Storage systems for storing and extracting energy using a volume of fluid stored under pressure at different pressures in two or more large storage regions. The large storage regions store the fluid under pressure and may be underground salt caverns, underground reservoirs, above ground gas storage facilities, sub-sea storage regions etc. Energy is stored in the storage systems by pumping fluid into one of the large storage regions. Energy is extracted from the storage regions by allowing the fluid to flow between the storage regions.

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STORAGE SYSTEMS FOR STORING AND EXTRACTING ENERGY

BACKGROUND

The present disclosure relates to a method of storing and extracting energy using large storage containers, such as salt caverns, subterranean reservoirs or the like. More specifically, but not by way of limitation methods are described for retrofitting an existing fluid storage system to store and extract energy therefrom using fluid disposed therein. The disclosure also relates to a kit for retrofitting a fluid storage system and use of a plurality of underground storage facilities, such as salt caverns.

The generation of energy, and the demand for energy, presents major concerns for many governments at present. Typically, energy is produced from fossil fuels in processes that have become extremely efficient in recent years. However, fossil fuels cannot be considered a long term solution to the ever increasing demand for energy, primarily because reserves of fossil fuels are diminishing. In addition, energy obtained from fossil fuels usually results in the emission of environmentally damaging materials, and is one factor that has been attributed to climate change.

As a result, many efforts have been made to find alternative energy sources that offer a potentially unlimited reserve of energy and are less harmful to the environment. Many solutions have been proposed, such a wind turbines, wave and tidal turbines, solar cell arrays and/or the like. To improve and further development in these technologies, as well as decrease the dependence on fossil fuels, many governments have set targets to deliver a certain percentage of a country’s or a region’s total energy from renewable sources.

A problem with renewable energy sources, such as wind, is that the supply of energy from these sources is often erratic. This is not only on a day-to-day basis, but often on a quarterly basis. As the dependence on renewable sources increases, the erratic nature of these sources has more impact upon the total energy supply. The random nature of electricity supply from wind and solar sources is predicted to become progressively more difficult to manage beyond 10% of the total energy supply.
To counteract this erratic nature, several interim energy storage methods have been explored to store energy at times when energy generation is high and the energy demand low, and then to release energy when the demand is high. The most widely used of the known interim storage methods is pumped hydro storage (PHS).

In the United Kingdom (UK), Ffestiniog power station is a pumped hydro storage facility and operates essentially by the use of two (water) reservoirs. These reservoirs are disposed at different heights - typically, a higher reservoir is provided approximately 300 metres above a lower reservoir. Water is pumped from the lower reservoir to the upper reservoir where it is stored. This is usually performed when there is an excess of generated energy, i.e., when the generated energy exceeds the current demand. When energy is required, i.e., when the demand exceeds the generated energy, the stored water in the upper reservoir is released to the lower reservoir and passes through four hydroelectric generators, generating electrical energy reasonably quickly. The general process is considered to be approximately 70% efficient, but requires large volumes of water, and large reservoirs, as well as a particular landscape.

Recently, there has been an increase in the required storage capacity for hydrocarbon gas, i.e., natural gas. Natural gas is currently stored in a variety of ways, in addition to above ground facilities (such as surface tanks), significant storage capacity within Europe is subterranean, including depleted reservoirs in oil/gas fields, aquifers, rock caverns, and underground salt cavities or caverns.

Gas storage requirements are often dictated by seasonal demand for heating and the frequency of gas shipments. Additionally, salt caverns must be operated within a pressure window, which requires that an inventory of base gas or cushion gas is maintained at all times so as to maintain a minimum pressure and provide stability to the salt caverns - typically, for salt caverns, the base gas is defined as approximately 30% of the cavern volume. Therefore, gas storage facilities employing salt caverns often have periods during the year where storage capacity is unused.
There exists a need, therefore, for storing energy so that is available for use in periods of demand in a manageable and cost efficient way. There also exists a need for extracting energy from such a method when needed. For example, renewable energy sources may produce energy at times when the energy is not needed or produce more energy than is needed. And the renewable energy sources may not produce energy/enough energy at time of energy demand. Moreover, the need is for an ability to store a large amount of energy in a cost efficient manner. Multiple small energy storage systems may be inefficient, expensive and complicated. In general, for cost efficiency and effectiveness, an energy storage system should be capable of providing a minimum of 3 Mega Watts for at least 2 hourrs.

The problem is solved by a method for storing energy using a plurality of large volume storage regions for storing fluid, wherein the fluid is stored under a first pressure in a first storage region and a second pressure in a second storage region. In the method one or more fluid communication channels is established between the first storage region and the second storage region, wherein the one or more fluid communication channels fluidly connect the first and second storage regions. A volume of fluid is disposed within the first and second storage regions, wherein the fluid does not further react with, or minimally reacts with, the first and second storage regions. A pressure differential is created between the first and second storage regions, wherein the first pressure is higher than the second pressure.

In embodiments of the present disclosure there are at least two large storage regions for storing a fluid. The storage regions are capable of storing in excess of 10,000 cubic metres of the fluid and are configured to store the fluid under pressure. Excess energy from a renewable energy source is converted into the storage fluid by charging one of the storage regions to a higher pressure than the other storage region. The charged pressure of the storage fluid is maintained in the storage region, this may be provided by using seals, valves, a fluid impervious
wall/liner of the storage region and/or the like. The charged storage region is then discharged by flowing fluid from the region to the second storage region, which contains the fluid at a lower pressure. As part of discharge, the stored energy is recovered in a useable form.

In some embodiments of the present disclosure energy is stored using a plurality of storage regions for storing fluid. The plurality of storage regions provide for storing large volumes, in excess of ten thousand cubic metres of fluid. This amount of storage capacity is necessary to provide for, among other things, efficiency/effectiveness of the system. For example, if both the storage region in the system contain 10,000 cubic metres of fluid, the maximum theoretical energy storage for a gasses with initial pressures 2500 and 500 psi (charged), and final pressures 1250 psi each (discharged) is 9.3 Mega Watts per hour, which will provide of the order of over 4 mega watts per hour for two hours.

The energy storage system comprises at least a first and a second storage region. One or more fluid communication channels are provided between the first storage region and the second storage region, wherein the one or more fluid communication channels fluidly connect the first and second storage regions, providing a volume of fluid to the first and second storage regions, wherein the fluid does not further react with, or minimally reacts with, the first and second storage regions. Energy is stored by creating and maintaining a pressure differential between the first and second storage regions.

The first and the second storage regions may comprise underground salt caverns formed in a salt formation; gas storage facilities, subterranean reservoirs and/or the like. Energy is extracted from the energy storage system by allowing the fluid to flow between the storage regions and drive an energy generator or the like.
The present invention relates to the realisation that energy can be stored in the storage regions by storing a fluid, *i.e.*, either a gas or a liquid, in the storage regions at different pressures. The fluid is preferably a working fluid. In this regard, at least two storage regions are provided or formed, wherein the two storage regions are fluidly connected to each other via at least one fluid communication channel. Fluid is able to flow or be passed from one to the other of the storage regions along this fluid communication channel.

Storage regions, as used herein, include a range of different, usually underground, regions. The storage regions are generally suited for storing a fluid, under pressure, in such a manner that the fluid can be contained within the storage regions. Preferably, the storage regions have well-defined boundaries, such as rock or salt outer walls. In particular, the term storage region includes aquifers, depleted gas/oil fields (both on- and off-shore), rock caverns, lined rock caverns, and salt cavities or caverns. The storage regions are not limited to underground regions and may also include surface tanks.

In some embodiments, the storage region includes a salt cavern, which is generally formed underground by a process known as solution mining. Salt caverns may be advantageous for storing gas and/or liquid as the walls thereof provide a reduced permeability to gas and/or liquid than conventional rock formations. Existing caverns are typically 100 m in diameter and approximately 100 m in height or depth. Usually, salt caverns are provided at approximately 700 meters below ground, although the depth is not limited to this value.

Energy is stored by creating and maintaining a pressure differential between the first storage region and the second storage region. In this way, potential energy is stored and is able to be released when the differences in pressures between the two storage regions try to equilibrate. The pressure in the first storage region acts to force or direct the volume of fluid towards and into the second storage region.
The volume of fluid is provided to both of the first and second storage regions. When liquid is used as the fluid the volumes of liquid in both storage regions may be different from each other. It is preferable if the volume of liquid in the first storage region is greater than the volume of liquid in the second storage region. In this way, the pressure differential may be improved using the total weight of the liquid in the first storage region compared to the second storage region, *i.e.*, via hydrostatic pressure differential. When gas is used as the fluid it is preferable if the volume and/or pressure of the gas is different between both storage regions.

The fluid communication channels may be formed in a number of ways. In a preferred embodiment, the fluid communication channels comprise pipes that extend from the inside of the first storage region, to the surface, along the surface, and to the inside of the second storage region. Alternatively, the fluid communication channel may be formed by boring horizontally between the first and second storage regions, and thus the inner surface thereof may be made from the underlying rock formation or, in the case of salt formations, salt. In this case, the bore hole may also comprise a series of pipes that fluidly connect the storage regions. Preferably, in both cases, the pipes have an inlet/outlet that is provided at the lowermost part of the storage regions, *i.e.*, the deepest sections of the storage regions. Such an arrangement may permit only the transfer of liquid, and not gas, between the storage regions, when liquid is used as the fluid. The pipes may also be arranged in an L-shape.

It is also within the scope of this disclosure to include more than one storage region on either side of the interface used to establish the pressure differential. That is, the second storage region may be in fluid communication with one or more additional storage regions interlinked such that fluid may pass freely between the storage regions. Equally, the first storage region may also be in fluid communication with one or more additional storage regions interlinked in a similar manner. The additional storage regions may be linked sequentially, *i.e.*, second storage region connected to third, third connected to fourth, *etc.*, or all the
storage regions may be individually linked to a single storage region, i.e., second linked to third and fourth. Any combination of these linking arrangements is also considered.

The problem is also solved by a method of extracting energy from a plurality of storage regions storing energy in accordance with the method described above, the method comprising the steps of: allowing fluid to flow between the first and second storage regions, via the one or more fluid communication channels, wherein the pressure differential causes fluid from the first storage region to flow to the second storage region, and extracting energy from the fluid flowing through the one or more fluid communication channels.

Ideally, when energy is to be extracted, fluid is permitted to flow between the first and second storage regions via the fluid communication channel. This is due to the pressure differential between the two storage regions, and this pressure differential forces fluid from the first storage region to flow to the second storage region.

