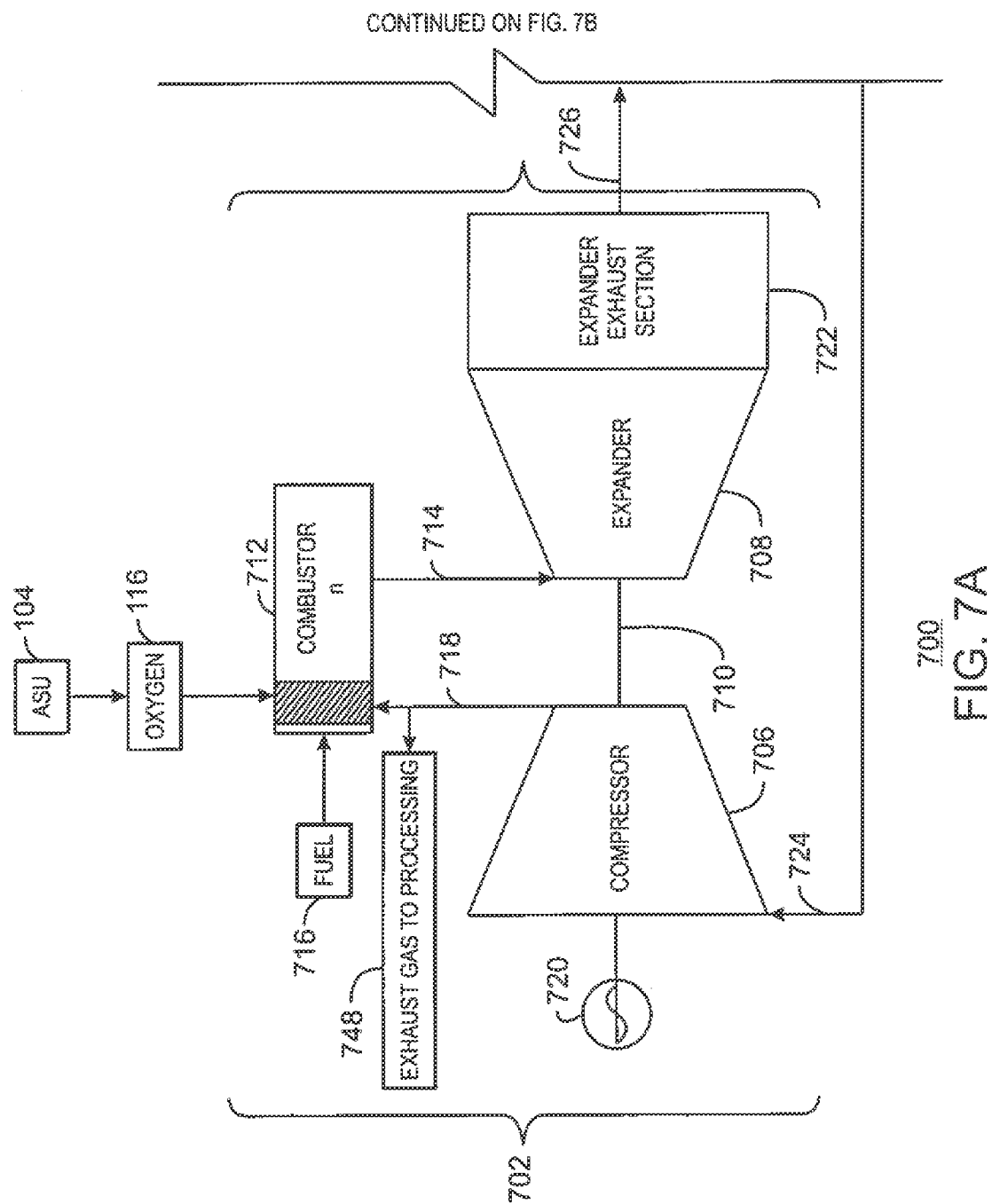


FIG. 6

2013EM028

7/8



2013EM028

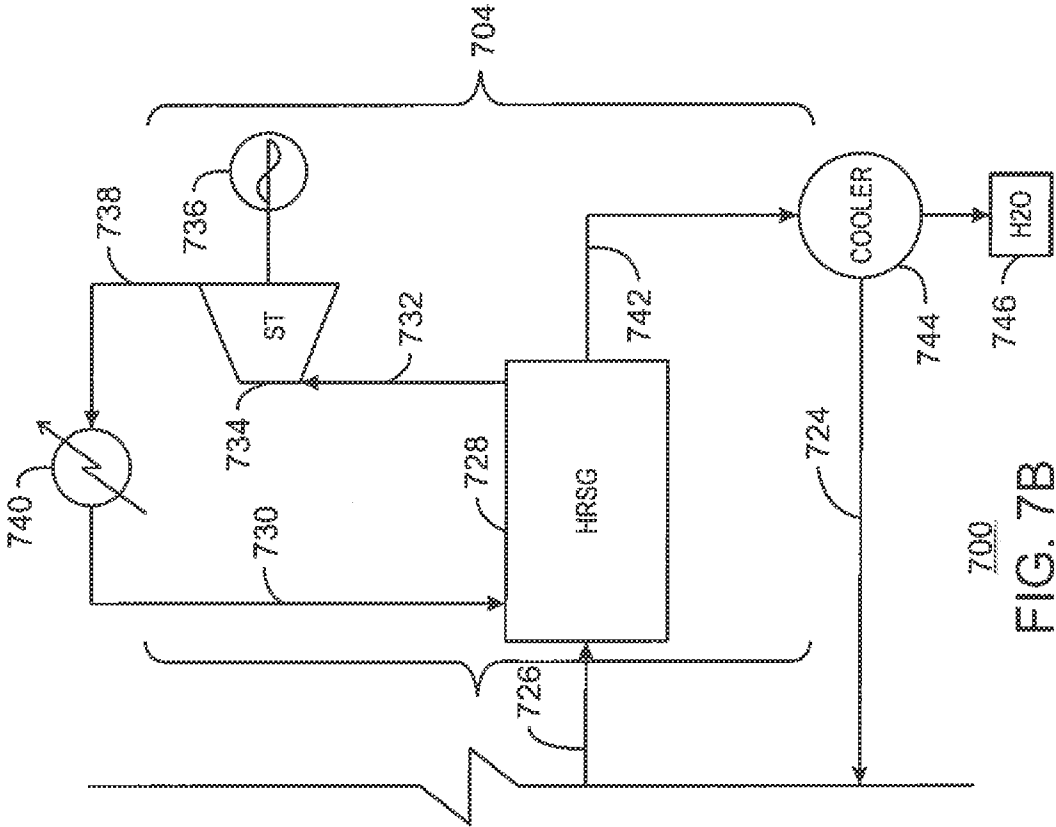


FIG. 7B

CONTINUED ON FIG. 7A