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Inventor(s)	Pedretti; Andrea et al.

SYSTEM FOR GENERATING ELECTRICITY OR HYDROGEN FROM NATURAL GAS

Abstract

A system for generating electricity or hydrogen from natural gas can be connected between a gas backbone pipe and a local gas distribution pipe. The system includes a thermal energy storage unit containing a thermal energy storage material heated by an energy source. The system also includes a heat exchanger in fluid communication with the thermal energy storage unit that receives a flow natural gas from the gas backbone pipe and a heated fluid from the thermal energy storage unit to heat the flow of natural gas. The system also includes an expander in fluid communication with the heat exchanger and that receives a flow of heated natural gas from the heat exchanger and to expand the flow of heated natural gas to cool it and reduce its pressure. A generator connected to the expander generates electricity from the expansion of the flow of heated natural gas by the expander.

Inventors: **Pedretti; Andrea (Thousand Oaks, CA), Altwegg; Peter (Montagnola, CH), Pfammatter; Daniel Roger (Montagnola, CH), Escher; Patrick Clemens (Dübendorf, CH)**

Applicant: **Energy Vault, Inc.** (Westlake Village, CA)

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Background/Summary

INCORPORATION BY REFERENCE TO ANY PRIORITY APPLICATIONS [0001] Any and all applications for which a foreign or domestic priority claim is identified in the Application Data Sheet as filed with the present application are hereby incorporated by reference under 37 CFR 1.57. This application is a national phase of PCT Application No. PCT/US2023/018295 which claims priority to U.S. Provisional Patent Application No. 63/363,232 filed Apr. 19, 2022, the entirety of which is incorporated herein by references and is considered part of the specification.

BACKGROUND
Field
[0002] The present invention is directed to green energy generation, and more particularly to a system and method for generating electricity or hydrogen from natural gas using a renewable energy source.
Description of the Related Art
[0003] Natural gas is a non-renewable energy source and fossil fuel that is widely used (e.g., for heating, cooking, to generate electricity). There is an increased focus on reducing the use of fossil fuels to reduce the greenhouse gas emissions to the atmosphere.
SUMMARY
[0004] There is a need for systems and methods that reduce the use of natural gas in generating electricity.
[0005] In accordance with one aspect of the disclosure, a system is provided to heat and expand natural gas between a gas backbone pipe and a local gas distribution pipe to generate electricity or produce hydrogen to capture energy that would otherwise be lost to entropy by expanding the gas between the gas backbone pipe and a local gas distribution pipe via a valve (e.g., throttle valve).
[0006] In some aspects, the techniques described herein relate to a system for generating electricity or hydrogen from natural gas, the system configured to be connected to a gas backbone pipe and a local gas distribution pipe. The system includes a thermal energy storage unit that contains a thermal energy storage material, the thermal energy storage unit configured to receive energy from an energy source to heat the thermal energy storage material. The system also includes a heat exchanger in fluid communication with the thermal energy storage unit, the heat exchanger configured to receive a flow natural gas from the gas backbone pipe and a heated fluid from the thermal energy storage unit that heats the flow of natural gas. The system also includes an expander in fluid communication with the heat exchanger, the expander configured to receive a flow of heated natural gas from the heat exchanger and configured to expand the flow of heated natural gas to cool it and reduce its pressure. The system also includes a generator connected to the expander and configured to generate electricity from the expansion of the flow of heated natural gas by the expander.
[0007] In some aspects, the techniques described herein relate to a system, wherein the thermal energy storage unit, heat exchanger, expander and generator are part of a standalone transportable unit.

[0008] In some aspects, the techniques described herein relate to a system where the energy source is a renewable energy source.
[0009] In some aspects, the techniques described herein relate to a system where the energy source is a photovoltaic plant.
[0010] In some aspects, the techniques described herein relate to a system where the energy source is a concentrated solar power plant.
[0011] In some aspects, the techniques described herein relate to a system where the energy source is an electric grid.
[0012] In some aspects, the techniques described herein relate to a system where the thermal energy storage material is water.
[0013] In some aspects, the techniques described herein relate to a system where the thermal energy storage material is pressurized water.
[0014] In some aspects, the techniques described herein relate to a system where the thermal energy storage material includes a solid material.
[0015] In some aspects, the techniques described herein relate to a system where the thermal energy storage material includes rocks.
[0016] In some aspects, the techniques described herein relate to a system where the thermal energy storage material includes packed gravel.
[0017] In some aspects, the techniques described herein relate to a system where the expander includes a first expander and a second expander.
[0018] In some aspects, the techniques described herein relate to a system wherein the heat exchanger includes a first heat exchanger between the gas backbone pipe and a first expander and a second heat exchanger between the first expander and a second expander.
[0019] In some aspects, the techniques described herein relate to a system further including an electrolyzer configured to receive the generated electricity from the generator to generate hydrogen.
[0020] In some aspects, the techniques described herein relate to a system where the generated hydrogen is injected into the local gas distribution pipe.
[0021] In some aspects, the techniques described herein relate to a system where the generated hydrogen is injected into a pipe separate from the local gas distribution pipe.
[0022] In some aspects, the techniques described herein relate to a system where the generated electricity is supplied to the electric grid.
[0023] In some aspects, the techniques described herein relate to a method for generating electricity or hydrogen from natural gas. The method includes heating via a heat exchanger a flow of natural gas flowing between a gas backbone pipe and a local gas distribution pipe. The method also includes expanding via an expander the flow of heated natural gas received from the heat exchanger. The method also includes generating electricity from an expansion of the flow of a heated natural gas by the expander.
[0024] In some aspects, the techniques described herein relate to a method where heating the flow of natural gas includes receiving a heated fluid in the heat exchanger from a thermal energy storage unit to heat the flow of natural gas.
[0025] In some aspects, the techniques described herein relate to a method where expanding the flow of heated natural gas includes cooling and reducing the pressure of the heated flow of natural gas.
[0026] In some aspects, the techniques described herein relate to a method where expanding the flow of heated natural gas occurs in multiple stages.
[0027] In some aspects, the techniques described herein relate to a method which includes generating hydrogen via an electrolyzer powered by the generated electricity.
[0028] In some aspects, the techniques described herein relate to a method which includes injecting the generated hydrogen into the local gas distribution pipe.