An energy extraction means, or at least a part thereof, may be disposed in the one or more fluid communication channels. Therefore, when fluid passes through the one or more fluid communication channels, the energy extraction means is able to convert the kinetic energy of the flowing fluid into electrical energy. The electrical energy may be passed or supplied to a power distribution system, such as the national grid, for delivery to a desired location. In a preferred embodiment, the energy extraction means is disposed above ground but in fluid communication with the one or more fluid communication channels. In other words, when the pipes of the fluid communication channels extend from the inside of the first storage region and the inside of the second storage region to ground, the energy extraction means may be disposed above ground and, at least partially, in the fluid pathway between the first and second storage regions. The energy extraction means may also be adapted to act as an interconnector between a pipe from the first storage region and a pipe from the second storage region.
In some preferred embodiments, the plurality of storage regions are, at least a part of, an existing gas storage system adapted to store gas. In this way, the system provides an efficient storage system. In such embodiments, the gas storage system has already been created and the gas storage system is provided with at least one gas injection pipe for injecting gas under pressure to the plurality of storage regions and at least one gas withdrawal pipe for withdrawing gas from the plurality of storage regions, and is provided with means for sealing the gas under pressure within the plurality of storage regions.

In some preferred embodiments, a retrofit procedure for retrofitting an existing gas storage system is provided to store additional energy.

It is preferred that the first and second storage regions form part of an existing gas storage system designed to store large quantities of gas therein, preferably natural gas. Accordingly, the formation and identification of these storage regions has ideally already been carried out when producing the gas storage system. Preferably, the gas storage system utilises a plurality of underground salt caverns as the plurality of storage regions.

Most gas storage systems are provided with pipework providing gas injection and withdrawal capabilities. Additionally, when gas is injected, the storage regions are typically sealed so as to prevent gas escaping the storage regions. Gas can, however, be released or withdrawn when desired.

In this regard, the system is retrofit in order to be able to store additional energy. The additional energy includes potential energy stored in the form of a pressure differential between at least two storage regions. Although the existing storage regions do not store energy per se, the volume of natural gas is usually used as fuel. The present invention provides the storage of additional energy beyond that provided by combusting the natural gas. Conveniently, a gas storage system
adapted as described herein, provides two sources of energy stored in the same location.

Preferably, the steps of creating and maintaining a pressure differential, allowing fluid to flow between the first and second storage regions, and extracting energy from the fluid flowing through the one or more fluid communication channels, form part of a retrofit procedure for retrofitting the existing gas storage system to be able to store and extract energy. In other words, these steps are performed once the existing gas storage system has been retrofit for storing energy.

In other words, the steps described above are performed on an existing gas storage system to further adapt the gas storage system to store energy.

Performing a retrofit greatly reduces the cost and time required to produce such a system because many of the useful components are already in place. Moreover, a retrofit procedure maximises the overall usability and cost efficiency of the gas storage system. Equally, when liquid is used as the fluid, temperature changes across the energy extraction means and/or the pump may be reduced in comparison to the temperature changes due to gas expansion and compression. When liquid is used, the temperature changes may be confined to the storage regions themselves and not influence the energy extraction means (particularly energy extraction means comprising a rotary component) and/or pump. Hydrostatic pressure differences may also contribute to the pressure differential.

The fluid communication aspect of the method may be part of an existing gas system, or part of the retrofit procedure. That is, a fluid communication channel is provided to fluidly connect the first and second storage regions. As above, the fluid communication channels may be provided above ground. In one preferred embodiment, the fluid communication channels are formed using pipework provided when forming the storage regions. This is particularly the case when forming underground salt caverns, i.e., via solution mining. As part of the retrofit procedure, pipes may be provided to link two separate pipes used for solution mining {i.e., a pipe from the first salt cavern as the first storage region to ground
with a pipe from the second salt cavern as the second storage region to ground). Alternatively, the fluid communication channel may be provided by linking the existing gas injection and withdrawal pipes for each storage region in a similar manner.

It should also be noted that some existing gas storage systems may operate using interconnected gas injection and withdrawal pipes for a plurality of storage regions, in which case the step of providing fluid communication between storage regions has already been performed as part of creating the existing gas storage system. Alternatively, providing fluid communication may involve drilling a bore hole horizontally between the two storage regions and providing the fluid communication channel, i.e., pipes, therein. It would be essential to seal the outside surface of the fluid communication channel such that fluid may only pass through the fluid communication channel rather than the bore hole in this case.

Providing a volume of fluid may be part of either the retrofit procedure or performed as part of the existing gas storage system. If liquid is to be used as the fluid, providing the liquid is preferably part of the retrofit procedure and involves supplying a volume of liquid into the first and/or second storage regions. If gas is to be used as the fluid, then the gas may already be stored in the storage regions as part of the gas storage system. In this case, the pressure differential may be set up by pumping gas from one storage region to the other. Of course, additional gas may also be supplied to the storage regions.

In some preferred embodiments, retrofitting includes providing energy extraction means, pump, and isolation means to the (in some cases, already established) fluid communication channel above ground.

In some configurations, preferably in accordance with the retrofit procedures, storing energy includes pumping fluid from the second storage region to the first storage region while the means for sealing the gas under pressure prevent gas from escaping the first and second storage regions and/or the one or more fluid
communication channels, wherein fluid is only permitted to flow between the first and second storage regions via the one or more fluid communication channels.

In this configuration, gas is prevented from leaving the confines of the first and second storage regions and escaping to the atmosphere and/or outside environment. However, when the fluid communication channel is above ground, fluid may pass between the storage regions via the fluid communication channel. The retrofit procedure may also include the provision of at least one pump to the fluid communication channel so as to facilitate the pumping of fluid during the energy storage cycle.

As gas is pumped between the first and second storage regions, the pressure in the two storage regions changes. Gas is permitted to only flow between the first and second storage regions via the fluid communication channel. Gas is then pumped along the fluid communication channel to the first storage region from the second storage region. This results in the pressure being greater in the first storage region in comparison to the second storage region. When underground, this is preferably achieved by sealing the outer surface of pipes forming the fluid communication channel to the inner surface of the bore. Ideally, the first storage region may be fluidly linked to several additional storage regions. Preferably, the pressure in the first storage region and the additional storage regions may be, ideally, at approximately 13.79 MPa (2,000 psi), while the pressure of the second storage region may be 3.45 MPa (500 psi).

As liquid is pumped from one storage region to the other, the pressure in the storage regions changes due to the fact that liquid is fairly incompressible and gas is prevented from leaving the storage regions. In other words, as the volume of liquid increases in the first storage region, the pressure of the gas therein also increases, and vice versa for the second storage region. Accordingly, a pressure differential can be established by pumping liquid from one storage region to the other. Gravitational energy can also be stored in the form of the volume (or rather height) of the liquid. This is particularly advantageous if the storage regions are
at different heights. As such, in some embodiments, the first gas storage region is disposed at higher vertical elevation to the second storage region.

Isolation means, which may include a valve, may also be disposed in the fluid communication channel such that, when the pressure differential reaches a desired level, the isolation means actuates and prevents any fluid from passing between the storage regions. In this regard, the pressure differential can be maintained simply by holding the fluid using the isolation means. This could lead to the pump being switched off. Further a controller may be provided that is adapted to monitor the pressure of each storage region. Accordingly, the controller may operate the pump and/or isolation means to obtain and maintain the desired pressure differential. Alternatively, the pump may be driven continuously so as to maintain the pressure differential.

Preferably, the volume of liquid stored in the first storage region is much greater than the volume of liquid stored in the second storage region after pumping. This is so as to compress the gas in the first storage region to create the pressure differential. However, in some case, particularly when the storage regions are at different heights, the different volumes of liquid may aid in the generation of the pressure differential as the volume of liquid has a hydrostatic pressure.

In an additional or alternative configuration, preferably in accordance with the retrofit procedure, storing energy in the system includes preventing fluid from flowing through the one or more fluid communication channels; and providing additional gas to the first storage region via the at least one existing gas injection pipe, and preventing the additional gas from exiting the first storage region using the existing means for sealing the gas under pressure.

In this second configuration, fluid is prevented from being transferred between the first and second storage regions - this also includes the transfer of liquid. Preferably, this is prevented by isolation means, which may include one or more valves, disposed in the fluid communication channel.
To create the pressure differential, gas may be injected into one or both of the first and second storage regions, preferably only the first storage region. This causes the pressure of gas to increase, and a pressure differential can be formed between the two storage regions. Ideally, gas is not permitted to leave the first or second storage regions and is sealed in the storage regions using the existing means for sealing gas under pressure. Some gas may be present in the fluid communication channel above ground, however.

Preferably, this can also be combined with storing a volume of liquid. In this case, the volume of liquid stored in the first storage region may be much greater than the volume of liquid stored in the second storage region. This may be provided by pumping the liquid from the second storage region to the first storage region, or it may be provided by simply supplying the liquid to the first storage region only. Additional gas may then be pumped into the first storage region, thereby increasing the pressure differential.

It should be noted that the first and second configurations can be used together. Specifically, the first configuration may be performed first, and the second configuration performed thereafter.

In a further additional configuration, the method further comprises the step of: pumping fluid from the second storage region to the first storage region, wherein preferably, gas may be pumped in to the system to store energy and passed between the two or more storage systems to release energy from the system in a cyclic fashion as and when energy storage and energy extraction is required.

Once fluid has been passed to the second storage region and energy has been extracted therefrom, *i.e.*, via a discharge cycle, the system must effectively be primed via a charging cycle, thereby storing energy. This is performed in accordance with step h) where fluid is pumped back to the first storage region.
Preferably, the pumping is performed using energy from renewable sources, for example, energy from one or more wind turbines.

Alternatively, the second storage region may take the place of the first storage region and be pressurised accordingly so as to form a pressure differential with the second storage region being at a higher pressure than the first.

In some embodiments, the retrofit procedure includes providing isolation means, the isolation means preferably including a valve, to the one or more fluid communication channels, the isolation means suitable for maintaining a pressure differential between the first and second storage regions, and wherein the isolation means can be actuated to prevent fluid from flowing through the one or more fluid communication channels.

The isolation means may be provided in either of the two configurations discussed above. The isolation means may be actuated so as to fluidly connect the first and second storage regions when the pressure differential has reached the desired level. Providing the isolation means can be advantageous because the pressure differential can be maintained without further energy being exerted, once the pressure differential is at the desired level.

In further embodiments, the retrofit procedure includes providing energy extraction means in or around the one or more fluid communication channels, the energy extraction means including a rotary component, and the step of extracting energy includes rotating the rotary component via the flowing fluid to generate electricity.

