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(54) **ENHANCED OIL RECOVERY SYSTEMS AND METHODS**

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(76) Inventor: **Andreas Nicholas Matzakos,**  
Missouri City, TX (US)

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(57) **ABSTRACT**

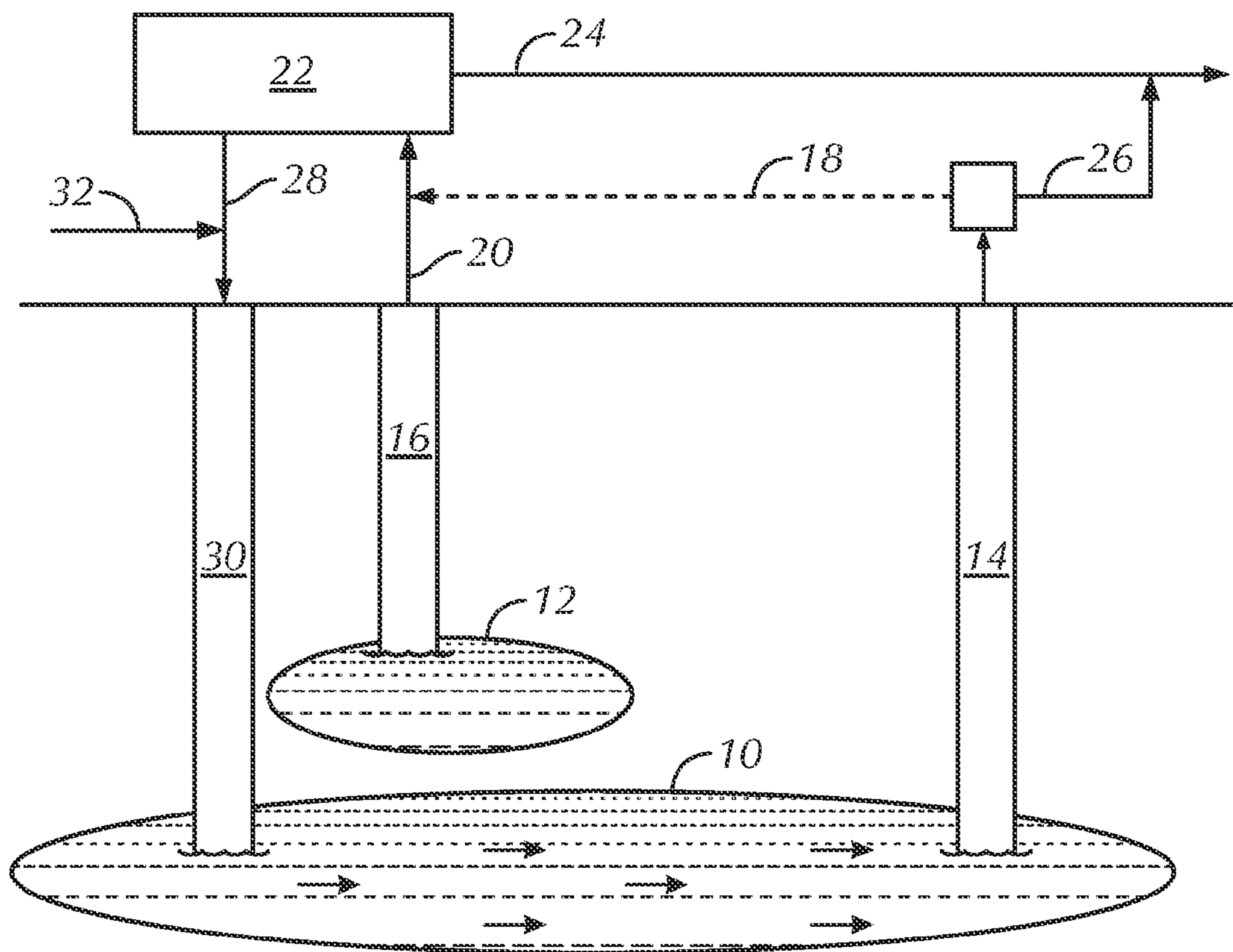
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There is disclosed a system for producing oil and/or gas comprising a mechanism for recovering oil and/or gas from an under-ground formation, the oil and/or gas comprising natural gas; a mechanism for converting at least a portion of the natural gas from the recovered oil and/or gas into an enhanced oil recovery solvent formulation; and a mechanism for releasing at least a portion of the enhanced oil recovery solvent formulation into the formation.

**Related U.S. Application Data**

(60) Provisional application No. 61/232,581, filed on Aug. 10, 2009.