[0029] In some aspects, the techniques described herein relate to a method which includes injecting the generated hydrogen into a pipe separate from the local gas distribution pipe.
[0030] In some aspects, the techniques described herein relate to a method which includes supplying at least a portion of the generated electricity to an electricity grid.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0031] FIG. **1** is a schematic view of one system for generating electricity from natural gas.
[0032] FIG. **2** is a schematic view of another system for generating electricity from natural gas.
[0033] FIG. **3** is a schematic view of a standalone system for generating electricity from natural gas.
[0034] FIG. **4** is a schematic view of a standalone system for generating hydrogen from natural gas.
[0035] FIG. **5** is a schematic view of a standalone system for generating electricity from natural gas.
[0036] FIG. **6** is a schematic view of a standalone system for generating hydrogen from natural gas.
DETAILED DESCRIPTION
[0037] FIG. **1** shows a system **100** for utilizing natural gas to generate electricity or hydrogen. Natural gas (e.g., hydrocarbon gas mixture including methane) is delivered via a gas pipe backbone **10** from a source to a city or industrial site at a pressure ranging from about 25 bar to about 100 bar (e.g., about 363 Psi to about 1450 Psi, 75 bar or 1087 Psi). The natural gas is transferred from the gas pipe backbone **10** to a local distribution pipe **90** via a connecting pipe **93**, with a valve **95** (e.g., throttling valve) coupled to the connecting pipe **93**. The valve **95** can be actuated (e.g., throttled) to reduce the pressure of the natural gas in the local distribution pipe **90** to a lower pressure, for example, of about 5 bar (e.g., about 73 Psi). The local distribution pipe **90** can connect to gas delivery pipes (not shown) that deliver natural gas to homes and businesses and industrial sites.
[0038] The system **100** advantageously uses a portion (e.g., 5%) of the natural gas flowing through the gas pipe backbone **10** to, in one implementation, generate electricity utilizing, in one example, a renewable energy source, and supplying the electricity to the electric grid or to an electricity storage device (e.g., batteries). In another implementation, the system **100** advantageously uses a portion (e.g., 5%) of the natural gas flowing through the gas pipe backbone **10** to generate hydrogen utilizing, in one example, a renewable energy source, and supplies the generated hydrogen, as further discussed below. In other implementations, electricity from the grid is used instead of a renewable energy source to generate electricity or generate hydrogen, as described below.
[0039] The system **100** includes a thermal energy storage unit **20** that can store thermal energy. In one implementation, the thermal energy storage unit **20** can house a liquid thermal energy storage material (e.g., water, pressurized water). In another implementation, the thermal energy storage unit **20** can house a solid thermal energy storage material (e.g., rocks, packed bed of gravel). The thermal energy storage unit **20** can receive heat or energy from an energy source **30** to heat the thermal energy storage material, for example, to a temperature of between about 100° C. to about 160° C., inclusive. In one implementation the energy source **30** is the electric grid, which delivers electricity to the thermal energy storage unit **20** (e.g., to a resistor in the thermal energy storage unit **20** to heat the thermal energy storage material). In another implementation, the energy source **30** is a renewable energy source, for example a solar (e.g. photovoltaic or PV) energy source or a wind energy source that provides electricity to, for example, a resistive heater (e.g., electrical resistor), in the thermal energy storage unit **20** that can heat the thermal energy storage material. In another implementation, the renewable energy source can be a concentrated solar energy source (e.g., concentrated solar power or CSP) that delivers heated air or a heated liquid to the thermal energy

storage unit **20** to heat the thermal energy storage material.