The energy extraction means may be provided in the form of a turbine to the fluid communication channel. Fluid passing the rotary component of the turbine causes the turbine to rotate and generate electricity. The turbine may also act as both a pump and an isolation means in some arrangements. When driven, the turbine may be adapted to force fluid through and so pump fluid to the first or second
caverns. Equally, the turbine may be "locked" so as to prevent fluid from passing through the fluid communication channels. When liquid is used as the working fluid, temperature changes are reduced compared to gas as a working fluid, thus demands on the energy extraction means and/or pump may be reduced.

In one embodiment, particularly when gas is injected into the first storage region to create a pressure differential, the method further comprises the step of releasing gas from the second storage region when the first and second storage regions are fluidly connected to avoid over pressurising the second storage region, and wherein preferably, the method further comprising the step of providing gas to the first storage region when the first and second storage regions are fluidly connected.

Releasing gas from the second storage region, when the first storage region and second storage region are fluidly connected, may result in the pressure differential being enhanced. Typically, working pressures of storage regions, in particular salt caverns, are in the region of 3.45 MPa to 13.79 MPa (500 to 2,000 psi), and thus releasing some of the gas decreases the lower pressure used to calculate the pressure differential. This also prevents over pressurising conditions, which could crack or damage the rock or salt formation or surrounding structures.

Moreover, supplying or injecting gas into the opposite storage region results in the pressure differential being applied over a greater length of time, thereby maximising the volume of fluid transferred.

In some realisations, the gas released from the second storage region may be stored and re-injected back into the first or second storage region at a later time.

A further embodiment comprises forming or identifying at least a third storage region adjacent the first and/or second storage regions; establishing or identifying one or more secondary fluid communication channels between the at least third storage region and the first and/or second storage regions, wherein the one or
more secondary fluid communication channels fluidly connect the at least third storage region and the first and/or second storage region.

Providing a third storage region, which is preferably a third salt cavern formed in a salt formation, can be used to essentially increase the volume of either the first or second storage regions. In this way, the third storage region may be fluidly connected to the first or second storage region and, after the pressure differential has been established, be at the same pressure as the first or second storage region. More storage regions may be linked in a similar way, either to the third, second, or first storage regions.

In one embodiment, the retrofit procedure further comprises fluidly sealing an outer surface of the isolation means and/or the energy extraction means such that fluid is unable to pass around the outer surface of the isolation means and/or the energy extraction means.

Performing such a step ensures that the first and second storage regions are fluidly isolated from each other such that fluid cannot pass between the caverns unless permitted to do so, i.e., by actuating the isolation means. This enhances the pressure differential and also means that, when allowed to equilibrate, fluid may only pass from the first to second storage regions via the fluid communication channel.

The fluidly sealing step may comprise inserting a filler around the outer surfaces of the energy extraction means and/or pump and/or isolation means. The filler is ideally gas-impermeable, particularly at pressures between 3.45 MPa to 13.79 MPa (500 to 2,000 psi). The filler may also solidify when disposed so as to maintain the components in the desired positions. This is particularly advantageous when the fluid communication channel is disposed underground.

In some preferred embodiments, the storage regions are salt caverns. In this case, it is preferred that the liquid, when used as the fluid, is salt saturated water
or brine, and the gas, when used as the fluid, is a natural gas or a condensing gas and preferably does not react with the salt saturated water or brine.

Natural gas is usually the gas that is stored in conventional and existing gas storage systems, and so the liquid ideally does not react with natural gas such that the gas stored is substantially equivalent in composition to the gas that can be extracted.

Salt saturated water or brine is preferably used because this prevents or minimises the further dissolution of the walls of salt caverns used as the storage regions, thus maintaining the caverns at the desired size. Preferably, the salt saturated water or brine has a density of 1200 kg/m³. This is advantageous because the kinetic energy of the brine flowing between the two salt caverns is proportional to the mass of the brine. Additionally, any hydrostatic pressure of salt saturated water is greater than water; this can also lead to some improvement in the pressure differential between the salt caverns, particularly when the salt caverns are at different heights.

Alternatively, the fluid may comprise a condensing gas, such as carbon dioxide. The condensing gas may be particularly advantageous because, when pressurised, can condense to form a liquid. In this way, the storage capacity of the storage regions can be significantly improved. A boiling liquid source may add storage capacity in the high pressure storage region, while also releasing gas at an approximately constant rate, thus aiding control of the pressure differential. However, energy storage and extraction rates would depend upon thermal considerations of the cavity and structural integrity. With regards to carbon dioxide, carbon dioxide has a critical point of 7.41 MPa (1,075 psi) at 32°C, which is within the operational ranges of the gas storage storage regions. This may be more suited to meet seasonal energy demands, and may only be realised once the existing gas storage facility is no longer used to store gas. Moreover, supercritical carbon dioxide, which essentially acts as a gas with a density of a liquid, has
further advantages, particularly with regards to the high energy efficiency of pumps adapted to pump supercritical carbon dioxide.

The problem is also solved by a kit for retrofitting an existing gas storage system to store and extract energy in the form of flowing fluid, the gas storage system comprising a plurality of storage regions for storing fluid, at least one gas injection pipe for injecting gas under pressure to the plurality of storage regions and at least one gas withdrawal pipe for withdrawing gas from the plurality of storage regions, and means for sealing the gas under pressure within the plurality of storage regions, the kit including:

energy extraction means adapted to extract energy from fluid flowing between the first and second storage regions through at least one fluid communication channel fluidly connecting the first and second storage regions via a pressure differential between the first and second storage regions, the kit further including at least one of:

a pump adapted to pump fluid from the second storage region to the first storage region to thereby create the pressure differential; and

isolation means adapted to prevent fluid from flowing along the one or more fluid communication channels, and to maintain the pressure differential when gas is injected into the first or second storage regions when fluid is prevented from flowing along the one or more fluid communication channels.

The retrofitting of a kit to an existing gas system is an important aspect of the present invention. The kit may be configured to create the pressure differential in one of the two ways discussed above; either by pumping fluid between two sealed storage regions (and thus not requiring the isolation means, although this is preferred), or by pressurising the gas in the storage regions by injecting additional gas into at least one sealed storage region (and thus not requiring the pump, although this is preferred).
In any case, the kit comprises the energy extraction means which may be inserted between the storage regions either above ground in or around the pipework connecting the two storage regions, or in an underground interconnecting bore hole. A fluid communication channel is established between the two storage regions. Preferably, the kit also comprises a number of pipes that form the fluid communication channel and can be arranged to extend from the energy extraction means in either direction to the storage regions.

The fluid communication channel may pass fluidly through the energy extraction means, and at least a part of the energy extraction means may be positioned in the fluid communication channel. Preferably, the pipes connect, above ground, existing pipework used either in the formation of the storage regions or for injecting and withdrawing gas therefrom. Alternatively, the pipes may be arranged so as to extend into the inner volumes of the first and second storage regions. The underground bore hole may include a fluid communication channel comprising a naturally formed inner surface, i.e., formed of a rock or salt formation.

The fluid communication channel preferably comprises L-shaped pipes that are adapted to have an inlet/outlet at a lowermost part of the storage regions. In this way, the inlet/outlet of the fluid communication channel may be totally submersed by liquid or a condensing gas at all times, in both storage regions. This means that the liquid or the condensing gas may only travel between the first and second storage regions, and not natural gas.

The kit may also further include a controller, wherein the controller is adapted to control actuation of the pump or isolation means. The controller may be further adapted to communicate with an existing gas injection and withdrawal controller so as to control the injection and withdrawal of gas to or from the plurality of storage regions when energy is to be extracted from the flowing fluid.
Ideally the controller is a retrofit controller and is adapted to communicate with the existing gas injection and withdrawal controller for each of the storage regions. In this way, the controller may either control the injection or withdrawal of gas from the storage regions, or may simply be adapted to obtain readings, such as pressure readings, from the existing controllers. Accordingly, the controller may calculate the pressure differential and operate the pump/isolation means when the desired pressure differential is reached. This may be an automated process, or it may be performed manually via input from a user. Feedback control may also be provided such that the controller may maintain the pressure differential by actuating the pump and/or isolation means.

The problem is also solved by a use of an existing gas storage system to store and extract energy from a flowing fluid, the gas storage system comprising a plurality of storage regions for storing fluid, at least one gas injection pipe for injecting gas under pressure to the plurality of storage regions and at least one gas withdrawal pipe for withdrawing gas from the plurality of storage regions, and means for sealing the gas under pressure within the plurality of storage regions,

wherein at least the first storage region is provided with fluid and is in fluid communication with a second storage region,

wherein the first storage region is pressurised to create a pressure differential, and

wherein the energy is extracted by the fluid flowing between the first storage region to the second storage region via the pressure differential.

The problem is also solved by a method for storing energy using at least one under-seabed storage region for storing fluid, the method comprising the steps of:

a) forming or identifying a first storage region, the first storage region located beneath the seabed;
b) providing a tank on the seabed, the tank fluidly connected to the first storage region and provided with a volume of liquid;

5 c) preventing the volume of liquid from flowing into the first storage region, wherein the energy is stored in the form of gravitational potential energy of the volume of liquid stored in the tank.

The concept of storing energy using storage regions can also be applied to storage regions formed off-shore, i.e., under the seabed. In one preferred embodiment, the storage regions include salt caverns. Salt formations are commonly found off-shore. Salt caverns in these formations can be created using similar solution mining techniques. In some case, these salt caverns are naturally created and store natural gas therein which can be extracted. It is also contemplated that such structures can be used for storing gas in a similar manner to that discussed above.

A tank is placed above the storage region such that the volume of the tank is in fluid communication, via a vertically disposed fluid communication channel. A volume of liquid, preferably salt saturated water or brine, is stored in the tank and is able to flow into the storage region. The volume of liquid is prevented from doing so, however, and thus energy is stored as potential energy. Preferably, the volume of liquid is prevented from flowing by isolation means disposed in the fluid communication channel. The isolation means preferably comprises a valve.

25 The problem is also solved by a method of extracting energy from at least one under-seabed storage region and tank storing energy in accordance with the method of storing energy above, the method comprising the steps of:

30 (d) allowing the volume of fluid to flow to the first storage region from the tank, and
(e) extracting energy from the flowing fluid.

In some embodiments, the isolation means are actuated in order to allow the liquid to flow into the storage region via the fluid communication channel. In doing so, the fluid passes through energy extraction means disposed in the fluid communication channel. Preferably, the flowing fluid causes a rotary component of the energy extraction means to rotate and subsequently generate electricity. The electricity may be supplied to the shore via cables disposed along the seabed.