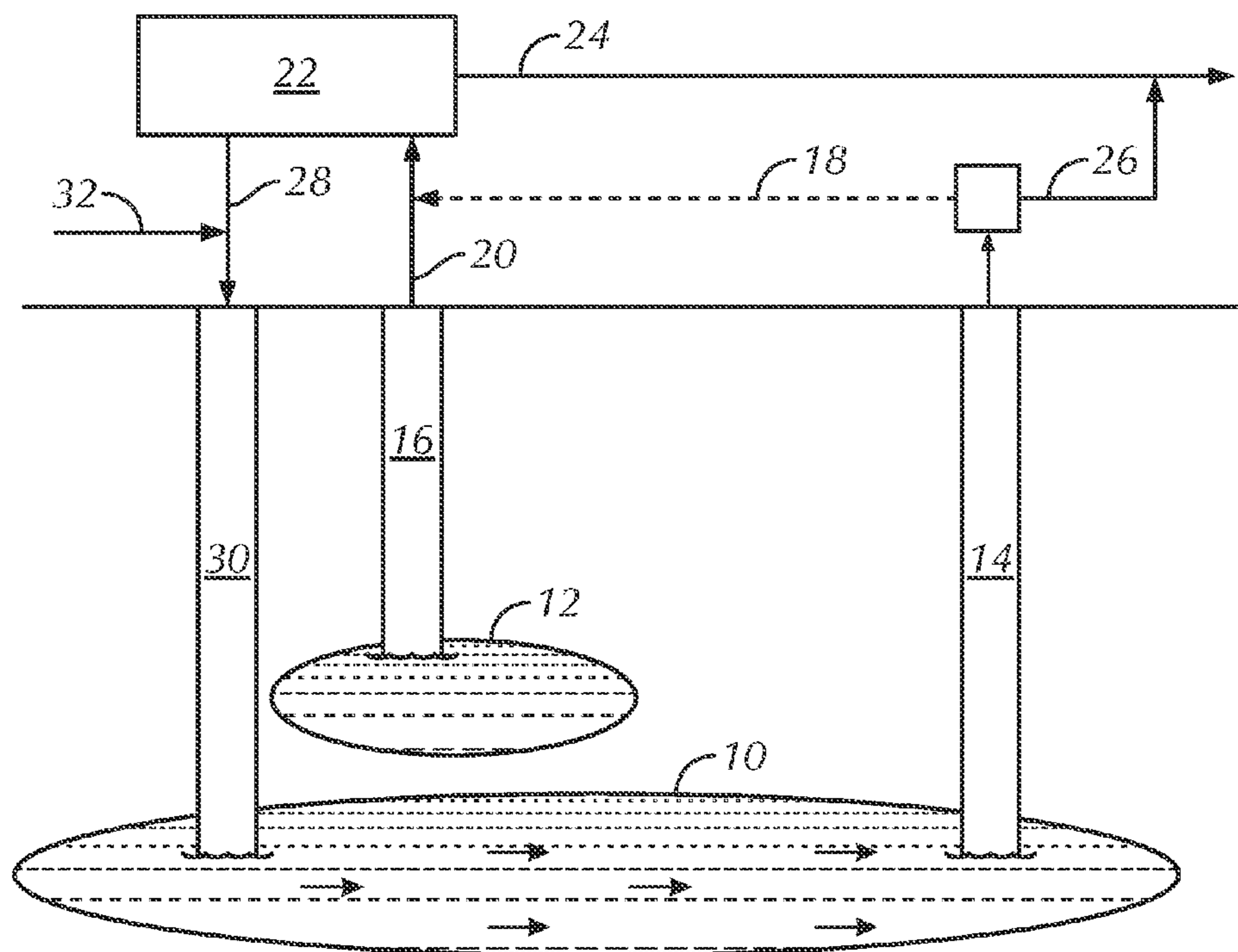


FIG. 1

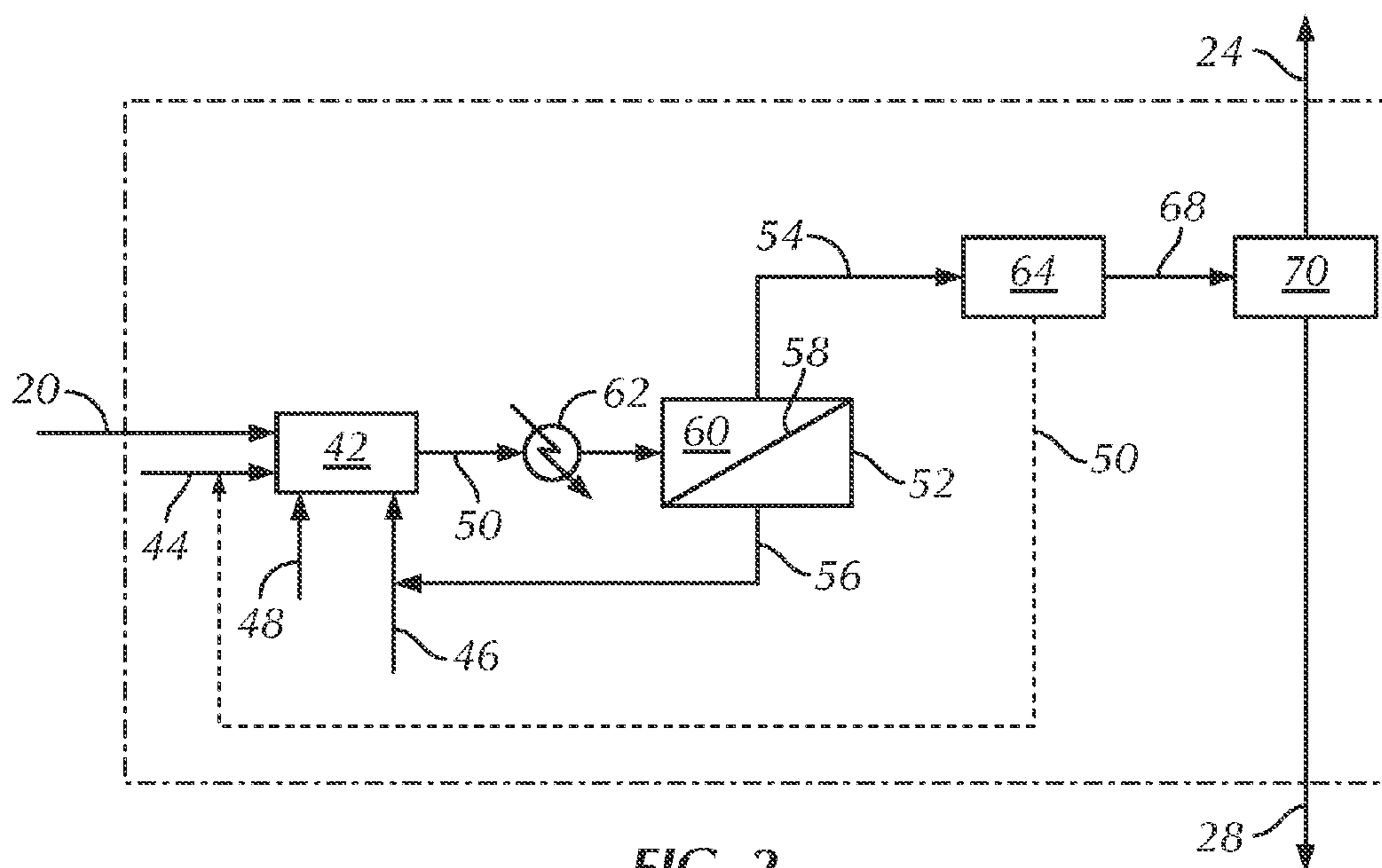


FIG. 2

## ENHANCED OIL RECOVERY SYSTEMS AND METHODS

### BACKGROUND OF THE INVENTION

**[0001]** Substantial amounts of natural gas are currently being produced from natural gas wells and from oil wells (for example, as associated gas), that are located in areas without a natural gas pipeline, or without enough natural gas demand. Such gas is sometimes referred to as stranded gas. Some of this gas is reinjected into the formation to boost production, or sent to another non-producing formation for disposal, while other may be burned for heating or electricity needs, or converted into other substances for easier transportation.