[0040] The thermal energy storage unit **20** is connected to a heat exchanger **40** via a pipe **22**. Where the thermal energy storage material is water, the thermal energy storage unit **20** supplies heated water to the heat exchanger **40** via the pipe **22**. Where the thermal energy storage material is a solid (e.g., rocks, packed gravel), the thermal energy storage unit **20** supplies heated air to the heat exchanger **40** via the pipe **22**. The heat exchanger **40** is connected to the gas pipe backbone **10** via a pipe **42**. The pipe **42** directs an amount of natural gas (e.g., between 5% and 10%, inclusive, of the volume supplied through the gas pipe backbone **10**) from the gas pipe backbone **10** to the heat exchanger **40**, where the natural gas is heated by the heated fluid supplied by the thermal energy storage unit **20**.

[0041] The heated natural gas exits the heat exchanger **40** via a pipe **44** that directs the heated natural gas to an expander **50** (e.g., turbine), which expands the heated natural gas to cool the gas, the cooled gas supplied to the local distribution pipe **90** via a pipe **52** at the nominal pressure of natural gas in the local distribution pipe **90** (e.g., nominal pressure of 5 bar, between 4.8 and 5.2 bar, etc.). In one implementation, the expander **50** is a single stage expander (e.g., single stage turbine). In another implementation, discussed further below, the expander **50** can be a two-stage expander (e.g., two-stage turbine). The expander **50** is connected (e.g., an output shaft of the expander **50** is connected) to a generator (e.g., electric generator) **60**, where the expansion of the natural gas by the expander **50** (e.g., turbine) generates electricity via the generator **60**. In one implementation, the electricity generated by the generator **60** is supplied to the electric grid. In another implementation, as discussed further below, the electricity generated by the generator **60** is supplied to an electrolyzer to generate hydrogen. In one implementation, the generator **60** can be a synchronous generator (e.g., that can rotate at 3600 rpm to sync with the electric grid), and the expander **50** can spin at 5000 or 6000 rpm (e.g., with a gear box in between the two). In another implementation, where the system **100** is used to generate hydrogen via an electrolyzer (as discussed further below), the generator can be a DC generator (e.g., 0.5 MW generator) that spins at 10,000 or 20,000 rpm and operates with an expander **50** that spins at 20,000 rpm, where the DC generator can be connected to the electrolyzer via a DC-DC converter, and the energy source that supplies energy to the thermal energy storage unit **20** can be a renewable energy source (e.g., photovoltaic plant) that provides 1 MW or 2 MW.

[0042] FIG. **2** shows a system **100′** for utilizing natural gas to generate electricity or hydrogen. Some of the features of the system **100′** are similar to features of the system **100** in FIG. **1**. Thus, reference numerals used to designate the various components of the system **100′** are identical to those used for identifying the corresponding components of the system **100** in FIG. **1**. Therefore, the structure and description for the various features and components of the system **100** and how it's operated and controlled in FIG. **1** are understood to also apply to the corresponding features and components of the system **100′** in FIG. **2**, except as described below.

[0043] The system **100′** differs from the system **100** in that the system **100′** includes a two-stage expander (e.g., first expander **50**A and second expander **50**B, such as a two-stage turbine) and two heat exchanger (e.g., first heat exchanger **40**A and second heat exchanger **40**B) and two generators (e.g., first generator **60**A and second generator **60**B) or optionally a single generator (e.g., generator **60**). A pipe **42**A connects the gas pipe backbone **10** with the first heat exchanger **40**A to direct natural gas into the heat exchanger **40**A where the natural gas is heated by the heated fluid (e.g., heated air, heated water) from the thermal energy storage unit **20**. The heated natural gas exits the first heat exchanger **40**A via a pipe **44**A and flows to the first expander **50**A, where the heated natural gas is expanded and cooled. The first expander **50**A is connected (e.g., via an output shaft) to the first generator **60**A, which generates electricity as a result of the expansion of the natural gas via the first expander **50**A. The cooled natural gas exits the first expander **50**A via a pipe **42**B and is directed to the second heat exchanger **40**B, where the natural gas is heated by the heated fluid (e.g., heated air, heated water) from the thermal energy storage unit **20**. The heated natural gas exits the second heat exchanger **40**B via a pipe **44**B and flows to the second expander **50**B, where the heated natural gas is expanded and cooled. The second expander **50**B is connected (e.g., via an output shaft) to the second generator **60**B, which generates electricity as a result of the expansion of the natural gas via the second expander **50**B. Alternatively, both expanders **50**A, **50**B are connected to a single generator (e.g., generator **60**, as shown in FIGS. **5-6**) instead of two separate generators **60**A, **60**B. The heated natural gas exits the second expander **50**B, which expands the heated natural gas to cool the gas, the cooled gas supplied to the local distribution pipe **90** via a pipe **52** at the nominal pressure of natural gas in the local distribution pipe **90** (e.g., nominal pressure of 5 bar, between 4.8 and 5.2 bar, etc.). In another implementation, as discussed further below, the electricity generated by the generators **60**A, **60**B is supplied to an electrolyzer to generate hydrogen.