In some embodiments, at least one under-seabed storage region is, at least a part of, an existing gas storage system or a naturally formed gas pocket, wherein step a) has already been performed; and wherein steps b) to c) comprise at least a part of a retrofit procedure for retrofitting the existing gas storage system or the naturally formed gas pocket to store additional energy.

Off-shore storage regions may either be naturally formed and house gas therein, or they may be purpose formed for storing gas as described above. Accordingly, it is beneficial if the method is utilised on an existing under-seabed storage region, such that the production costs associated therewith are reduced. An under-seabed storage region will also contain a volume of cushion or base gas. This is necessary for maintaining stability of, and withdrawal rates from, the under-seabed storage region.

The method may further comprise the step of pumping liquid from the first storage region to the tank when fluid is prevented from flowing from the tank to the first storage region. The steps of the method may be performed in a cyclic fashion.

In some embodiments, at least a second storage region is fluidly connected to the first storage region, and energy is extracted from the fluid flowing between the first storage region and the at least second storage region.
In this arrangement, liquid flowing into the first storage region may also be forced into a second (or third) storage region fluidly connected thereto. Second energy extraction means may be disposed in the fluid connection between these storage regions such that energy can additionally be extracted by the fluid being forced horizontally into the storage regions.

The volume of liquid preferably comprises salt saturated water or brine and, further preferably, has a higher density than sea water. This means that the brine is preferentially driven downwards by the weight of seawater positioned above. Equally, this also means that the tank does not need to comprise a top cover. The tank may include a porous membrane as the top cover, but this is optional.

The problem is also solved by a kit for retrofitting an under-seabed storage region, for storing fluid, to store and extract energy in the form of flowing fluid, the kit including:

a tank for storing a volume of liquid, the tank adapted to be positioned on the seabed;

energy extraction means adapted to extract energy from liquid flowing between the tank and a first storage region through a fluid communication channel fluidly connecting the tank and the first storage region via an energy differential, the first storage region located beneath the seabed; and

isolation means adapted to prevent fluid from flowing along the fluid communication channel, and maintain the energy differential.

The kit may further comprise a pump adapted to pump fluid from the first storage region to the tank to thereby create the energy differential. Preferably, the kit further comprises a pumping pipe adapted to fluidly connect the pump with the first storage region, wherein fluid can be pumped from the first storage region even when the isolation means prevent fluid from flowing. Ideally, a volume of
liquid is present in the pumping pipe at all times, meaning that only liquid passes through the pump. The pump may be specifically adapted to pump liquid in this case.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is described in conjunction with the appended figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion. In the following drawings:

Fig. 1 shows a part of an existing gas storage system;

Fig. 2 shows a gas system that has been retrofitted above ground to store energy in accordance with the present invention;

Fig. 3 shows a gas system that has been retrofitted underground to store energy in accordance with the present invention;

Fig. 4 shows a flow diagram indicating a method for retrofitting the existing gas storage system;

Fig. 5A shows an alternate embodiment involving a plurality of salt caverns for storing liquid;

Fig. 5B shows an alternate embodiment involving a plurality of salt caverns for storing gas; and

Fig. 6 shows an alternate embodiment using an offshore salt cavern.

In the appended figures, similar components and/or features may have the same reference label. Further, various components of the same type may be distinguished by following the reference label by a dash and a second label that distinguishes among the similar components. If only the first reference label is used in the specification, the description is applicable to any one of the similar
components having the same first reference label irrespective of the second reference label.

DETAILED DESCRIPTION

The ensuing description provides preferred exemplary embodiment(s) only, and is not intended to limit the scope, applicability or configuration of the invention. Rather, the ensuing description of the preferred exemplary embodiment(s) will provide those skilled in the art with an enabling description for implementing a preferred exemplary embodiment of the invention. It being understood that various changes may be made in the function and arrangement of elements without departing from the scope of the invention as set forth in the appended claims.

Specific details are given in the following description to provide a thorough understanding of the embodiments. However, it will be understood by one of ordinary skill in the art that the embodiments maybe practiced without these specific details. For example, circuits may be shown in block diagrams in order not to obscure the embodiments in unnecessary detail. In other instances, well-known circuits, processes, algorithms, structures, and techniques may be shown without unnecessary detail in order to avoid obscuring the embodiments.

Also, it is noted that the embodiments may be described as a process which is depicted as a flowchart, a flow diagram, a data flow diagram, a structure diagram, or a block diagram. Although a flowchart may describe the operations as a sequential process, many of the operations can be performed in parallel or concurrently. In addition, the order of the operations may be re-arranged. A process is terminated when its operations are completed, but could have additional steps not included in the figure. A process may correspond to a method, a function, a procedure, a subroutine, a subprogram, etc. When a process corresponds to a function, its termination corresponds to a return of the function to the calling function or the main function.
Moreover, as disclosed herein, the term "storage medium" may represent one or more devices for storing data, including read only memory (ROM), random access memory (RAM), magnetic RAM, core memory, magnetic disk storage mediums, optical storage mediums, flash memory devices and/or other machine readable mediums for storing information. The term "computer-readable medium" includes, but is not limited to portable or fixed storage devices, optical storage devices, wireless channels and various other mediums capable of storing, containing or carrying instruction(s) and/or data.

Furthermore, embodiments may be implemented by hardware, software, firmware, middleware, microcode, hardware description languages, or any combination thereof. When implemented in software, firmware, middleware or microcode, the program code or code segments to perform the necessary tasks may be stored in a machine readable medium such as storage medium. A processor(s) may perform the necessary tasks. A code segment may represent a procedure, a function, a subprogram, a program, a routine, a subroutine, a module, a software package, a class, or any combination of instructions, data structures, or program statements. A code segment may be coupled to another code segment or a hardware circuit by passing and/or receiving information, data, arguments, parameters, or memory contents. Information, arguments, parameters, data, etc. may be passed, forwarded, or transmitted via any suitable means including memory sharing, message passing, token passing, network transmission, etc.

It is to be understood that the following disclosure provides many different embodiments, or examples, for implementing different features of various embodiments. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed. Moreover, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second
features are formed in direct contact, and may also include embodiments in which additional features may be formed interposing the first and second features, such that the first and second features may not be in direct contact.

Fig. 1 shows an exemplary gas storage system as is generally known in the art. In the Figure, two storage regions, specifically salt caverns 2, 4, are shown at a depth below the surface G. Storage regions, as used herein, include a range of different, usually underground, regions. The storage regions are suited for storing a fluid, preferably under pressure, in such a manner that the fluid can be contained within the storage regions. Although not particularly limited to the following, the term storage region can include any one of, or any combination of, aquifers, depleted gas/oil fields (both on- and off-shore), rock caverns, lined rock caverns, and salt cavities or caverns. The storage regions are not limited to underground regions and may also include surface tanks.

In a preferred embodiment, as shown in Fig. 1, the storage regions include salt caverns 2, 4, which are particularly advantageous for storing gas. For simplicity, the working embodiments herein are described with respect to the salt caverns 2, 4, although it should be appreciated that the techniques can be applied to any of the storage regions described above.

Typically, salt caverns 2, 4 are adapted to be able to store gas therein, preferably natural gas. Although only two salt caverns 2, 4 are shown in Fig. 1, it should be appreciated that the gas storage system can comprise any number of salt caverns 2, 4, but preferably includes a plurality thereof. Existing salt caverns 2, 4 typically have a diameter of about 100 m, a height or depth of 100 m, and are positioned around 700 m below the surface G, although these parameters are not limited to the values given.

Typically, gas is supplied or injected into the salt caverns 2, 4 via a gas injection and withdrawal pipe 2a, 4a, which fluidly connects the salt caverns 2, 4 to the
surface G. Although the gas injection and withdrawal pipes 2a, 4a are shown as a single pipe in Fig. 1, it should be appreciated that a separate gas withdrawal pipe and a separate gas injection pipe may be provided to the salt caverns 2, 4. In addition, any number of separate pipes may be provided depending upon the size and capacity of the salt caverns 2, 4.

When gas is to be stored, e.g., when a shipment of gas arrives, the gas is injected into the salt caverns 2, 4 via the gas injection and withdrawal pipes 2a, 4a. In some gas storage systems, a control unit 2b, 4b is provided on the surface G. The control unit 2b, 4b may comprise a pump in order to inject the gas into the salt caverns 2, 4. The gas is usually pressurised and typical working pressures are in the region of 3.45 MPa to 13.79 MPa (500 to 2,000 psi). To achieve such pressures, the control unit 2b, 4b may also be provided with a valve system to prevent the gas from escaping the salt caverns 2, 4 once injected therein. The control unit 2b, 4b may be a manually operated unit or may be automated. In some configurations, the gas injection and withdrawal pipes 2a, 4a may be linked above ground to a single control unit/pump and gas may be directed to individual salt caverns via a series of valves disposed in the connecting pipe. Alternatively, each gas injection and withdrawal pipe 2a, 4a is provided separately.

Once pressurised and sealed below the surface G, the gas remains in the salt caverns 2, 4 until such a time that it is needed, e.g., during a peak demand. Accordingly, the gas is withdrawn from the salt caverns 2, 4, via the gas injection and withdrawal pipes 2a, 4a, to the surface G and is supplied to the desired location thereafter. The above injection and withdrawal processes are then repeated in a cyclic fashion. The usage of salt caverns 2, 4 for such storage of gas is well known and is not further discussed herein.

Several alternative methods and systems for storing gas have been proposed and are in use today. The salt caverns 2, 4 offer several advantages compared to these other methods; namely, that they offer greater withdrawal and injection
rates compared to the total capacity for storing gas, meaning that several cycles can be performed over the course of a year.

However, salt caverns 2, 4 have several disadvantages, primarily in that they are relative costly to form and require the correct environment to be formed therein, i.e., an underground salt formation. In this sense, typically, the formation of these salt caverns 2, 4 involves the pumping of water into a bore hole that terminates in the salt formation, whereby this water dissolves the salt formation and increases the size of the salt cavern 2, 4. The salt water is then removed from the cavern. This process is generally known as solution mining.

As discussed previously, the volume of gas required to be stored is dependent upon seasonal demand for natural gas as well as delivery rates from locations where natural gas is extracted. Accordingly, at various times in the year, the salt caverns 2, 4 are not at full capacity and have storage capacity available. This means that the salt caverns 2, 4 are not utilised to their full potential.