**[0002]** Enhanced Oil Recovery (EOR) may be used to increase oil recovery in fields worldwide. There are three main types of EOR, thermal, chemical/polymer and gas injection, which may be used to increase oil recovery from a reservoir, beyond what can be achieved by conventional means—possibly extending the life of a field and boosting the oil recovery factor.

**[0003]** Thermal enhanced recovery works by adding heat to the reservoir. The most widely practised form is a steamdrive, which reduces oil viscosity so that it can flow to the producing wells. Chemical flooding increases recovery by reducing the capillary forces that trap residual oil. Polymer flooding improves the sweep efficiency of injected water. Miscible gas injection works in a similar way to chemical flooding. By injecting a fluid that is miscible with the oil, trapped residual oil can be recovered.

**[0004]** U.S. Pat. No. 6,005,011 discloses a plant and process for converting associated gas from crude oil to methanol at or near the wellhead. The process uses partial oxidation of the associated gas, direct quench, liquid phase methanol conversion wherein substoichiometric H<sub>2</sub>:CO is converted to methanol, and a loop purge to a gas turbo generator to provide all of the plant power requirements. This results in avoiding a complex vapor phase, multiple reactor methanol loop and steam-catalytic reforming, and obtains a compact, low-cost, self-sufficient facility suitable for remote locations. U.S. Pat. No. 6,005,011 is herein incorporated by reference in its entirety.

**[0005]** U.S. Patent Application Number 2003/0225169 discloses a method and apparatus for converting natural gas from a remote source into hydrocarbon liquid stable at room temperature, comprising a skid or trailer-mounted portable gas-to-liquids reactor. The reactor includes a preprocessor which desulfurizes and dehydrates the natural gas, a first-stage reactor which transforms the preprocessed natural gas into synthesis gas, and a liquid production unit using a Fisher-Tropsch or similar polymerization process. The hydrocarbon liquid may be stored in a portable tank for later transportation or further processed on site in a portable hydrocarbon cracking unit to yield fuel or lubricating oils. U.S. Patent Application Number 2003/0225169 is herein incorporated by reference in its entirety.

**[0006]** U.S. Patent Application Number 2004/0149438 discloses a method for recovering oil from a natural oil reservoir includes the steps of separating air to produce an oxygen rich stream and a nitrogen rich stream, providing a natural gas stream and feeding at least part of the oxygen rich stream and the natural gas stream into a gas to liquid or GTL conversion installation to produce hydrocarbon products and heat. The heat produced in the gas to liquid conversion installation is used to produce energy to pressurize the nitrogen in the nitro-

gen rich stream to produce a pressurized nitrogen rich stream. The pressurized nitrogen rich stream is passed into a natural oil reservoir to enhance the recovery of oil from the reservoir. U.S. Patent Application Number 2004/0149438 is herein incorporated by reference in its entirety.

**[0007]** There is a need in the art for improved systems and methods for processing, transportation, disposal, or storage of natural gas. There is a further need in the art for improved systems and methods for enhanced oil recovery. There is a further need in the art for improved systems and methods for enhanced oil recovery using a liquid hydrocarbon, for example through viscosity reduction, chemical effects, and miscible flooding. There is a further need in the art for improved systems and methods for making hydrocarbon containing enhanced oil recovery agents.

### SUMMARY OF INVENTION

**[0008]** In one aspect, the invention provides a system for producing oil and/or gas comprising a mechanism for recovering oil and/or gas from an underground formation, the oil and/or gas comprising natural gas; a mechanism for converting at least a portion of the natural gas from the recovered oil and/or gas into an enhanced oil recovery solvent formulation; and a mechanism for releasing at least a portion of the enhanced oil recovery solvent formulation into the formation.

**[0009]** In another aspect, the invention provides a method for producing oil and/or gas comprising recovering oil and/or gas from an underground formation, the oil and/or gas comprising natural gas; converting at least a portion of the natural gas from the recovered oil and/or gas into an enhanced oil recovery solvent formulation; and releasing at least a portion of the enhanced oil recovery solvent formulation into the formation.

**[0010]** Advantages of the invention include one or more of the following:

**[0011]** Improved systems and methods for disposing of natural gas and associated gas.

**[0012]** Improved systems and methods for enhanced recovery of hydrocarbons from a formation with a liquid hydrocarbon formulation.

**[0013]** Improved systems and methods for producing a liquid hydrocarbon formulation.

**[0014]** Improved systems and methods for processing, transportation, disposal, and/or storage of natural gas.

**[0015]** Improved systems and methods for enhanced oil recovery.

**[0016]** Improved systems and methods for enhanced oil recovery using a liquid hydrocarbon.

**[0017]** Improved systems and methods for enhanced oil recovery using a compound which is miscible with oil in place.

**[0018]** Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

### BRIEF DESCRIPTION OF DRAWINGS

**[0019]** FIG. 1 is a simplified process flow diagram of processes according to embodiments disclosed herein.

[0020] FIG. 2 is a simplified process flow diagram of processes according to embodiments disclosed herein.

#### DETAILED DESCRIPTION

[0021] In one aspect, embodiments disclosed herein relate to processes for enhanced oil recovery. More specifically, embodiments disclosed herein relate to the recovery of natural gases from an underground formation, production of solvents from the recovered natural gases, and injection of the solvents downhole to enhance oil recovery. The natural gases recovered and converted to solvents may be produced or co-produced with oil at the injection wellsite or proximate the injection wellsite, such as from the same or adjacent or other nearby gas and oil fields. Additionally, conversion of the natural gases to solvents to be injected for enhanced oil recovery may be advantageously performed at the production wellsite, injection wellsite or proximate the injection wellsite according to embodiments disclosed herein.

[0022] In addition to the production of solvents from natural gases, processes according to embodiments disclosed herein may additionally result in conversion of the natural gases into various hydrocarbons, such as paraffins and olefins, including those boiling in the range of gasoline, diesel, fuel oil, and other hydrocarbon fractions. In some embodiments, these various hydrocarbons may be combined and further processed with oleaginous materials recovered from wellsites using enhanced oil recovery according to embodiments disclosed herein.

[0023] Natural gases recovered from wellsites may include components such as nitrogen, methane, ethane, and propane, among other components. A typical natural gas feed to be processed in accordance with embodiments disclosed herein may contain nitrogen, carbon dioxide, methane, ethane, propane and other  $C_{3+}$  components, such as isobutane, normal butanes, pentanes, and the like. In some embodiments, the natural gas stream may include, in approximate mole percentages, 60 to 95% methane, up to about 20% ethane and other  $C_2$  components, up to about 10% propane and other  $C_3$  components, up to about 5%  $C_{4+}$  components, up to about 10% or more nitrogen, and up to about 1% carbon dioxide. The composition of the natural gas may vary, depending upon the source (i.e., the gas field from which the natural gas is produced).

