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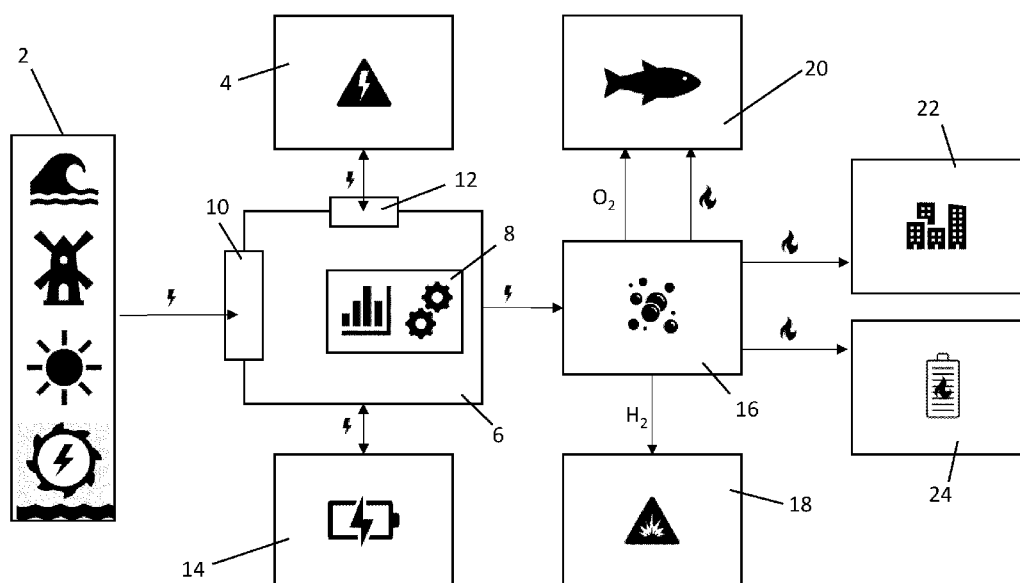


Fig. 1

(57) Abstract: An energy production and storage system comprises a power input connection (10) for a renewable energy source (2); an electrolysis device (16) for electrolysis of water to produce oxygen, hydrogen, and heat; an electrical energy storage device (14); a two-way grid connection (12) coupled to an external electrical grid (4); and a controller (8). The controller (8) is configured to: (i) receive information relating to: actual or potential energy production from the renewable energy source (2), the amount of stored energy in the electrical energy storage device (14), and balancing requirements for the external electrical grid (4); (ii) use the energy from the renewable energy source (2) to power the electrolysis device (16) and/or for storage in the energy storage device (14); and (iii) based on the received information, operate the energy production and storage system as a balancing service provider by either: drawing power from the grid (4) to supply the electrolysis device (16), or supplying power to the grid (4) from the electrical energy storage device (14),

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thereby acting as a switch to aid in balancing for the external electrical grid (4).

ENERGY PRODUCTION AND STORAGE SYSTEM

The present invention relates to an energy production and storage system, in particular to a system using energy from a renewable energy source and electrolysis of water to produce hydrogen, oxygen and heat. The invention is also concerned
5 with related methods of controlling energy production, such as in relation to grid balancing and energy storage.

Numerous systems are known for the production of energy, especially electrical energy. In recent times it has become increasingly desirable to increase the amount of energy production from renewable energy sources, e.g. for environmental reasons
10 as well as economic and political reasons. However, for many renewable energy sources problems arise due to the significant variations in the amount of power produced for different weather conditions or other outside factors. This leads to a mismatch of supply and demand. That is often dealt with by connectivity to a grid to allow for “top up” power when the renewable energy sources cannot meet all of
15 the instantaneous demand. When there is an excess of power then either the “free” energy from renewables is not used, or in some cases the system is configured to allow for a two way grid connection so that energy can be sold back to the grid when the local energy production exceeds local energy demand.

In recent times it has been proposed to combine renewable energy production with a
20 local energy storage system, specifically making use of the ability to use electricity in chemical processes that can produce hydrogen amongst other things. In this way there can be a more efficient pairing of local energy production and local energy consumption. For example, US2011081586 discloses a self-contained system integrating renewable energy production with production of hydrogen/oxygen via
25 electrolysis and energy storage via storage of hydrogen as an energy carrier. The stored hydrogen can be used via a fuel cell to increase electrical power output, such as when the renewable energy source cannot satisfy the local energy demand. This removes the need for reliance on connection to the grid. WO2022014766 also discloses a combination of renewables and electrolysis, which in that case is
30 combined in with aquaculture so that oxygen produced by the electrolysis is used for fish-farming. Hydrogen is produced and stored locally, then used locally via a fuel cell to make electrical power. That electricity, along with power from other sources (e.g. solar) is used for temperature control of the fish farm.

Viewed from a first aspect, the present invention provides an energy production and
35 storage system comprising:

- a power input connection for receiving electrical power from a renewable energy source;
- an electrolysis device for electrolysis of water to produce oxygen, hydrogen, and heat;

- an electrical energy storage device;
- a grid connection configured for two-way connectivity to receive power from and supply power to an external electrical grid; and
- a controller in communication with the power input connection, the electrolysis device, the electrical energy storage device and the grid connection, wherein the controller is configured to
 - (i) receive information relating to: actual or potential energy production from the renewable energy source, the amount of stored energy in the electrical energy storage device, and balancing requirements for the external electrical grid;
 - (ii) use the energy from the renewable energy source to power the electrolysis device and/or for storage in the energy storage device; and
 - (iii) based on the received information, operate the energy production and storage system as a balancing service provider by either: drawing power from the external electrical grid to supply the electrolysis device, or supplying power to the external electrical grid from the energy storage device, thereby acting as a switch to aid in balancing for the external electrical grid.