The present invention aims to utilise this empty space within the salt caverns 2, 4. With reference to Fig. 2, a known or existing gas storage system is shown wherein the salt caverns 2, 4 of Fig. 1 have been retrofit with a kit to store fluid and extract energy from this fluid.

Fig. 2 and Fig. 3 show two adjacent salt caverns 2, 4 in a similar manner to the existing gas storage system shown in Fig. 1. However, the salt caverns 2, 4 are linked together via a fluid communication channel 6. The fluid communication channel 6 may be provided at any orientation relative to the salt caverns 2, 4, but should preferably provide fluid communication between the two salt caverns 2, 4.

A preferred embodiment is shown in Fig. 2. In this figure, the fluid communication channel 6 preferably extends from the inner volume of the first salt cavern 2, to the surface G, along the surface G (preferably horizontally), and to the inner volume of the second salt cavern 4.
In an alternative embodiment shown in Fig. 3, the fluid communication channel 6 may be a naturally occurring fluid communication channel 6, or may be formed by boring between the two salt caverns 2, 4 such that the inner surface of the fluid communication channel 6 is formed of salt. Such methods of horizontal boring or drilling are known in the art and are not discussed further herein. Underground fluid communication channels 6 may be provided, but this is dependent upon the stability of the salt caverns 2, 4 and the surround rock/salt formation.

Preferably, the fluid communication channel 6 is formed of pipes that, when fitted together, provide a fluid flow path between the first and second salt caverns 2, 4. The pipes may be installed in the desired configuration using known techniques in the art.

For above ground fluid communication channels, the pipes of the fluid communication channel 6 may be retrofit to the first and second salt caverns 2, 4 such that the retrofit pipes extend from the inner volume of the first salt cavern 2, above and along the surface G, and to the inner volume of the second salt cavern 4. In a preferred configuration, exemplified in Fig. 2, additional pipes 6a, 6b are provided as part of a retrofit kit and fluidly connect existing vertical components of the gas injection and withdrawal pipes 2a, 4a, or equivalent vertical components used in the formation of the salt caverns 2, 4, i.e., the solution mining process. In this case, the fluid communication channel 6 may comprise the additional pipes 6a, 6b, the gas injection and withdrawal pipe 2a, and the gas injection and withdrawal pipe 4a.

For underground fluid communication channels, the pipes of the fluid communication channel 6 are optional, however, depending upon the relative orientation and construction of the fluid communication channel 6. In particular, if the fluid communication channel 6 is provided so as to connect the lowermost sections of the salt caverns 2, 4 (i.e., the deepest sections), then the pipes are not necessary.
Either the pipes of the fluid communication channel 6, or the gas injection and withdrawal pipes 2a, 4a, preferably fluidly connect the lowermost section of the first salt cavern 2 with the lowermost section of the second salt cavern 4. In this way, it is to be appreciated that fluid may flow between the salt caverns 2, 4 through the fluid communication channel 6. The pipes may be provided in an L-shape configuration as in Fig. 3.

Although only shown as a single fluid communication channel 6 in Figs. 2 and 3, any number of fluid communication channels 6 may be provided between the first salt cavern 2 and the second salt cavern 4.

The fluid communication channel 6 may also be provided with energy extraction means 10. The energy extractions means 10 may be placed in or around the pipes of the fluid communication channel 6, depending upon the exact configuration of the energy extraction means 10. The energy extraction means 10 is adapted to extract or generate energy from a flowing fluid. Ideally, the fluid communication channel 6 passes through a part of the energy extraction means 10, i.e., an inlet and/or outlet of the energy extraction means 10. Preferably, the energy extraction means 10 comprises a turbine or the like with a rotary component. The rotary component of the turbine may be placed in the pipes of the fluid communication channel 6 such that flowing fluid causes the rotary component to rotate. Preferably, the additional pipes 6a, 6b extend from the energy extraction means 10, as seen in Fig. 2.

The fluid communication channel 6 may also be provided with isolation means 12. The isolation means 12 can be configured to be actuated so as to prevent fluid flowing through the fluid communication channel 6, but may also be able to be actuated to allow fluid to flow through the fluid communication channel 6. Preferably, the isolation means 12 comprises one or more valves. In Figs. 2 and 3, two valves are disposed within the fluid communication channel 6, one either side of the energy extraction means 10. Any number of isolation means 12 and/or valves may be disposed in the fluid communication channel 6.
Moreover, the fluid communication channel 6 and/or the energy extraction means 10 may be provided with a pump 22. In Figs. 2 and 3, the pump 22 is shown as an integral component with the energy extraction means 10, although the pump 22 may be separate component. In one embodiment, the energy extraction means 10 and pump 22 are the same component. In this regard, the rotary component of the energy extraction means 10 may be driven in a reversible manner and adapted to create a pumping effect. Equally, the pump 22 may be part of the existing gas storage system; that is, the pump used to inject gas into the first and second salt caverns 2, 4 via the gas injection and withdrawal pipes 2a, 4a.

In the preferred embodiment of Fig. 2, the energy extraction means 10 are preferably linked to a retrofit controller 16 that is adapted to control the energy extraction means 10, isolation means 12, and/or pump 22. In some configurations, the controller 16 may communicate with the existing gas storage control units 2b, 4b. The controller 16 preferably monitors the pressure of each salt cavern 2, 4, via pressure sensors, and can obtain and maintain the desired pressure differential by actuating the energy extraction means 10, isolation means 12, and/or pump 22. The desired pressure differential may be input by a user or may be calculated based upon the total volume of gas to be stored in the gas storage system. The energy extraction means 10 may preferably be linked to a power supply system, such as the national grid.

As shown in Fig. 3, the energy extraction means 10 may be linked to the surface G via cables 14. In this arrangement, the energy extraction means 10 may be linked to the controller 16 via the cables 14, wherein the cables 14 provide both a communication link to the energy extraction means 10 such that the energy extraction means 10 may be controlled by the controller 16, and an electrical link such that electricity generated by the energy extraction means 10 may be communicated to the surface G. In this sense, the electrical link may pass through the controller 16 or via an alternative route, i.e., through a transformer and then to a power supply system, such as the national grid. Moreover, the cables 14 may
also provide a communication link to the isolation means 12 and/or pump 22, such that these components can also be controlled by the controller 16.

Preferably, to retrofit the abovementioned components above ground, the additional pipes (or additional pipes 6a, 6b) are placed and connected so as to form the fluid communication channel 6. When underground, as in Fig. 3, a bore 18 is formed by drilling down to a similar depth as the salt caverns 2, 4. The fluid communication channel 6 may then be provided by horizontally drilling from the end of the bore 18 to the first and second salt caverns 2, 4 and, preferably, disposing the pipes of the fluid communication channel 6 therein. The energy extraction means 10 may then be lowered down into the bore 18 and positioned at the intersection between the bore 18 and fluid communication channel 6. Alternatively, the energy extraction means 10 may be fitted to a drill head and subsequently detached and positioned at the appropriate location during drilling. The pipes may be attached to an inlet and/or outlet of the energy extraction means 10, or the energy extraction means 10 may be disposed around the pipes. The isolation means 12 and the pump 22 may be pre-disposed in the pipes or form part of the energy extraction means 10.

In Fig. 3, the cables 14 connecting the energy extraction means 10 to the controller 16 are disposed in the bore 18 and are provided to the surface G. In some embodiments, a filler 20 may be provided to surround either the outer surface of the energy extraction means 10 and/or the outer surface of the isolation means 12 and/or the outer surface of the pump 22. This is to prevent fluid from passing around the outer surfaces of the energy extraction means 10 and/or the isolation means 12 and/or the pump 22. As shown in Fig. 3, the filler 20 surrounds the energy extraction means 10 and the outer surface of the pipes, wherein the isolation means 12 are disposed within the pipes. It is also within the scope of this disclosure that the energy extraction means 10 and isolation means 12 are provided as a single, sealed unit, whereby the energy extraction means 10 comprises an inlet facing the first salt cavern 2 and an outlet facing the second salt cavern 4.
In accordance with the principles of the invention, the first and second salt caverns 2, 4 are provided with a volume of fluid. In one embodiment, the volume of fluid is a volume of gas and, more specifically, may be the gas that the first and second salt caverns 2, 4 are designed to store, i.e., natural gas. The gas may alternatively be a mixture of different gases, or may be a condensing gas.

In another embodiment, the fluid may be a liquid. The liquid may be disposed either before the energy extraction means 10 is positioned and sealed by the filler 20 by being pumped down the bore 18, or the liquid may be provided via the gas injection and withdrawal pipes 2a, 2b at any time during the retrofit procedure. The pipes of the fluid communication channel 6 ideally comprise an inlet/outlet, which may be disposed at the lowermost section of the salt caverns 2, 4. This means that the inlet/outlet of the pipes may be totally submersed in liquid at all times, meaning that only liquid, and not gas, can travel along the fluid communication channel 6. A first volume of liquid V1 may be provided in the first salt cavern 2, and a second volume of liquid V2 may be provided in the second salt cavern 4, as shown in Fig. 2 and 3. Preferably the volumes of liquid V1 and V2 are different, wherein V1 is greater than V2.

Preferably, the liquid is salt saturated water or brine with a density between 1100 and 1300 kg/m³, preferably 1200 kg/m³. The reason for using such a liquid is that the dissolution of salt from the walls of the salt caverns 2, 4 is prevented or at least minimised. Even more preferably, the natural gas does not react with the liquid.

Fig. 4 details the method for performing energy storage and for performing energy extraction using the components discussed above. The method starts at step S1 which involves creating a pressure differential between the salt caverns 2, 4. Forming the pressure differential involves one of two operations, or a combination of both. These are indicated in Fig. 4 by steps S11 and S12.
As a first operation, the first and second salt caverns 2, 4 are sealed using the existing valve systems (or means for storing gas under pressure) disposed in the control units 2b, 4b, step S1la, such that the total volume of gas stored in both salt caverns 2, 4 is approximately constant. This method step is usually performed in advance when gas is to be stored in the existing gas storage system. At step S1lb, fluid is pumped from the second salt cavern 4 to the first salt cavern 2, via operation of the pump 22. Therefore, the volume and/or pressure of fluid in each salt cavern 2, 4 changes during pumping. The fluid is preferably passed from/to each salt cavern 2, 4 only via the fluid communication channel 6; that is, the means for sealing gas under pressure maintains the volume of gas in the whole system (first salt cavern 2, second salt cavern 4, and fluid communication channel 6) at an approximately constant level.

When gas is used as the fluid, this means that the overall gas pressure in the first salt cavern 2 increases relative to the pressure in the second salt cavern 4. This is apparent given that the total volume of gas in the first and second salt caverns 2, 4 is approximately fixed via the existing valve systems actuated in step S1la.