[0024] The natural gas recovered may be converted into enhanced oil recovery solvents and heavier hydrocarbons according to processes detailed further below. For example, the methane, ethane, and/or propane may be converted into heavier hydrocarbons, such as butanes, pentanes, hexanes, and the like, which may be useful as enhanced oil recovery solvents. The enhanced oil recovery solvents may then be separated from the heavier hydrocarbons and injected via an injection well for enhanced oil recovery operations.

[0025] In some embodiments disclosed herein, the recovery of oil and/or natural gas from an underground formation may be accomplished by any known method of oil recovery and/or enhanced oil recovery. Suitable methods include sub-sea production, surface production, including primary, secondary, or tertiary production.

[0026] In some embodiments, oil and/or gas may be recovered from an oil reservoir into a well, and flow through the well and flow line to a facility, which may include solvent production processes and injection operations. Following conversion of the natural gas into enhanced oil recovery solvents, the solvents may be injected via an injection well to

increase the flow of oil, including heavy paraffins and oleaginous material, from the field to be recovered via production wells. In some embodiments, enhanced oil recovery solvents may be injected as a mixture with an agent, such as steam, water, natural gas, a surfactant, a polymer flood agent, and additional solvents for injection via an injection well to increase the flow of oil, including heavy paraffins and oleaginous material, from the field to be recovered via production wells.

[0027] Conversion of natural gases at the wellsite to enhanced oil recovery solvents may be performed using processes such as partial oxidation processes, autothermal reformers, steam reformers, convective reformers, and other processes to convert the natural gas (i.e., methane, ethane, and propane) into a synthesis gas (carbon monoxide and hydrogen), followed by Fischer-Tropsch reactors, heavy paraffin synthesis (HPS) reactors, or other processes for conversion of a synthesis gas into heavier hydrocarbons (i.e.,  $C_{4+}$  hydrocarbons). The heavier natural gas components (propane, butane, etc.) may be separated prior to the natural gas conversion reactor and used as enhanced oil recovery solvents. This arrangement may allow the separation of the produced solvent from the light components of the natural gas, when the solvent reaches the producing wells.

[0028] Fischer-Tropsch reactors useful in embodiments disclosed herein may include, for example, fixed, slurry, microchannel or fluidized bed reactors, that may be catalyzed, for example, using a cobalt or iron based catalyst. Examples of Fischer-Tropsch processes are described, for example, in U.S. Pat. Nos. 4,624,968 and 6,479,557, and EP Publication No. EP 0 428 223 A1, each of which are incorporated herein by reference. HPS processes are described, for example, in U.S. Pat. No. 6,479,557, which is incorporated herein by reference.

[0029] Reformers useful in embodiments disclosed herein may include, for example, a Haldor Topsoe convective reformer, such as described in U.S. Pat. No. 7,060,118 and incorporated herein by reference. Other reformers useful in embodiments disclosed herein may include a Davy Process Technology compact reformer, such as described in U.S. Pat. No. 6,903,140 and incorporated herein by reference, or a membrane steam reformer, such as available from Shell Oil Company, described in U.S. Pat. No. 6,821,501 and incorporated herein by reference. Suitable reforming processes for the production of synthesis gas are described, for example, in U.S. Pat. Nos. 5,628,931, 6,852,762, 7,462,209, and WO-98/01514, each of which are incorporated herein by reference.

[0030] The above described reforming and Fischer-Tropsch technologies may be placed in series or may be mass and/or heat integrated. Other reforming and Fischer-Tropsch technologies known in the art may also be used.

[0031] In other embodiments, compact gas-to-liquids (GTL) technology and other similar processes for conversion of light hydrocarbons into heavier hydrocarbons may also be used. For example, compact GTL units, such as those disclosed in U.S. Pat. Nos. 7,501,456; and 7,351,750 incorporated herein by reference, which may include reformers and Fischer-Tropsch reactors with heat and mass integration.

[0032] Embodiments disclosed herein may advantageously allow for on-site processing of natural gases to produce enhanced oil recovery solvents using feedstocks and fuels readily available at the wellsite, reducing natural gas and/or solvent transportation (to and/or from the wellsite), processing, and other costs typically associated with enhanced oil

recovery operations. Embodiments disclosed herein may further provide for portability of the natural gas-to-solvent process equipment. Modularity and/or portability of the process equipment may advantageously allow the equipment to be useful for oilfields having difficult access and/or offshore oilfields, as well as the ability to relocate the process equipment to other production fields for enhanced oil recovery.

[0033] Within the scope of this application, the expression “enhanced oil recovery solvent” denotes a composition used to extract heavier and/or residual oil from an underground formation, for example, by reducing the oil apparent viscosity and/or increasing the mobility of the oleaginous materials to be produced during enhanced oil recovery operations. The mixture of solvent and natural gas may make the injectant “first contact” or “multiple contact” miscible and allows the excess stranded gas to be utilized for enhanced oil recovery. Mere reinjection of the stranded gas alone is not economical or efficient for enhanced oil recovery since it bypasses much of the oil and makes a channel through to the producing well, requiring higher recompression power and larger equipment.

[0034] The term “enhanced oil recovery solvent” may include, but is not limited to, hydrocarbons including propane, butane, pentane, hexane, heptane, octane, and mixtures thereof. For example, a solvent may be a linear paraffin of intermediate molecular weight, e.g. C<sub>3</sub>-C<sub>10</sub>. Solvents of C<sub>4</sub> and above may behave more like a liquid at downhole (production) conditions, and may be able to easily mix with the oil, reducing the bubble point of the oil and increasing its miscibility at lower reservoir pressures.

FIG. 1:

[0035] Referring now to FIG. 1, a simplified process flow diagram of an enhanced oil recovery process according to embodiments disclosed herein is illustrated. Reservoir 10, may contain, for example, residual oil not recovered during primary oil recovery operations. Natural gas may be contained in reservoir 10 and/or a proximately located reservoir 12. Natural gas produced from reservoir 10 and/or reservoir 12 via wellbore 14 and/or wellbore 16, respectively, may be fed via flow lines 18 and/or 20 to system 22 for the conversion of the natural gas to enhanced oil recovery solvents.