[0044] Advantageously, using the two-stage expander in the system **100**′ (e.g., expander **50**A and expander **50**B with reheating with heat exchanger **40**B in between) advantageously allows the system **100**′ to reduce the pressure drop between each stage, which facilitates the design of the thermal energy storage unit **20** and thermal energy storage material used. For example, where the gas backbone pipe **10** operates at a pressure of 100 bar and the local gas distribution pipe **90** operates at a nominal pressure of 5 bar, having the two-stage expansion allows the first expander **50**A to reduce the pressure of the natural gas from 100 bar to about 20 bar, and allows the second expander **50**B to reduce the pressure of the natural gas from 20 bar to 5 bar. Advantageously, the two-stage expansion allows the thermal energy storage material to have a temperature of between 100° C. and 160° C. (e.g., 120° C.) for the fluid supplied to the heat exchangers **40**A, **40**B, which allows for water (e.g., pressurized water at about 3-6 bar, such as in a boiler) to be used as the thermal energy storage material. The thermal energy storage unit **20** can in such an implementation be simplified in design (e.g., a boiler for pressurized water), allowing the system **100**, **100**′, **100**A-**100**D to be supplied as a package or standalone system. In contrast, when a single state expansion is used in the system, dropping from 100 bar to 5 bar via an expander would require the thermal energy storage material to have a temperature of about 300° C. for the fluid supplied to the heat exchanger.

[0045] FIG. **3** shows a system **100**A for utilizing natural gas to generate electricity. Some of the features of the system **100**A are similar to features of the system **100** in FIG. **1**. Thus, reference numerals used to designate the various components of the system **100**A are identical to those used for identifying the corresponding components of the system **100** in FIG. **1**. Therefore, the structure and description for the various features and components of the system **100** and how it's operated and controlled in FIG. **1** are understood to also apply to the corresponding features and components of the system **100**A in FIG. **3**, except as described below.

[0046] The system **100**A differs from the system **100** in that the system **100**A is optionally a standalone system that can be housed in a container **2**A or attached to a frame. The system **100**A can advantageously be transported (e.g., in the container **2**A) to a location where the system **100**A can be connected to a gas pipe backbone and a local gas distribution pipe (e.g., such as the gas pipe backbone **10** and local gas distribution pipe **90**). In one example, multiple systems **100**A can be transported to different locations in a geographic area (e.g., outside a city or county) where there is an existing gas distribution network, each connected to a gas pipe backbone and a local gas distribution pipe, thereby advantageously provide for energy resiliency (e.g., multiple systems **100**A can operate in the event one needs maintenance, scheduled or unscheduled).

[0047] The system **100**A can be connected, via connector **41**, to a gas pipe backbone (e.g., gas pipe backbone **10** operating at a relatively higher delivery pressure, such as 25-100 bar) to direct a portion of natural gas flowing through the gas pipe backbone to the heat exchanger **40** and then the expander **50**. The system **100**A in the container **2**A can be connected to the local distribution pipe (e.g., local distribution pipe **90**) via connector **53** to return said portion of natural gas in an expanded state and at a relatively lower pressure (e.g., 5 bar nominal). The system **100**A can also have a connection **31** via which, in one example, electrical energy (e.g., from a photovoltaic plant, from the electric grid) is provided to the thermal energy storage unit **20** to heat (e.g., via a resistive heater) the thermal energy storage material therein, where the thermal energy storage unit **20** then supplies a heated fluid (e.g., heated air, hot water, hot pressurized water) to the heat exchanger **40** to heat said portion of natural gas. In another implementation, the connection **31** is one via which, in one example, a heated fluid (e.g. heated air, heated water, such as from a concentrated solar power plant) is provided to the thermal energy storage unit **20**, which then supplies a heated fluid (e.g., heated air, hot water, hot pressurized water) to the heat exchanger **40** to heat said portion of natural gas. The system **100**A can have an electrical connection **70** via which electricity generated by the generator **60** can be supplied out of the container **2**A (e.g., to the electric grid, to an energy storage unit, such as batteries, etc.).

[0048] FIG. **4** shows a system **100**B for utilizing natural gas to generate hydrogen. Some of the features of the system **100**B are similar to features of the system **100**A in FIG. **3**, which is based on system **100** in FIG. **1**. Thus, reference numerals used to designate the various components of the system **100**B are identical to those used for identifying the corresponding components of the system **100**A in FIG. **3**. Therefore, the structure and description for the various features and components of the system **100**A and how it's operated and controlled in FIG. **3**, which is based on the structure and description for the various features of the system **100** in FIG. **1**, are understood to also apply to the corresponding features and components of the system **100**B in FIG. **4**, except as described below.

[0049] The system **100**B differs from the system **100**A in that the generator **60** supplies electricity to an electrolyzer **80** to generate hydrogen, which can exit the system via a pipe and/or connector **81**. The electrolyzer **80** can be a conventional electrolyzer (e.g., using potassium hydroxide, an alkaline electrolyzer) that produces hydrogen at, for example, 16 bar to 30 bar of pressure. The system **100**B is optionally a standalone system that can be housed in a container **2**B or attached to a frame. The system **100**B can advantageously be transported (e.g., in the container **2**B) to a location where the system **100**B can be connected to a gas pipe backbone and a local gas distribution pipe (e.g., such as the gas pipe backbone **10** and local gas distribution pipe **90**). In one implementation, the generated hydrogen can be supplied to a container in a compressed or pressurized form, which can then be transported. In another implementation, the generated hydrogen can be injected into a parallel pipeline to the local gas distribution pipe (e.g., pipe **90**). In still another implementation, the generated hydrogen can be injected directly into the local gas distribution pipe (e.g., pipe **90**) and can make, for example 5-10% of the flow through the local gas distribution pipe, thereby advantageously reducing the greenhouse gas emissions for the distributed gas. In one implementation, where the energy source that provides electricity or a heated fluid (e.g., heated air, heated water) to the thermal energy storage unit **20** is a renewable energy source (e.g., photovoltaic plant, concentrated solar energy plant), the hydrogen generated by the electrolyzer **80** would be green hydrogen.