When liquid is used as the fluid, the pressure of the gas stored within the salt caverns 2, 4 also changes because the first and second salt caverns 2, 4 are sealed. More specifically, the pressure in the first salt cavern 2 increases as the volume of liquid V1 in the first salt cavern 2 increases, while the pressure in the second salt cavern 4 decreases as the volume of liquid V2 in the second salt cavern 4 decreases.

Because the surrounding surfaces of the energy extraction means 10 and pump 22 are sealed, preferably by the filler 20, no fluid can be transferred between the salt caverns 2, 4 with the exception of the pumped fluid. At step S1lc, the isolation means 12 may then be activated to prevent the fluid from flowing back to the second salt cavern 4, or the pump 22 may be operated on a continuous basis to maintain the pressure differential. In one embodiment, the pump 22 may be
driven by a number of renewable energy sources, such as wind turbines provided on the surface G. In any case, the pressure differential is created and maintained.

As a second operation, at step S12a the isolation means 12 are actuated to prevent fluid from flowing between the salt caverns 2, 4, effectively fluidly isolating the first salt cavern 2 from the second salt cavern 4. At step S12b, the salt caverns 2, 4 are pressurised by injecting gas into one or both of the salt caverns 2, 4, via the existing gas injection and withdrawal pipes 2a, 4a. Because the isolation means 12 prevent fluid flowing between the salt caverns 2, 4, the pressures of the first salt cavern 2 and second salt cavern 4 are effectively independent of each other. Accordingly, a pressure differential can be established by increasing the pressure of the gas in one salt cavern 2, 4 compared to the other salt cavern 2, 4. In this operation, a pump 22 is not required.

In such an operation, when liquid is used as the fluid, it is preferable if the volume of liquid provided in each salt cavern 2, 4 is initially different, i.e., before the pressurising process. This can be performed by pumping liquid from the second salt cavern 4 to the first salt cavern 2, or simply by providing the liquid to only the first salt cavern 2. When transferring the liquid, it may be beneficial to release the pressure in the salt caverns 2, 4 during liquid transfer so as to reduce the burden on the pump 22. Alternatively, the pressure differential may be established, when the fluid is a gas, by pumping additional gas from the surface G into one or both of the salt caverns 2, 4. One of the salt caverns 2, 4 may be vented during this process to further increase the pressure differential.

As above, a combination of both operations may be utilised. That is, the fluid may be pumped from the second to the first salt cavern 4, 2 and then gas may be injected into the first salt cavern 2 to increase the resulting pressure differential, when the isolation means 12 are actuated to prevent fluid flow. This is shown in Fig. 4 by the interconnecting line between steps S1lc and S12a. This may be beneficial as the requirements of the pump 22 below ground, when used, need not be as high as the requirements as the pumping system provided to the
existing gas storage system, i.e., the pumping system for supplying gas via the
gas injection and withdrawal pipes 2a, 4a. In other words, the pumping system
may be able to pump to higher pressures than the pump 22.

In accordance with the invention, the first and second salt caverns 2, 4 are
provided at different pressures, thereby creating a pressure differential between
the two salt caverns 2, 4. Ideally, the pressure differential is in the range of 1.72
to 5.17 MPa (250 to 750 psi), preferably between 2.41 to 4.48 MPa (350 to 650 psi),
and more preferably, between 3.10 to 3.79 MPa (450 and 550 psi). A
pressure differential of 3.45 MPa (500 psi) approximates a height difference of
300 m in the conventional liquid storage and energy extracting systems. In other
words, according to the invention, energy is stored in the form of the pressure
differential. In other embodiments, the pressure differential may be between 3.45
MPa (500 psi) and 10.34 MPa (1,500 psi) depending upon the working pressures
of the salt cavern 2, 4.

Preferably, when liquid is used as the fluid, the first salt cavern 2 is provided with
a first volume of liquid V1 that is substantially greater than a second volume of
liquid V2 provided to the second salt cavern 4, either initially or when pumped.
Although the primary contribution to the pressure differential comes from the gas
stored in the first and second caverns 2, 4 at different pressures, the liquid has its
own hydrostatic pressure, which is dependent upon the depth of the liquid
measured from the surface thereof; the hydrostatic pressure of 100 m of salt
saturated brine is around 1.17 MPa (170 psi). Thus, a difference in volume of
liquid between the two salt caverns 2, 4 can contribute to some of the pressure
differential described above. However, the primary reason for using liquid as the
working fluid is to reduce temperature changes across the pump 22 and energy
extraction means 10.

Once the pressure differential is created, the method proceeds to step S2,
wherein fluid is able to flow between the first and second salt caverns 2, 4.
Preferably, this step includes actuating the isolation means 12 so as to cause fluid
from the first salt cavern 2 (which is at a higher pressure than the second salt
cavern 4) to flow to the second salt cavern 4 due to the created pressure
differential. Alternatively, if no isolation means 12 are present, this may simply
involve stopping the action of the pump 22 - this is particularly relevant for the
first operation discussed above.

In both situations, fluid is forced or directed to flow from the first salt cavern 2 to
the second salt cavern 4 by the pressure differential. Because the only channel
that fluid can be transferred to the second cavern 4 is the fluid communication
channel 6, the fluid flows through the pipes of the fluid communication channel 6
and the energy extraction means 10.

Accordingly, as indicated at step S3, electricity is generated by the fluid flowing
through the energy extraction means 10. Preferably, this causes the rotary
component of the energy extracting means 10 to rotate and subsequently
generate electricity, which is then communicated to the surface G via the cables
14.

Several additional steps may be utilised at the same time as step S3. Step 3a
involves injecting more gas into the first salt cavern 2 when fluid is able to flow
between the first and second salt caverns 2, 4, i.e., step S2 has been performed.
This may aid in forcing additional fluid, both liquid and gas, through the fluid
communication channel 6 by essentially increasing the duration for which the
pressure differential acts on the fluid stored in the first salt cavern 2.
Alternatively, or in addition, at step S3b the second salt cavern 4 may be vented
to allow gas therein to pass to the surface G. This will reduce the pressure in the
second salt cavern 4, which may also increase the magnitude of the pressure
differential. The gas that is vented is preferably collected in a storage tank on the
surface G and may be re-injected into the first or second salt cavern 2, 4 at a
later time.
Once the pressure differential has equalised, and thus fluid has stopped flowing between the first and second salt caverns 2, 4, the method returns to either steps S12a or S12a. If the method proceeds to step S12a, the fluid may be pumped back into the first salt cavern 2 via the pump 22, at step S4. As above, when the pumping of the fluid occurs, especially when the fluid is liquid, gas may be vented from the first and/or second caverns 2, 4 to reduce the load on the pump 22.

In accordance with the above, it is shown that gas storage systems employing salt caverns 2, 4 to store gas may also be retrofit in such a way as to be able to store and extract energy in the form of a flowing fluid. Such a retrofit system offers several advantages, not least that the total storage capacity present in these gas storage systems may be used more effectively. Owing to the natural properties of the salt caverns 2, 4, the salt caverns 2, 4 are ideally suited for holding gas and liquid, particularly salt saturated water. Therefore, vessels for storing liquid, such as reservoirs for example, do not need to be produced, and the costs associated to produce such an energy system can be reduced.

While it has generally been described that present invention is to be retrofit and applied to existing gas storage systems, it is within the scope of this disclosure that the salt caverns 2, 4 and required apparatus for storing gas are purposefully provided for a new facility. That is, a gas storage system may be created with the intention of fitting the above described system and kit.

Although the salt caverns 2, 4, are described as being positioned at the same or similar depth underground, it is within the scope of this disclosure to retrofit salt caverns 2, 4 at different depths. This is primarily beneficial when liquid is used as the fluid such that the hydrostatic pressure contributes more to the pressure differential. That is, a difference in depth may also aid in fluid flow between the salt caverns 2, 4 in a similar way to the height difference of the two reservoirs of conventional liquid storage and energy extracting systems.
In the embodiments described above, two methods are disclosed for creating the pressure differential. The first generally involves pumping fluid between the two salt caverns 2, 4 wherein the salt caverns 2, 4 are sealed such that gas therein cannot escape, or is prevented from escaping to the outside environment. This method may, preferably, be used when there is an excess of electrical energy to be stored, e.g., from a number of wind turbines. As discussed above, the pressures within the salt caverns 2, 4 vary with the pumping of fluid between both salt caverns 2, 4.

When the fluid to be used is a liquid, it is also contemplated that an additional volume of gas may be stored in the salt caverns 2, 4 when the pressure differential is set up; namely, by pumping gas into the lower pressure salt cavern 4, which is also the salt cavern 4 with the smaller volume of liquid. This is particularly advantageous as more energy is required to inject gas at a higher pressure, and so the method above can essentially use the pumping of liquid to pressurise the gas to a high pressure in the first salt cavern 2. Gas can then be pumped into the second salt cavern 4, if it is required to be stored, at a reduced energy cost. Equally, the extraction of gas from the first salt cavern 2 may be more energy efficient as the gas is at a higher pressure, and thus may be withdrawn at a higher withdrawal rate.

The second method involves pressurising the fluid in the respective salt caverns 2, 4 without substantially transferring fluid therebetween. It is preferred that some transfer of fluid could be performed initially such that either the volume of liquid or initial gas pressure in each salt cavern 2, 4 is different to aid in the pressure differential. This method may, preferably, be used when there is an excess of gas to be stored. In a similar configuration to above, when electrical energy is to be stored, the pump 22 can be used to transfer fluid and subsequently compress the gas. Both methods may be used in combination as discussed above. In essence, there are a number of combinations of storing excess gas and electrical energy in the system when the pressure differential is established. While the pressure differential may be altered by these actions, the overall energy cost of extracting
or pumping gas may mean that the system is more energy efficient compared to
conventional gas storage systems.

Fig. 5 shows an alternative configuration involving a plurality of salt caverns 2, 4, 40. Although Figs. 5A and 5B show the energy extraction means 10 and fluid communication channels 6, 41, 43 as being disposed underground, it should be appreciated that they may be disposed above ground. As seen in the Fig. 5A, three additional caverns 40 are fluidly connected to the first salt cavern 2, via secondary fluid communication channels 41. The configuration of the first salt cavern 2 and the second salt cavern 4 is the same as any of the configurations described above. The first salt cavern 2 also has a volume of liquid V1 therein which is greater than the volume of liquid V2 stored in the second salt cavern 4. In this configuration, the pressure of the gas in the first and additional salt caverns 2, 40 is approximately equal and set at a value PI. As the volume of liquid V2 is less in the second cavern 4, for example, as a result of pumping liquid from the second salt cavern 4 to the first salt cavern 2, the pressure of the second salt cavern 4 is set at P2 and is less than PI. In this case, when fluid, namely liquid, is allowed to flow between the first and second salt caverns 2, 4 (step S2 of Fig. 4), the pressure of the first salt cavern 2 and all of the additional salt caverns 40 act to force the liquid through the fluid communication channel 6 to the second salt cavern 4.