[0036] In system 22, the natural gas, such as methane, may be converted into heavier hydrocarbons, including enhanced oil recovery solvents and heavier hydrocarbons. The heavier hydrocarbons may be separated from the enhanced oil recovery solvents, and the heavier hydrocarbons may be recovered via flow line 24, and optionally combined with the residual oil recovered via wellbore 14 in flow line 26 for further recovery, transport, and processing, such as various refining and hydrotreating processes useful for the production of desired end products.

[0037] The enhanced oil recovery solvents may be recovered from system 22 via flow line 28 and may be injected via wellbore 30 into reservoir 10 for enhanced oil recovery. The enhanced oil recovery solvent migrates from the high pressure injection wellbore 30 toward the low pressure production wellbore 14, dissolving, fluidizing, suspending, or dispersing residual oil within reservoir 10, the admixture of which may be recovered via wellbore 14 and processed as described above.

[0038] In some embodiments, enhanced oil recovery solvent in stream 30 may be admixed with other components, such as fed via flow line 32, useful in enhanced oil recovery prior to injection into reservoir 10 via wellbore 30. For

example, additional solvents, natural gases, steam, water, emulsifiers, and other agents that may be used during enhanced oil recovery operations may be fed via flow line 32 and combined with enhanced oil recovery solvents produced in system 22. In other embodiments, enhanced oil recovery solvent injection may be alternated or followed with injection of another agent, such as water, steam, natural gas, carbon dioxide, nitrogen, and other agents as are known in the art, to enhance the residual oil recovery.

FIG. 2:

[0039] Referring now to FIG. 2, a system 22 useful in enhanced oil recovery processes according to embodiments disclosed herein is illustrated, where like numerals represent like parts. Natural gas recovered via flow line 20 may be fed to steam reformer 42. Additional reactants, such as water, may be fed to reformer 42 via flow line 44. Reformer 42 may be heated, for example, by combusting natural gas or other fuels available at the site, which may be fed along with air via flow lines 46 and 48, respectively.

[0040] Reformer 42 may be used to convert natural gas and steam to carbon monoxide and hydrogen over an appropriate catalyst, such as a nickel or cobalt catalyst, at temperature in the range from about 800° C. to about 1000° C., for example. The reactions occurring during steam reforming may be represented by the following:



and



[0041] As carbon monoxide is the desired product, conditions favoring Reaction (1) over Reaction (2), such as elevated temperatures, for example, from about 700° C. to about 1100° C. or from about 800° C. to about 1000° C., may be used. Further, reaction variables, such as reaction pressure, space velocity, and feedstock, may affect the relative rates between Reactions (1) and (2) and the resulting product mixture.

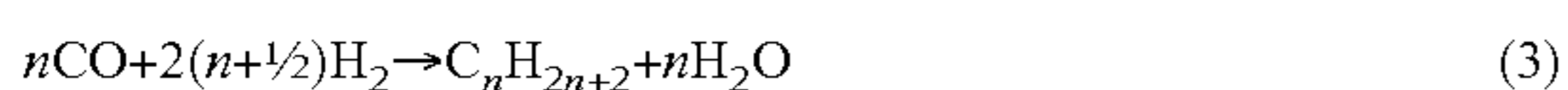
[0042] Following conversion of the natural gas in reformer 42, the resulting synthesis gas may be recovered via flow line 50. Reformers, including steam reformers, may result in a synthesis gas having a molar ratio of hydrogen to carbon monoxide in the range from about 2:1 to about 4:1, depending upon the composition of the natural gas feedstock.

[0043] The hydrogen to carbon monoxide ratio of the synthesis gas recovered via flow stream 50 may then be adjusted to a desired feed inlet ratio for the Fischer-Tropsch or Heavy Paraffin Synthesis (HPS) reaction. For example, a membrane separation unit 52 may be used to separate a portion of the hydrogen from the synthesis gas to produce a hydrogen depleted fraction (carbon monoxide enriched) recovered via flow line 54 and a hydrogen enriched fraction (carbon monoxide depleted) recovered via flow line 56. Membrane separation unit 52 may include membrane 58, such as a palladium-alloy supported membrane or other polymeric or rubbery type membranes. In particular embodiments, membrane 58 may include PRISM™ membranes that are available commercially. Membrane 58, for example, may allow hydrogen to selectively permeate through the membrane, concentrating carbon monoxide on the high pressure side 60. Hydrogen recovered via flow line 56 may be used as fuel for heating of reformer 42, may be used in other chemical reactions, or may

be stored or exported, in some embodiments. If necessary, the synthesis gas may be cooled to a desired temperature prior to separating hydrogen from the mixture, such as via heat exchanger 62. Heat integration of system 22 may allow heat recovered in heat exchanger 62 to be used, for example, for preheating the water or natural gas feeds 20, 44 prior to steam reforming reactor 42.

[0044] If the feed natural gas contains an appreciable amount of carbon dioxide (for example from about 5 to 40% molar), then the molar ratio of hydrogen to carbon monoxide produced in the reformer may be close to the desired ratio of 2:1 for the subsequent Fischer-Tropsch reaction. In that case, the hydrogen separation membrane may not be necessary.

[0045] The hydrogen depleted fraction may be fed via flow line 54 to Fischer-Tropsch reactor or HPS reactor 64, containing an appropriate catalyst if necessary, for conversion of the carbon monoxide and hydrogen to paraffins and other hydrocarbons. The desired hydrogen to carbon monoxide ratio of the hydrogen depleted fraction recovered from membrane separation unit 52 via flow line 54 may depend upon the range of hydrocarbon products desired from reactor 64. For example, a heavy paraffin synthesis reaction is illustrated as follows:



[0046] As shown in Reaction (3), varying the ratio of hydrogen to carbon monoxide may vary the paraffins produced. While Reaction (3) is illustrated with only one hydrocarbon product ( $\text{C}_n\text{H}_{2n+2}$ ), one skilled in the art recognizes that the extent of reaction may vary, resulting in a range of hydrocarbon products, where the average chain length may be  $n$  units.

[0047] In some embodiments, the desired syngas ratio for use in an HPS process may be calculated using the following Equation:

$$\text{H}_2:\text{CO ratio} = (2(n + \frac{1}{2}))/n = 2 + 1/n \quad (4)$$

[0048] In Equation (4),  $n$  represents the number of carbons in the average length of paraffin desired. For example, using Equation (4), if  $\text{C}_{10}$  paraffins are the primary paraffin product desired, then the desired syngas ratio of hydrogen to carbon monoxide is 2.10:1. As another example, if  $\text{C}_{20}$  paraffins are the primary paraffin product desired, then the desired syngas ratio of hydrogen to carbon monoxide is 2.05:1. Adjusting the separator permeate pressure (the pressure on the low pressure side of membrane 58) may allow the ratio of hydrogen to carbon monoxide to be adjusted to the desired level.