[0050] FIG. **5** shows a system **100**C for utilizing natural gas to generate electricity. Some of the features of the system **100**C are similar to features of the system **100**′ in FIG. **2**. Thus, reference numerals used to designate the various components of the system **100**C are identical to those used for identifying the corresponding components of the system **100**′ in FIG. **2**. Therefore, the structure and description for the various features and components of the system **100**′ and how it's operated and controlled in FIG. **2** are understood to also apply to the corresponding features and components of the system **100**C in FIG. **5**, except as described below.

[0051] The system **100**C differs from the system **100**′ in that the system **100**C is optionally a standalone system that can be housed in a container **2**C or attached to a frame. The system **100**C can advantageously be transported (e.g., in the container **2**C) to a location where the system **100**C can be connected to a gas pipe backbone and a local gas distribution pipe (e.g., such as the gas pipe backbone **10** and local gas distribution pipe **90**).

[0052] In one example, multiple systems **100**C can be transported to different locations in a geographic area (e.g., outside a city or county) where there is an existing gas distribution network, each connected to a gas pipe backbone and a local gas distribution pipe, thereby advantageously provide for energy resiliency (e.g., multiple systems **100**C can operate in the event one needs maintenance, scheduled or unscheduled).

[0053] The system **100**C can be connected, via connector **41**, to a gas pipe backbone (e.g., gas pipe backbone **10** operating at a relatively higher delivery pressure, such as 25-100 bar) to direct a portion of natural gas flowing through the gas pipe backbone to the heat exchangers **40**A and then the expander **50**A, as discussed previously. The system **100**C in the container **2**C can be connected to the local distribution pipe (e.g., local distribution pipe **90**) via connector **53** to return said portion of natural gas in an expanded state and at a relatively lower pressure (e.g., 5 bar nominal). The system **100**C can also have a connection **31** via which, in one example, electrical energy (e.g., from a photovoltaic plant, from the electric grid) is provided to the thermal energy storage unit **20** to heat (e.g., via a resistive heater) the thermal energy storage material therein, where the thermal energy storage unit **20** then supplies a heated fluid (e.g., heated air, hot water, hot pressurized water) to the heat exchangers **40**A, **40**B to heat said portion of natural gas. In another implementation, the connection **31** is one via which, in one example, a heated fluid (e.g. heated air, heated water, such as from a concentrated solar power plant) is provided to the thermal energy storage unit **20**, which then supplies a heated fluid (e.g., heated air, hot water, hot pressurized water) to the heat exchangers **40**A, **40**B to heat said portion of natural gas. The system **100**C can have an electrical connection **70** via which electricity generated by the generator **60** (which is connected to the expanders **50**A, **50**B) can be supplied out of the container **2**C (e.g., to the electric grid, to an energy storage unit, such as batteries, etc.).

[0054] FIG. **6** shows a system **100**D for utilizing natural gas to generate hydrogen. Some of the features of the system **100**D are similar to features of the system **100**C in FIG. **5**, which is based on system **100**′ in FIG. **2**. Thus, reference numerals used to designate the various components of the system **100**D are identical to those used for identifying the corresponding components of the system **100**C in FIG. **5**. Therefore, the structure and description for the various features and components of the system **100**C and how it's operated and controlled in FIG. **5**, which is based on the structure and description for the various features of the system **100**′ in FIG. **2**, are understood to also apply to the corresponding features and components of the system **100**D in FIG. **6**, except as described below.

[0055] The system **100**D differs from the system **100**C in that the generator **60** supplies electricity to an electrolyzer **80** to generate hydrogen, which can exit the system via a pipe and/or connector **81**. The electrolyzer **80** can be a conventional electrolyzer (e.g., using potassium hydroxide, an alkaline electrolyzer) that produces hydrogen at, for example, 16 bar to 30 bar of pressure. The system **100**D is optionally a standalone system that can be housed in a container **2**D or attached to a frame. The system **100**D can advantageously be transported (e.g., in the container **2**D) to a location where the system **100**D can be connected to a gas pipe backbone and a local gas distribution pipe (e.g., such as the gas pipe backbone **10** and local gas distribution pipe **90**). In one implementation, the generated hydrogen can be supplied to a container in a compressed or pressurized form, which can then be transported. In another implementation, the generated hydrogen can be injected into a parallel pipeline to the local gas distribution pipe (e.g., pipe **90**). In still another implementation, the generated hydrogen can be injected directly into the local gas distribution pipe (e.g., pipe **90**) and can make, for example 5-10% of the flow through the local gas distribution pipe, thereby advantageously reducing the greenhouse gas emissions (e.g., reducing CO2 emissions) for the distributed gas. In one implementation, where the energy source that provides electricity or a heated fluid (e.g., heated air, heated water) to the thermal energy storage unit **20** is a renewable energy source (e.g., photovoltaic plant, concentrated solar energy plant), the hydrogen generated by the electrolyzer **80** would be green hydrogen.