Fig. 5B shows yet another alternative configuration. In this case, two additional salt caverns 40 are provided in fluid communication with the first salt cavern 2, via secondary fluid communication channels 41, and a further additional salt cavern 42 is provided in fluid communication with the second salt cavern 4, via tertiary fluid communication channel 43. The configuration of the first salt cavern 2 and the second salt cavern 4 is the same as any of the configurations described above. This arrangement is particularly advantageous when gas is used as the fluid. In this case, gas may be pressurised using the pump 22 such that the additional salt caverns 40 and the first salt cavern 2 are pressurised at a first pressure PI, and the second salt cavern 4 and the further additional salt cavern
42 are pressurised at a second pressure P2, wherein P1 is greater in magnitude than P2. As above, when the isolation means 12 is released or the pump 22 ceases pumping (step S2 above), the pressures equilibrate causing fluid, namely gas, to flow between the first and second salt caverns 2, 4 via the fluid communication channel 6 and energy extraction means 10.

Although Figs. 5A and 5B show the salt caverns 40, 42 with gas injection and withdrawal pipes 2a, 4a, and control units 2b, 4b, the salt caverns 40, 42 may be provided without these components.

The present invention has described a method for storing and extracting energy from underground salt caverns 2, 4 in the form of flowing fluid. Preferably, the method is applied to an existing gas storage system and a kit may be retrofitted thereto in order to realise the above described method. Retrofitting the existing salt caverns 2, 4 in such a way greatly increases the utilisation of the salt caverns 2, 4 by making use of empty space within the salt caverns 2, 4 to store fluid.

Moreover, energy is stored in an efficient manner and also such that great quantities of energy may be extracted from the salt caverns 2, 4 when required. At present, the Holford facility in Cheshire, UK, comprises eight salt caverns with a total capacity of 160 million cubic metres. Assuming that these caverns may allow for 20% of the capacity to be used for storing liquid, more particularly salt saturated water or brine, then this means that 32 million cubic metres of liquid can be stored therein. A pressure differential of approximately 3.52 MPa (510 psi) translates to approximately $96 \times 10^{12}$ J. This stored energy can be used to meet peak demands when required, thus compensating for the erratic nature of renewable energy sources.

With reference to Fig. 5A, such a system can provide approximately 1.03 GWhr of energy when applied to the salt caverns 2, 4 of the Holford facility. In this case, seven salt caverns may be set at the pressure P1, of approximately 13.79 MPa (2,000 psi), and a single salt cavern set at the pressure P2, of approximately 3.45
MPa (500 psi). With reference to Fig. 5B, such a system can provide approximately 2.89 GWhr of energy when applied to the salt caverns 2, 4 of the Holford facility. In this case, four salt caverns may be set at the pressure P1, of approximately 13.79 MPa (2,000 psi), and four salt caverns set at the pressure P2, of approximately 3.45 MPa (500 psi).

An alternative embodiment encompassing the concepts of the present invention relates to storage regions, preferably salt caverns 50, provided below the seabed S. Many salt formations exist offshore that are currently not used to their full advantage. In this alternative embodiment, a salt cavern 50 may be identified or, preferably, formed in the seabed S.

Again, salt cavern 50 used herein is one example of a storage region to which the invention is applicable. The storage regions described previously can be substituted with the salt cavern 50. It should be apparent that the techniques discussed herein with reference to the salt cavern 50 can equally be applied to any storage region.

In Fig. 6, a salt cavern 50 is provided and is fluidly connected to the seabed S via a fluid communication channel 6. Preferably, the fluid communication channel 6 is provided in a vertical orientation, which may be beneficial for the installation of pump 22 and/or energy extraction means 10. The fluid communication channel 6 may comprise any of the fluid communication channels 6 discussed above. Preferably, the fluid communication channel 6 is formed by boring into the underlying rock/salt formation, such that the inner surface of the fluid communication channel 6 comprises the rock/salt formation. Alternatively, the fluid communication channel may comprise pipes. Energy extraction means 10, which is similar to the energy extraction means 10 described above, may be disposed in the fluid communication channel 6. Preferably, the energy extraction means 10 is provided at approximately 90° relative to the orientation of the energy extraction means 10 described above. The energy extraction means 10 preferably comprises a turbine including a rotary component.
Isolation means 12, such as a valve, may be provided in the fluid communication channel 6. Preferably, the isolation means 12 are provided at an opening of the fluid communication channel 6 with the seabed S, although the isolation means may be disposed at any position within the fluid communication channel 6. The isolation means 12 may comprise any of the isolation means 12 discussed above. A pump 22 may be provided wherein the pump 22 is adapted to pump fluid, primarily liquid, from the salt cavern 50 to the seabed S. The pump 22 is shown as being on the seabed S in Fig. 6; however, the position of the pump 22 is not particularly limited as long as it is capable of pumping fluid to the seabed S. Equally, the pump 22 may be realised via rotation of the rotary component of the energy extraction means 10, in a similar fashion as discussed above.

A tank 52 is provided on the seabed S above the fluid communication channel 6. Preferably the tank 52 comprises a hole in a lower surface thereof that communicates with the opening of the fluid communication channel 6. In some embodiments, the tank 52 may have no lower surface at all. Equally, the tank 52 may have no upper surface. Preferably, the tank 52 is formed only of side walls defining an enclosed space, wherein the side walls extend from the seabed S towards the surface of the sea. The upper surface of the tank 52 may be formed of a membrane.

In this configuration, a volume of liquid is stored in the tank 52. The liquid is preferably salt saturated water or brine because this prevents or minimises the further dissolution of the walls of the salt cavern 50, thus maintaining the caverns at the desired size. Preferably, the salt saturated water or brine has a density of 1200 kg/m³. This is advantageous because the liquid is denser than sea water, meaning that the brine is not readily able to flow out of the tank 52 when the upper surface thereof is not present. In other words, the brine is confined to the tank 52 by virtue of being denser than sea water.
This alternative embodiment functions as follows. Firstly, a volume of liquid, preferably brine, is stored in the tank 52. This may be provided either by pumping the liquid from the top surface of the tank 52, i.e., via external means such as supplying the liquid from the shore or via a boat, or may be provided by pumping the liquid from the salt cavern 50. This may also be performed when the salt cavern 50 is being formed via solution mining.

In this regard, once the liquid is supplied to the tank 52, the isolation means 12 prevents the liquid from flowing through the fluid communication channel 6. Preferably the isolation means 12 prevents the flowing of the liquid even when the liquid is being supplied to the tank 52. In this regard, the pump 22 may be provided with a pumping pipe 54. The pumping pipe 54 may be provided externally of the fluid communication channel 6 (as shown in Fig. 6). In this regard, the isolation means 12 completely seals off the fluid communication channel 6, while liquid can be pumped from the salt cavern 50 to the tank 52 via the pumping pipe 54.

The pumping pipe 54 is, however, preferably provided internally to the fluid communication channel 6. In this regard, the isolation means 12 may prevent fluid passing though the fluid communication channel 6 with the exception of fluid passing through the pumping pipe 54; that is, the pumping pipe 54 passes through the isolation means 12.

It should be noted that a volume of cushion gas or base gas for providing a stabilising pressure to the salt cavern 50 is provided, as indicated by Vg in Fig. 6. It is also preferred if the pumping pipe 54 always contains a volume of liquid such that only liquid may be passed through the pump 22, thereby avoiding damage to the pump 22.

The isolation means 12 preferably is able to withstand large pressures generated by the hydrostatic pressure of the volume of sea water and the liquid, i.e., brine, above the isolation means 12. The isolation means 12 may also be combined with
the energy extraction means 10 as described above, e.g., the isolation means 12 may be the locked configuration of the turbine. Although one isolation means 12 and one energy extraction means 10 are shown, the numbers thereof are not limited.

To extract energy, the isolation means 12 may be controlled to allow fluid to pass through the fluid communication path 6. In the case that the isolation means 12 is a valve, the valve may be opened. Accordingly, the volume of liquid stored in the tank 52 is forced through the fluid communication channel 6 and through the energy extraction means 10. The fluid, namely the brine, may then rotate the rotary component of the energy extraction means 10 and thus generate electricity by converting the kinetic energy of the fluid. Once the fluid has filled the salt cavern 50, either completely or to predetermined partial limit, the isolation means 12 prevents the flow of any further fluid, and the pump 22 actuates to pump the fluid back to the tank 52. Preferably, the pump 22 is operated on the basis of energy produced via an offshore wind farm or the like.

The present embodiment aims to reproduce the conventional liquid storage and energy extracting systems where water is stored in a reservoir at a certain height and is allowed to fall through a hydroelectric turbine when energy is to be extracted. In this regard, the pressure differential described in the aforementioned embodiments is replicated here by the weight of the liquid (and sea water) acting on the isolation means 12 and the relatively empty volume of the salt cavern 50 - note that, as with the salt caverns 2, 4 above, a minimum volume of cushion gas is required in order to maintain a usable and workable pressure.

The advantage of the present embodiment is that the storage capacity required by salt caverns is halved in comparison with the embodiments described above. Moreover, the pressure differential can be increased owing to the depth of sea water that is positioned above the tank 52; that is, by the hydrostatic pressure of the sea water.
A further advantage may be realised when additional salt caverns are disposed adjacent to the salt cavern 50 and fluidly connected thereto. In a preferred arrangement, the additional salt caverns are provided with a fluid communication channel 6 and energy extraction means 10 in a similar manner to the embodiments described above; for example, with reference to Fig. 2. In this way, when liquid is forced into the salt cavern 50 (i.e., when the isolation means 12 are opened), fluid may be forced to flow into the additional salt caverns and through the energy extraction means 10.

The present embodiment may also, preferably, be retrofit to an existing salt cavern 50 used for storing gas. In this regard, the salt cavern 50 may either be used to store natural gas, or may have already been used for extracting natural gas - i.e., no longer storing gas. A kit for retrofitting this embodiment therefore includes at least a pump 22, energy extraction means 10, and isolation means 12.