[0049] The extent of hydrogen separation required in membrane separation unit 52 may depend upon the feedstock composition (i.e., the hydrogen to carbon monoxide ratio resulting from the reformer) and the desired hydrogen to carbon monoxide ratio for the inlet to paraffin synthesis reactor 64. For example, for a synthesis gas having a hydrogen to carbon monoxide ratio of about 3:1, the separation device may remove approximately one-third of the hydrogen, reducing the hydrogen to carbon monoxide ratio to 2:1 for feed to reactor 64. In certain embodiments, the hydrogen to carbon monoxide ratio in the hydrogen depleted fraction 54 may range from approximately 1.8:1 to 2.2:1. Higher or lower ratios may be accommodated, depending upon the paraffin synthesis reactor used and the desired chain length of the resulting paraffins. In some embodiments, desired ratios of hydrogen to carbon monoxide may be produced by blending different syngas streams having varying syngas compositions and/or syngas components. The different syngas streams may

include streams obtained from different steps in the process, recycle streams, and streams originating from different geographical sources. Other separation devices may also be used to obtain the desired hydrogen to carbon monoxide ratio for the feed gas fed to reactor 64.

[0050] The hydrogen adjusted synthesis gas output from the separation device 52 may be at an appropriate temperature and pressure condition to feed hydrocarbon synthesis reactor 64. For example, HPS reactors may operate at a temperature from about 300° C. to about 350° C. and a pressure from about 10 bara to about 30 bara. Fischer-Tropsch processes may use elevated temperatures, normal or elevated pressures, and catalyst(s), such as magnetic iron oxides or cobalt catalysts.

[0051] Products produced from a Fischer-Tropsch process may include hydrocarbons having a broad molecular weight distribution and may include branched and/or unbranched paraffins. For example, the Fischer-Tropsch products may be  $\text{C}_{3-200}$  hydrocarbons,  $\text{C}_{5-80}$  hydrocarbons, and  $\text{C}_{6-20}$  hydrocarbons, or mixtures thereof. These products, or portions thereof, may be liquid at temperatures between 5° C. and 30° C. (at 1 bar), and usually are paraffinic of nature. In some embodiments, up to 20% by weight or up to 5% by weight, of either olefins or oxygenated compounds may be present.

[0052] In Fischer-Tropsch processes, the syngas is contacted with a suitable catalyst in one or more catalytic conversion zones, in which the hydrocarbons are formed. The Fischer-Tropsch process may be performed under conventional synthesis conditions known in the art. Typically, the catalytic conversions may be effected at a temperature in the range from 100° C. to 600° C., or from 180° C. to 270° C. Total pressures for the catalytic conversion process are in the range from 1 to 200 bar absolute, or from 10 to 70 bar absolute.

[0053] The HPS process may contain Fischer-Tropsch catalysts. Reaction conditions for the production of paraffins from syngas in HPS processes may vary widely. For example, temperatures may be in the range from about 100 to about 400° C., or in the range from 200 to 250° C. Total pressures may be in a range from about 0.1 to about 10 MPa, or in the range from 2 to 6 MPa. The Gas Hourly Space Velocity (GHSV) may be from about 100 to 10000 NI/I/h, or from 500 to 2000 NI/I/h.

[0054] As shown in Reaction (3) above, paraffin synthesis results in the production of water and hydrocarbons, which may be separated by any means known in the art. The water may be recovered and recycled via flow line 66 to reformer 42, injected into reservoir 10, or stored or exported, in some embodiments. Further efficiencies for system 22 may be attained by recovering and integrating the heat produced from hydrocarbon synthesis reactor 64.

[0055] The hydrocarbons produced in reactor 64 may be recovered via flow line 68. Hydrocarbon products recovered from reactor 64 via flow line 68 may include paraffins and by-products such as olefins and oxygen-containing products, such as ethers and alcohols.

[0056] As mentioned above, the hydrocarbons recovered via flow line 68 may range in molecular weight, such as from a  $\text{C}_3$  to a  $\text{C}_{20}$  or higher. Following the hydrocarbon synthesis process, the hydrocarbon products may be separated into various fraction to recover the desired enhanced oil recovery solvents. For example, the hydrocarbon products recovered via flow line 68 may be fed to separator 70 to separate enhanced oil recovery solvents from heavier hydrocarbon materials. Enhanced oil recovery solvents may be recovered

from separator **70** via flow line **28** and injected into reservoir **10** (FIG. **1**) as described above. The heavier hydrocarbon materials may be recovered from separator **70** via flow line **24**, which may be admixed, if desired, with residual oil recovered via flow line **26** (FIG. **1**).

**[0057]** In some embodiments, C1 and C2 hydrocarbons from reactor **64** may be recycled to reformer **42** and/or reactor **64**. C3 to C6 hydrocarbons may be injected into reservoir **10** by line **28** and well **30**. C7 and heavier hydrocarbons may be mixed with produced oil for export by line **24**.

**[0058]** In some embodiments, the hydrocarbon solvent to be injected into reservoir **10** by line **28** and well **30** has a composition with less than 50 mol % methane, 5-40 mol % propane, 5-40 mol % butane, and 2-20 mol % pentane. In other embodiments, the hydrocarbon solvent to be injected into reservoir **10** by line **28** and well **30** has a composition with less than 40 mol % methane, 10-20 mol % propane, 5-15 mol % butane, and 3-10 mol % pentane.

**[0059]** In some embodiments, the hydrocarbon to be mixed with produced oil for export by line **24** has a composition with less than 5 mol % methane, less than 5 mol % propane, and less than 10 mol % butane.

**[0060]** Processes disclosed herein may include any number of reactors, including slurry bed reactors, ebulliating bed reactors, microchannel reactors and fixed bed reactors. The processes may be operated in a single pass mode or in a recycle mode. The processes may be carried out in one or more reactors, either parallel or in series.

**[0061]** All of the products of a process step may be subjected to the next process step. However, it is possible to send only portions of the products of a process step to the next process step.

**[0062]** Embodiments of the invention are now further described by means of the following Examples.

### EXAMPLES

**[0063]** The following examples are derived from modeling techniques. Although the work has been performed, the Inventors do not present these examples in the past tense to comply with applicable rules.