[0056] Advantageously, the system **100**, **100′**, **100**A-**100**D allow for the decoupling of the heat source (in source and time) to generate electricity or hydrogen. For example, where electricity (e.g., 1 KWh) is supplied to the thermal energy storage unit **20** to heat the thermal energy storage material therein, such electricity can be provided from a renewable source (e.g. photovoltaic plant) over a period of time (e.g., 4 hours), or can be provided from the electric grid (e.g., by bidding or downbidding for electricity from the grid for a set period of time), and the heat from the thermal energy storage unit **20** can be provided to the heat exchanger(s) **40**, **40**A, **40**B over a different and/or extended period of time that is disconnected from the period of time at which the electricity is delivered to the thermal energy storage unit **20**. In one example, electricity can be supplied to the thermal energy storage unit **20** during the weekend, where there is lower demand for natural gas (e.g., from industry), and the thermal energy storage unit **20** can thereafter supply the stored heat to the heat exchanger(s) **40**, **40**A, **40**B to heat the natural gas flowing through the system **100**, **100′**, **100**A-**100**D over several days or a week thereafter. The thermal energy storage unit **20** (e.g., storing water or rocks or gravel as the thermal energy storage material) can be relatively large and inexpensive to provide heat to the heat exchanger(s) **40**, **40**A, **40**B over several days or a week. Accordingly, in one implementation, the system **100**, **100′**, **100**A-**100**D can be used to provide a baseload of energy (e.g., base amount of electricity or base amount of hydrogen) that can be provided, for example, 24 hrs. per day, seven days per week.

[0057] In one implementation, the amount of electricity or hydrogen generated by the system **100**, **100′**, **100**A-**100**D can be tuned as needed (e.g., so that nominal gas pressure in the local gas distribution pipe is about 5 bar but varies between 4.8 and 5.2 bar). Advantageously, the system **100**, **100′**, **100**A-**100**D increases the efficiency of the gas pipeline by heating and expanding natural gas (e.g., via the heat exchanger(s) **40**, **40**A, **40**B and expander(s) **50**, **50**A, **50**B). For example, for every 1 KWh supplied to the thermal energy storage unit **20** (e.g., to heat the thermal energy storage material therein that is later supplied to the heat exchanger), more than 1 KWh (e.g., 1.5, 1.7, 2.0 KWh) are generated by the expansion of heated gas (e.g., via the expander(s) **50**, **50**A, **50**B). Additionally, because of the efficiency of the system **100**, **100′**, **100**A-**100**D (e.g., which is at least about 150%), the energy needed to be supplied to the thermal energy storage unit **20** can be smaller. For example, where a renewable energy source is used to heat the thermal energy storage unit **20**, for example a photovoltaic plant or concentrated solar energy plant, the solar energy field for the plant can be smaller.

Additional Embodiments

[0058] In embodiments of the present invention, a system and method for generating electricity or hydrogen from natural gas may be in accordance with any of the following clauses:

[0059] Clause 1. A system for generating electricity or hydrogen from natural gas, the system configured to be connected to a gas backbone pipe and a local gas distribution pipe, comprising:

[0060] a thermal energy storage unit that contains a thermal energy storage material, the thermal energy storage unit configured to receive energy from an energy source to heat the thermal energy storage material; [0061] a heat exchanger in fluid communication with the thermal energy storage unit, the heat exchanger configured to receive a flow natural gas from the gas backbone pipe and a heated fluid from the thermal energy storage unit that heats the flow of natural gas; [0062] an expander in fluid communication with the heat exchanger, the expander configured to receive a flow of heated natural gas from the heat exchanger and configured to expand said flow of heated natural gas to cool it and reduce its pressure; and [0063] a generator connected to the expander and configured to generate electricity from an expansion of the flow of heated natural gas by the expander.

[0064] Clause 2. The system of clause 1, wherein the thermal energy storage unit, heat exchanger, expander and generator are part of a standalone transportable unit.

[0065] Clause 3. The system of any of clauses 1-2, wherein the energy source is a renewable energy source.