The above described method and kit are exemplary only and should not be considered limiting in any way. Rather, the scope of the invention is defined by the appended claims.
WHAT I S CLAIMED IS:

1. A method for storing energy, the method comprising the steps of:
   storing a first volume of fluid under a first pressure in a first storage region;
   storing a second volume of fluid under a second pressure in a second storage region, wherein:
   - the first and the second storage regions comprise regions configured for storing fluids under pressure;
   - the first storage region is connected by one or more fluid communication channels to the second storage region; and
   - the first and the second storage regions are configured to store at least 10,000 cubic metres, 100,000 cubic metres or preferentially 1,000,000 cubic metres of the fluid; and
   - maintaining a pressure differential between the first and second storage regions, wherein the first pressure is a higher pressure than the second pressure.

2. The method of claim 1, wherein the first and the second storage regions comprise inner-walls that are impervious to the fluid.

3. The method of claim 1 or claim 2, wherein the inner-walls comprise rock or salt.

4. A method of extracting energy from a plurality of underground storage regions storing energy in accordance with any of the preceding claims, the method comprising the steps of:
   flowing fluid between the first and second storage regions via the one or more fluid communication channels, wherein the pressure differential
causes fluid from the first storage region to flow to the second storage region through the one or more fluid communication channels; and

extracting energy from the fluid flowing through the one or more fluid communication channels.

5. The method of any of the preceding claims, further comprising:
pumping fluid from the second storage region into the first storage region.

6. The method of any of the preceding claims, further comprising:
preventing fluid from flowing through the one or more fluid communication channels; and

pumping additional fluid into the first storage region.

7. The method of claim 5 or 6, further comprising:
using a renewable energy source to pump the fluid.

8. The method of any of the preceding claims, wherein the fluid comprises natural gas.

9. The method of any of the preceding claims, wherein the fluid comprises a condensing gas that is adapted to condense when pressurised in the first storage region.

10. The method of any of the preceding claims, wherein the first and the second storage regions comprise underground salt caverns formed in a salt formation.

11. The method of any of claims 1 to 10, wherein the first and the second storage regions comprise underground caverns or depleted underground reservoirs.
12. The method of any of the preceding claims, wherein the first storage region is disposed at a higher vertical height than the second storage region.

13. The method of any of the preceding claims, wherein:

the first storage region contains the fluid at a higher pressure than the fluid in the second storage region; and

the first storage region contains a larger volume of the fluid than the second storage region.

14. A method for storing energy using a plurality of storage regions for storing fluid, the method comprising the steps of:

(a) forming or identifying a first storage region;

(b) forming or identifying a second storage region adjacent the first storage region;

(c) establishing or identifying one or more fluid communication channels between the first storage region and the second storage region, wherein the one or more fluid communication channels fluidly connect the first and second storage regions;

(d) providing a volume of fluid to the first and second storage regions, wherein the fluid does not further react with, or minimally reacts with, the first and second storage regions; and

(e) creating and maintaining a pressure differential between the first and second storage regions, wherein the first storage region is provided at a higher pressure than the second storage region.
15. A method of extracting energy from a plurality of underground storage regions storing energy in accordance with the method of claim 14, the method comprising the steps of:

(f) allowing fluid to flow between the first and second storage regions, via the one or more fluid communication channels, wherein the pressure differential causes fluid from the first storage region to flow to the second storage region, and

(g) extracting energy from the fluid flowing through the one or more fluid communication channels.

16. The method of claim 14, wherein the plurality of storage regions are, at least a part of, an existing gas storage system adapted to store gas, wherein:

steps (a) to (b) have already been performed to create the gas storage system, the gas storage system provided with at least one gas injection pipe for injecting gas under pressure to the plurality of storage regions and at least one gas withdrawal pipe for withdrawing gas from the plurality of storage regions, and provided with means for sealing the gas under pressure within the plurality of storage regions; and

at least step (e) comprises at least a part of a retrofit procedure for retrofitting an existing gas storage system to store additional energy.

17. The method of claim 16, wherein step (e) includes pumping fluid from the second storage region to the first storage region while the means for sealing the gas under pressure prevent gas from escaping the first and second storage regions and/or the fluid communication channel, wherein fluid is only permitted to flow between the first and second storage regions via the one or more fluid communication channels.
18. The method of claim 16, wherein step (e) includes preventing fluid from flowing through the one or more fluid communication channels; and providing additional gas to the first storage region via the at least one existing gas injection pipe, and preventing the additional gas from exiting the first storage region using the existing means for sealing the gas under pressure.

19. The method of claim 15, further comprising the step of:

(h) pumping fluid from the second storage region to the first storage region, wherein steps (e) to (h) are repeated in a cyclic fashion.

20. The method of claim 16, wherein the retrofit procedure includes providing isolation means, the isolation means including a valve, to the one or more fluid communication channels, the isolation means suitable for maintaining a pressure differential between the first and second storage regions, and

wherein the isolation means can be actuated to prevent fluid from flowing through the one or more fluid communication channels.

21. The method of claim 16, wherein the retrofit procedure includes providing energy extraction means in or around the one or more fluid communication channels, the energy extraction means including a rotary component, and the step of extracting energy includes rotating the rotary component via the flowing fluid to generate electricity.

22. The method of claim 15, further comprising the step of

(g) releasing gas from the second storage region when the first and second storage regions are fluidly connected to avoid over pressurising the second storage region.
23. The method of claim 22, wherein the method further comprises the step of

(g) providing gas to the first storage region when the first and second storage regions are fluidly connected.

24. The method of claim 14, wherein the volume of fluid is a liquid, the method further comprising:

forming or identifying at least a third storage region adjacent the first and/or second storage regions;

establishing or identifying one or more secondary fluid communication channels between the at least third storage region and the first and/or second storage region, wherein the one or more secondary fluid communication channels fluidly connect the at least third storage region and the first and/or second storage region.

25. The method of claim 19, wherein the retrofit procedure further comprises fluidly sealing an outer surface of the isolation means such that fluid is unable to pass around the outer surface of the isolation means.

26. The method of claim 14, wherein the volume of fluid is a liquid comprising salt saturated water or brine.

27. The method of claim 14, wherein the volume of fluid is a gas that is a natural gas.

28. The method of claim 27, wherein the pressure differential is created by providing more gas to the first storage region than the second storage region when gas is prevented from flowing along the one or more fluid communication channels.
29. The method of claim 14, wherein the volume of fluid is a condensing gas that is adapted to condense when pressurised in the first storage region.

30. The method of claim 14, wherein the plurality of storage regions is a plurality of underground salt caverns, the first storage region is a first salt cavern, and the second storage region is a second salt cavern, wherein the salt caverns are formed in a salt formation.

31. A kit for retrofitting an existing gas storage system to store and extract energy in the form of flowing fluid, the gas storage system comprising a plurality of storage regions for storing fluid, at least one gas injection pipe for injecting gas under pressure to the plurality of storage regions and at least one gas withdrawal pipe for withdrawing gas from the plurality of storage regions, and means for sealing the gas under pressure within the plurality of storage regions, the kit including:

    energy extraction means adapted to extract energy from fluid flowing between the first and second storage regions through at least one fluid communication channel fluidly connecting the first and second storage regions via a pressure differential between the first and second storage regions, the kit further including at least one of:

    a pump adapted to pump fluid from the second storage region to the first storage region when the first and second storage regions are sealed by the means for sealing gas under pressure to thereby create the pressure differential; and

    isolation means adapted to prevent fluid from flowing along the one or more fluid communication channels, and to maintain the pressure differential
when gas is injected into the first or second storage regions when fluid is prevented from flowing along the one or more fluid communication channels.

32. The kit according to claim 31, wherein the kit further includes a controller, the controller adapted to control actuation of the pump or isolation means, the controller further adapted to communicate with an existing gas injection and withdrawal controller so as to control the injection and withdrawal of gas to or from the plurality of storage regions when energy is to be extracted from the flowing fluid.

33. The kit according to claim 31, wherein the plurality of storage regions is a plurality of underground salt caverns, the first storage region is a first salt cavern, and the second storage region is a second salt cavern, wherein the salt caverns are formed in a salt formation.
Fig. 2
A. CLASSIFICATION OF SUBJECT MATTER
B65G 5/00(2006.01)i, F17C 5/00(2006.01)i, F17C 7/00(2006.01)i, F17C 13/00(2006.01)i, E02D 31/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
B65G 5/00; F01K 13/02; F17C 5/00; F03B 13/06; F03B 13/00; F01K 23/00; F17C 7/00; F17C 13/00; E02D 31/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: storage, salt cavern, energy, gas, subterranean, underground, pressure, volume

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>X</td>
<td>W0 93-06367 A1 (GRIPPING, ARNOLD W.J.) 01 April 1993 See page 2, line 17 - page 5, line 33; claim 1 and figures 1, 2.</td>
<td>1-3, 14, 16-18, 24, 26-33</td>
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<td>Y</td>
<td>US 4691524 A (HOLSCHER, HUGO) 08 September 1987 See column 2, line 48 - column 4, line 2; claim 34 and figures 1.</td>
<td>15, 19-23, 25</td>
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<td>Y</td>
<td>US 4808029 A (GRIPPING, ARNOLD W.J.) 28 February 1989 See column 3, line 5 - column 5, line 45; claim 1 and figure 2.</td>
<td>1-3, 14-33</td>
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<td>A</td>
<td>US 2009-0013697 A1 (LANDRY et al) 15 January 2009 See paragraph [0016], claim 55 and figure 2.</td>
<td>1-3, 14-33</td>
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<td>A</td>
<td>US 4182128 A (GARDNER, JAMES H.) 08 January 1980 See column 3, line 58 - column 4, line 39 and claims 1, 5.</td>
<td>1-3, 14-33</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

Date of the actual completion of the international search
29 January 2016 (29.01.2016)

Date of mailing of the international search report
12 February 2016 (12.02.2016)

Name and mailing address of the ISA/KR
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Korean Intellectual Property Office
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Facsimile No. +82-42-472-7140

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HWANG, Chan Yoon
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Form PCT/ISA/210 (second sheet) (January 2015)
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<td>2. □ Claims Nos.: because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:</td>
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<td>3. ☒ Claims Nos.: 4-13 because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).</td>
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<td>2. ☒ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.</td>
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<td>4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:</td>
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**Remark on Protest**

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☒ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☒ No protest accompanied the payment of additional search fees.
## INTERNATIONAL SEARCH REPORT

Information on patent family members

**PCT/US2015/058906**

<table>
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<td>wo 93-06367 Al</td>
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