#### Example 1

**[0064]** Enhanced oil recovery solvent is produced using a system **22** similar to that illustrated in FIG. **2**. A natural gas is fed to a reformer **42** and the hydrogen content in the synthesis gas is adjusted to have a hydrogen to carbon monoxide ratio of about 2:1. Fischer-Tropsch synthesis of the 2:1 hydrogen to carbon monoxide gas results in a hydrocarbon stream having a product following the Flory-Schultz molecular weight distribution. The Fischer-Tropsch products are fed to separator **70** (in this Example, separator **70** is a three stage flash) at a feed rate of 2000 barrels per day (BPD), (e.g., 10 compact gas-to-liquids trains converting 20 MM scfd natural gas feed to liquid).

**[0065]** The resulting enhanced oil recovery solvent (stream **28**) contains 78.9% of the moles in the feed gas and 53.4% by weight of the feed. The enhanced oil recovery solvent has concentrations of 18 mol % propane, 10.6 mol % butane, 4.7 mol % pentane, and 38 mol % methane. These solvent concentrations are advantageous over other solvents produced by oil-gas separation processes, which may include compositions of greater than 70 mol % methane and less than 7 mol % for each of C<sub>3</sub>-C<sub>5</sub>.

**[0066]** The hydrocarbon product (stream **24**) has a flow rate of 708 BPD, a molecular weight of 108, and an American Petroleum Institute (API) gravity of 70. The hydrocarbon product contains 2.5 mol % propane and 9.4 mol % butane and may be blended with oil products. Alternatively, the propane and butane concentration may be reduced using additional processing if necessary or required to meet Reid Vapor Pressure (RVP) requirements.

**[0067]** As shown above, enhanced oil recovery processes disclosed herein may advantageously produce enhanced oil recovery solvents at a wellsite, such as an injection wellsite, using natural gas produced at or near the injection wellsite. The enhanced oil recovery solvent may then be injected downhole to result in enhanced oil recovery from the reservoir.

**[0068]** Advantageously, embodiments described herein may provide higher oil recovery than the miscible gas enhanced oil recovery processes currently in use. Other advantages include improved use of stranded gas, as the stranded gas may be used as a solvent (i.e., injection product), or only a portion of the stranded gas may be converted to a solvent, with the remaining portion re-injected to the reservoir or used as a fuel for conversion of the natural gas to hydrocarbon liquids. Use of stranded gas may provide environmental benefits, as the gas would not be flared or otherwise require disposal. Further, use of stranded gas may advantageously provide a convenient and economical source of solvents and/or oil product additives. Additionally, processes according to embodiments disclosed herein may create immediate value from the natural gas by producing some heavy liquid product that may be blended with the produced oil.

**[0069]** Additional advantages provided by embodiments disclosed herein may include compact and/or modular process equipment, decreasing capital requirements and providing for portability of the equipment, making the equipment also useful for difficult to access oilfields and for offshore use. For example, compact GTL systems useful in embodiments disclosed herein may include one or multiple reactor trains, allowing for adjustment of capacity to match the field production profile. Thus, embodiments disclosed herein may be suitable for use in small fields, large fields, and for producing offshore fields from floating structures. They can also be deployed in other fields after the useful life of one field has expired.

**[0070]** Embodiments disclosed herein may additionally advantageously provide for extra light hydrocarbon value in the latter portions of field life. When the solvent is produced from the wells, it will typically be in excess. Part or all of the solvent can be blended with the produced oil to provide additional value.

#### Illustrative Embodiments

**[0071]** In one embodiment, there is disclosed a system for producing oil and/or gas comprising a mechanism for recovering oil and/or gas from an underground formation, the oil and/or gas comprising natural gas; a mechanism for converting at least a portion of the natural gas from the recovered oil and/or gas into an enhanced oil recovery solvent formulation; and a mechanism for releasing at least a portion of the enhanced oil recovery solvent formulation into the formation. In some embodiments, the mechanism for recovering comprises a well in the underground formation and a recovery facility at a topside of the well; wherein the mechanism for

converting comprises a converting facility fluidly connected to the recovery facility; and wherein the converting facility is adapted to produce the enhanced oil recovery solvent formulation from at least a portion of the natural gas recovered from the well. In some embodiments, the mechanism for recovering comprises a first well drilled in the underground formation for recovering the oil and/or gas, and a production facility at a topside of the first well; and wherein the mechanism for releasing the enhanced oil recovery solvent formulation comprises a second well in the underground formation for releasing the enhanced oil recovery solvent formulation into the formation. In some embodiments, the first well is at a distance of 15 meters to 250 kilometers from the second well. In some embodiments, the underground formation is beneath a body of water, and/or the mechanism for converting is above the body of water, such as a production platform; floating production, storage, and offshore loading vessel (FPSO); or a tension leg platform. In some embodiments, the system also includes a mechanism for injecting water and/or steam, the mechanism adapted to inject water and/or steam into the underground formation after the enhanced oil recovery solvent formulation has been released into the formation. In some embodiments, the mechanism for converting comprises a reformer to convert at least a portion of the natural gas into a syngas comprising carbon monoxide and hydrogen. In some embodiments, the mechanism for converting comprises a reactor for reacting at least a portion of the syngas to create the enhanced oil recovery solvent. In some embodiments, the enhanced oil recovery solvent comprises less than 70 mol % methane; from 5 to 40 mol % propane; from 3 to 30 mol % butane; and from 1 to 20 mol % pentane. In some embodiments, the enhanced oil recovery solvent comprises less than 40 mol % methane; from 15 to 25 mol % propane; from 5 to 15 mol % butane; and from 3 to 10 mol % pentane. In some embodiments, the system also includes a mechanism for separating the natural gas into a first stream to be converted into the enhanced oil recovery solvent formulation, and a second stream to be mixed with the enhanced oil recovery solvent formulation and released into the formation. In some embodiments, the second stream comprises carbon dioxide. In some embodiments, the first stream comprises methane and ethane.

**[0072]** In one embodiment, there is disclosed a method for producing oil and/or gas comprising recovering oil and/or gas from an underground formation, the oil and/or gas comprising natural gas; converting at least a portion of the natural gas from the recovered oil and/or gas into an enhanced oil recovery solvent formulation; and releasing at least a portion of the enhanced oil recovery solvent formulation into the formation.