[0066] Clause 4. The system of any of clauses 1-3, wherein the energy source is a photovoltaic plant.
[0067] Clause 5 The system of any of clauses -3, wherein the energy source is a concentrated solar power plant.
[0068] Clause 6. The system of any of clauses 1-3, wherein the energy source is an electricity grid.
[0069] Clause 7. The system of any of clauses 1-6, wherein the thermal energy storage material is water.
[0070] Clause 8. The system of any of clauses 1-7, wherein the thermal energy storage material comprises pressurized water.
[0071] Clause 9. The system of any of clauses 1-6, wherein the thermal energy storage material comprises a solid material.
[0072] Clause 10. The system of any of clauses 1-6 and 9, wherein the thermal energy storage material comprises rocks.
[0073] Clause 11. The system of any of clauses 1-6 and 9-10, wherein the thermal energy storage material comprises packed gravel.
[0074] Clause 12. The system of any of clauses 1-11, wherein the expander comprises a first expander and a second expander.
[0075] Clause 13. The system of any of clauses 1-12, wherein the heat exchanger comprises a first heat exchanger between the gas backbone pipe and a first expander and a second heat exchanger between the first expander and a second expander.
[0076] Clause 14. The system of any of clauses 1-13, further comprising an electrolyzer configured to receive the generated electricity from the generator to generate hydrogen.
[0077] Clause 15. The system of clauses 14, wherein the generated hydrogen is injected into the local gas distribution pipe.
[0078] Clause 16. The system of clauses 14, wherein the generated hydrogen is injected into a pipe separate from the local gas distribution pipe.
[0079] Clause 17. The system of any of clauses 1-13, wherein the generated electricity is supplied to an electricity grid.
[0080] Clause 18. A method for generating electricity or hydrogen from natural gas, comprising:
[0081] heating via a heat exchanger a flow of natural gas flowing between a gas backbone pipe and a local gas distribution pipe; [0082] expanding via an expander the flow of heated natural gas received from the heat exchanger; and [0083] generating electricity from an expansion of the flow of heated natural gas by the expander.
[0084] Clause 19. The method of clause 18, wherein heating the flow of natural gas includes receiving a heated fluid in the heat exchanger from a thermal energy storage unit to heat the flow of natural gas.
[0085] Clause 20. The method of any of clauses 18-19, wherein expanding the flow of heated natural gas includes cooling and reducing the pressure of the heated flow of natural gas.
[0086] Clause 21. The method of any of clauses 18-20, wherein expanding the flow of heated natural gas occurs in multiple stages.
[0087] Clause 22. The method of any of clauses 18-21, further comprising generating hydrogen via an electrolyzer powered by the generated electricity.
[0088] Clause 23. The method of clause 22, further comprising injecting the generated hydrogen into the local gas distribution pipe.
[0089] Clause 24. The method of clause 22, further comprising injecting the generated hydrogen into a pipe separate from the local gas distribution pipe.
[0090] Clause 25. The method of any of clauses 18-24, further comprising supplying at least a portion of the generated electricity to an electricity grid.
[0091] While certain embodiments of the inventions have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the disclosure.

Indeed, the novel methods and systems described herein may be embodied in a variety of other forms. Furthermore, various omissions, substitutions and changes in the systems and methods described herein may be made without departing from the spirit of the disclosure. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the disclosure. Accordingly, the scope of the present inventions is defined only by reference to the appended claims.

[0092] Features, materials, characteristics, or groups described in conjunction with a particular aspect, embodiment, or example are to be understood to be applicable to any other aspect, embodiment or example described in this section or elsewhere in this specification unless incompatible therewith. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive. The protection is not restricted to the details of any foregoing embodiments. The protection extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

[0093] Furthermore, certain features that are described in this disclosure in the context of separate implementations can also be implemented in combination in a single implementation. Conversely, various features that are described in the context of a single implementation can also be implemented in multiple implementations separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations, one or more features from a claimed combination can, in some cases, be excised from the combination, and the combination may be claimed as a subcombination or variation of a subcombination.

[0094] Moreover, while operations may be depicted in the drawings or described in the specification in a particular order, such operations need not be performed in the particular order shown or in sequential order, or that all operations be performed, to achieve desirable results. Other operations that are not depicted or described can be incorporated in the example methods and processes. For example, one or more additional operations can be performed before, after, simultaneously, or between any of the described operations. Further, the operations may be rearranged or reordered in other implementations. Those skilled in the art will appreciate that in some embodiments, the actual steps taken in the processes illustrated and/or disclosed may differ from those shown in the figures. Depending on the embodiment, certain of the steps described above may be removed, others may be added. Furthermore, the features and attributes of the specific embodiments disclosed above may be combined in different ways to form additional embodiments, all of which fall within the scope of the present disclosure. Also, the separation of various system components in the implementations described above should not be understood as requiring such separation in all implementations, and it should be understood that the described components and systems can generally be integrated together in a single product or packaged into multiple products.

[0095] For purposes of this disclosure, certain aspects, advantages, and novel features are described herein. Not necessarily all such advantages may be achieved in accordance with any particular embodiment. Thus, for example, those skilled in the art will recognize that the disclosure may be embodied or carried out in a manner that achieves one advantage or a group of advantages as taught herein without necessarily achieving other advantages as may be taught or suggested herein.

[0096] Conditional language, such as “can,” “could,” “might,” or “may,” unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements, and/or steps. Thus, such conditional language is not generally intended to imply that features, elements, and/or steps are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without user input or prompting, whether these features, elements, and/or steps are included or are to be performed in any particular embodiment.

[0097] Conjunctive language such as the phrase “at least one of X, Y, and Z,” unless specifically stated otherwise, is otherwise understood with the context as used in general to convey that an item, term, etc. may be either X, Y, or Z. Thus, such conjunctive language is not generally intended to imply that certain embodiments require the presence of at least one of X, at least one of Y, and at least one of Z.

[0098] Language of degree used herein, such as the terms “approximately,” “about,” “generally,” and “substantially” as used herein represent a value, amount, or characteristic close to the stated value, amount, or characteristic that still performs a desired function or achieves a desired result. For example, the terms “approximately”, “about”, “generally,” and “substantially” may refer to an amount that is within less than 10% of, within less than 5% of, within less than 1% of, within less than 0.1% of, and within less than 0.01% of the stated amount. As another example, in certain embodiments, the terms “generally parallel” and “substantially parallel” refer to a value, amount, or characteristic that departs from exactly parallel by less than or equal to 15 degrees, 10 degrees, 5 degrees, 3 degrees, 1 degree, or 0.1 degree.

[0099] The scope of the present disclosure is not intended to be limited by the specific disclosures of preferred embodiments in this section or elsewhere in this specification, and may be defined by claims as presented in this section or elsewhere in this specification or as presented in the future. The language of the claims is to be interpreted broadly based on the language employed in the claims and not limited to the examples described in the present specification or during the prosecution of the application, which examples are to be construed as non-exclusive.

[0100] Of course, the foregoing description is that of certain features, aspects and advantages of the present invention, to which various changes and modifications can be made without departing from the spirit and scope of the present invention. Moreover, the devices described herein need not feature all of the objects, advantages, features and aspects discussed above. Thus, for example, those of skill in the art will recognize that the invention can be embodied or carried out in a manner that achieves or optimizes one advantage or a group of advantages as taught herein without necessarily achieving other objects or advantages as may be taught or suggested herein. In addition, while a number of variations of the invention have been shown and described in detail, other modifications and methods of use, which are within the scope of this invention, will be readily apparent to those of skill in the art based upon this disclosure. It is contemplated that various combinations or subcombinations of these specific features and aspects of embodiments may be made and still fall within the scope of the invention. Accordingly, it should be understood that various features and aspects of the disclosed embodiments can be combined with or substituted for one another in order to form varying modes of the discussed devices.

Claims

1. A system for generating electricity or hydrogen from natural gas, the system configured to be connected to a gas backbone pipe and a local gas distribution pipe, comprising: a thermal energy storage unit that contains a thermal energy storage material, the thermal energy storage unit configured to receive energy from an energy source to heat the thermal energy storage material; a heat exchanger in fluid communication with the thermal energy storage unit, the heat exchanger configured to receive a flow of natural gas from the gas backbone pipe and a heated fluid from the thermal energy storage unit that heats the flow of natural gas; an expander in fluid communication with the heat exchanger, the expander configured to receive a flow of heated natural gas from the heat exchanger and configured to expand said flow of heated natural gas to cool it and reduce its pressure; and a generator connected to the expander and configured to generate electricity from an expansion of the flow of heated natural gas by the expander.

2. The system of claim 1, wherein the thermal energy storage unit, heat exchanger, expander and generator are part of a standalone transportable unit.

3. The system of claim 1, wherein the energy source is a renewable energy source.

4. The system of claim 1, wherein the energy source is a photovoltaic plant.

5. The system of claim 1, wherein the energy source is a concentrated solar power plant.

6. (canceled)

7. The system of claim 1, wherein the thermal energy storage material is water.

8. (canceled)

9. The system of claim 1, wherein the thermal energy storage material comprises a solid material.

10. The system of claim 1, wherein the thermal energy storage material comprises rocks.

11. The system of claim 1, wherein the thermal energy storage material comprises packed gravel.

12. The system of claim 1, wherein the expander comprises a first expander and a second expander.

13. The system of claim 1, wherein the heat exchanger comprises a first heat exchanger between the gas backbone pipe and a first expander and a second heat exchanger between the first expander and a second expander.

14. The system of claim 1, further comprising an electrolyzer configured to receive the generated electricity from the generator to generate hydrogen.

15. The system of claim 14, wherein the generated hydrogen is injected into the local gas distribution pipe.

16. The system of claim 14, wherein the generated hydrogen is injected into a pipe separate from the local gas distribution pipe.

17. (canceled)

18. A method for generating electricity or hydrogen from natural gas, comprising: heating via a heat exchanger a flow of natural gas flowing between a gas backbone pipe and a local gas distribution pipe; expanding via an expander the flow of heated natural gas received from the heat exchanger; and generating electricity from an expansion of the flow of heated natural gas by the expander.

19. The method of claim 18, wherein heating the flow of natural gas includes receiving a heated fluid in the heat exchanger from a thermal energy storage unit to heat the flow of natural gas.

20. The method of claim 18, wherein expanding the flow of heated natural gas includes cooling and reducing a pressure of the flow of heated natural gas.

21. The method of claim 18, wherein expanding the flow of heated natural gas occurs in multiple stages.

22. The method of claim 18, further comprising generating hydrogen via an electrolyzer powered by the generated electricity.

23. The method of claim 22, further comprising injecting the generated hydrogen into the local gas distribution pipe.

24. (canceled)

25. (canceled)