**[0073]** In some embodiments, the method also includes recovering the enhanced oil recovery solvent formulation from the oil and/or gas, if present, and then injecting at least a portion of the recovered enhanced oil recovery solvent formulation into the formation. In some embodiments, releasing comprises injecting at least a portion of the enhanced oil recovery solvent formulation into the formation in a mixture with one or more of hydrocarbons; water in the form of liquid and/or vapor; natural gas other than enhanced oil recovery solvent; carbon dioxide; carbon monoxide; or mixtures thereof. In some embodiments, the method also includes heating the enhanced oil recovery solvent formulation prior to injecting the enhanced oil recovery solvent formulation into the formation, or while within the formation. In some embodiments, another material is injected into the formation

after the enhanced oil recovery solvent formulation is injected, for example the another material selected from the group consisting of air, nitrogen, water in the form of liquid and/or vapor, natural gas, carbon dioxide, and/or mixtures thereof. In some embodiments, the enhanced oil recovery solvent formulation is injected at a pressure from 0 to 37,000 kilopascals above the initial reservoir pressure, measured prior to when enhanced oil recovery solvent injection begins. In some embodiments, any oil, as present in the underground formation prior to the injecting the enhanced oil recovery solvent formulation, has a viscosity from 0.14 cp to 6 million cp, for example a viscosity from 0.3 cp to 30,000 cp, or from 5 cp to 5,000 cp. In some embodiments, the underground formation comprises a permeability from 0.0001 to 15 Darcies, for example a permeability from 0.001 to 1 Darcy. In some embodiments, the method also includes converting at least a portion of the recovered oil and/or gas into a material selected from the group consisting of transportation fuels such as gasoline and diesel, heating fuel, lubricants, chemicals, and/or polymers.

**[0074]** While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

1. A system for producing oil and/or gas comprising:
  - a mechanism for recovering oil and/or gas from an underground formation, the oil and/or gas comprising natural gas;
  - a mechanism for converting at least a portion of the natural gas from the recovered oil and/or gas into an enhanced oil recovery solvent formulation; and
  - a mechanism for releasing at least a portion of the enhanced oil recovery solvent formulation into the formation.

2. The system of claim 1,
  - wherein the mechanism for recovering comprises a well in the underground formation and a recovery facility at a topside of the well;
  - wherein the mechanism for converting comprises a converting facility fluidly connected to the recovery facility; and
  - wherein the converting facility is adapted to produce the enhanced oil recovery solvent formulation from at least a portion of the natural gas recovered from the well.

3. The system of claim 1,
  - wherein the mechanism for recovering comprises a first well drilled in the underground formation for recovering the oil and/or gas, and a production facility at a topside of the first well; and

wherein the mechanism for releasing the enhanced oil recovery solvent formulation comprises a second well in the underground formation for releasing the enhanced oil recovery solvent formulation into the formation.

4. The system of claim 3, wherein the first well is at a distance of 15 meters to 250 kilometers from the second well.

5. The system of claim 1 wherein the underground formation is beneath a body of water, and/or the mechanism for converting is above the body of water, such as a production platform; floating production, storage, and offshore loading vessel (FPSO); or a tension leg platform.

6. The system of claim 1, further comprising a mechanism for injecting water and/or steam, the mechanism adapted to



inject water and/or steam into the underground formation after the enhanced oil recovery solvent formulation has been released into the formation.

7. The system of claim 1, wherein the mechanism for converting comprises a reformer to convert at least a portion of the natural gas into a syngas comprising carbon monoxide and hydrogen.

8. The system of claim 7, wherein the mechanism for converting comprises: a reactor for reacting at least a portion of the syngas to create the enhanced oil recovery solvent.

9. The system of claim 1, wherein the enhanced oil recovery solvent comprises:

- less than 70 mol % methane;
- from 5 to 40 mol % propane;
- from 3 to 30 mol % butane; and
- from 1 to 20 mol % pentane.

10. The system of claim 1, wherein the enhanced oil recovery solvent comprises:

- less than 40 mol % methane;
- from 15 to 25 mol % propane;
- from 5 to 15 mol % butane; and
- from 3 to 10 mol % pentane.

11. The system of claim 1, further comprising a mechanism for separating the natural gas into a first stream to be converted into the enhanced oil recovery solvent formulation, and a second stream to be mixed with the enhanced oil recovery solvent formulation and released into the formation.

12. The system of claim 11, wherein the second stream comprises carbon dioxide.

13. The system of claim 11, wherein the first stream comprises methane and ethane.

14. A method for producing oil and/or gas comprising:
- recovering oil and/or gas from an underground formation, the oil and/or gas comprising natural gas;
  - converting at least a portion of the natural gas from the recovered oil and/or gas into an enhanced oil recovery solvent formulation; and
  - releasing at least a portion of the enhanced oil recovery solvent formulation into the formation.

15. The method of claim 14, further comprising recovering the enhanced oil recovery solvent formulation from the oil and/or gas, if present, and then injecting at least a portion of the recovered enhanced oil recovery solvent formulation into the formation.

16. The method of claim 14, wherein releasing comprises injecting at least a portion of the enhanced oil recovery solvent formulation into the formation in a mixture with one or more of hydrocarbons; water in the form of liquid and/or vapor; natural gas other than enhanced oil recovery solvent; carbon dioxide; carbon monoxide; or mixtures thereof.

17. The method of claim 14, further comprising heating the enhanced oil recovery solvent formulation prior to injecting the enhanced oil recovery solvent formulation into the formation, or while within the formation.

18. The method of claim 14, wherein another material is injected into the formation after the enhanced oil recovery solvent formulation is injected, for example the another material selected from the group consisting of air, nitrogen, water in the form of liquid and/or vapor, natural gas, carbon dioxide, and/or mixtures thereof.

19. The method of claim 14, wherein the enhanced oil recovery solvent formulation is injected at a pressure from 0 to 37,000 kilopascals above the initial reservoir pressure, measured prior to when enhanced oil recovery solvent injection begins.

20. The method of claim 14, wherein any oil, as present in the underground formation prior to the injecting the enhanced oil recovery solvent formulation, has a viscosity from 0.14 cp to 6 million cp, for example a viscosity from 0.3 cp to 30,000 cp, or from 5 cp to 5,000 cp.

21. The method of claim 14, wherein the underground formation comprises a permeability from 0.0001 to 15 Darcies, for example a permeability from 0.001 to 1 Darcy.

22. The method of claim 14, further comprising converting at least a portion of the recovered oil and/or gas into a material selected from the group consisting of transportation fuels such as gasoline and diesel, heating fuel, lubricants, chemicals, and/or polymers.

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