By integrating the use of a renewable energy source and electrolysis with the ability to provide balancing services then advantages are provided with respect to increasing the effective use of renewables in a synchronous grid. This in turn enhances the benefits of the renewable energy source. At the same time the system can produce 'green hydrogen', i.e. hydrogen produced by 100% renewable energy, as well as also using the electrolysis device to take excess (preferably renewable) energy from the grid when needed, e.g. for balancing purposes. In this way the invention can also extend to a renewable energy system comprising the energy production and storage system of the first aspect as well as one or both of the renewable energy source (or a plurality of renewable energy sources) and/or an external electrical grid configured for supply of renewable energy. This is to be differentiated from non-renewable energy from an external electrical grid, i.e. it is preferred for the electrical grid to be able to allocate electrical energy from renewable sources for use by the energy production and storage system of the first aspect.

Thus, as well as all the benefits of the prior art systems using renewables in combination with electrolysis then there is an added benefit via provision of a switching effect to help with balancing of the external electrical grid, e.g. in relation to automatic or manual frequency reserve capacities such as Frequency Restoration Reserve (FRR) or Fast Frequency Reserve (FFR) systems, and especially for

balancing of renewable resources on the grid. The switching effect depends on the size of the electrolysis device and on the related size of the energy storage device. The electrical energy storage device may have a storage capacity and discharge rate enabling the supply of a peak power that is at least equivalent to the power needed to operate the electrolysis device, or alternatively it may be a peak power that is a half, a quarter, or a tenth of the power needed to operate the electrolysis device. Where the energy storage device may provide a power output equivalent to the load provided by the electrolysis device, e.g. x MW, then the switch effect can be $\pm x$ MW, where x might typically be a value from 1 MW up to 150 MW or more. For example, with an electrolysis device (or set of devices) that requires 5 MW and an energy storage device that is able to provide 5 MW, typically only being needed in a short burst for balancing of the grid, then the switch effect would be ± 5 MW, i.e. giving a two-way switch effect where either 5 MW is drawn from the grid, or 5 MW is provided to the grid.

With reference to (iii) above in order to provide an increased balancing ability the controller may additionally be configured to: store power from the grid in the energy storage device in order to increase the peak power drawn from the grid, and/or provide power from the renewable energy storage device to the grid in order to increase the peak power supplied to the grid. Advantageously the stored power from the grid is power drawn from renewable energy sources. Thus, the switch effect can become greater than $\pm x$ MW and may for example be at least $\pm 2x$ MW, e.g. if the output of the renewable energy source is at least the same as the power output capability of the electrical energy storage device. It will also be appreciated that the controller may be configured to vary the amount of (renewable) power that flows to or from the grid, thereby allowing for finer control of the balancing effect.

The controller may be configured to receive information relating to supply conditions linked to the capacity of the grid. This may for example include the cost of grid supplied power. The renewable energy source and/or the electrical energy storage device may be used to export/import power to the grid not only for reasons linked to balancing of the grid, but also based on considerations such as the trading price of electricity on the grid. In this regard the trading price reflects not only commercial considerations but also is representative of technical information such as the relative availability of renewable electricity as weather conditions vary. The grid may provide renewable energy, i.e. energy from renewable sources elsewhere on the grid. The considerations at the controller may include assessment of the relative pricing of renewable energy from the grid compared to non-renewable energy from the grid and the controller may for example be designed to aid achieving a target price and/or availability for renewable energy on the external electrical grid irrespective of the price/availability of non-renewable energy, e.g. by increasing storage of energy at the energy production and storage system during

- times of high renewable energy production/low electricity demand and/or by providing renewable energy to the grid during times of low renewable energy production/high electricity demand on the grid. In this way the decision about how to power the electrolysis device or how to charge the electrical energy storage device (e.g. a battery) can be based on environmental considerations (e.g. environmental “cost”) as well as on financial considerations. The grid may be used in addition to the locally available renewable energy from the renewable energy source if this is not sufficient or the grid may be used as a sole energy source if local renewable energy is not available.
- 10 The controller may be provided as a part of an electrical switching system that can receive electrical energy from various power sources and provide electrical energy to various power consumers. The power sources may include the power input connection for power from the renewable energy sources, the grid connection, and the electrical energy storage device. The consumers may include the electrolysis
- 15 device, the grid connection, and the electrical energy storage device. The electrical switching system may also provide power to other local consumers, such as industrial or agricultural consumers that may also utilise other products of the overall system, e.g. a fish farm or other aquaculture system. The controller may receive data from the renewable energy sources and/or from an electrical grid
- 20 connected to the grid connection. For example, the power input connection and the grid connection may be configured for communication of both electrical power and data. This may also be the case for other connections to the controller and/or the electrical switching system, e.g. connections to the electrical energy storage device and/or the electrolysis device.
- 25 The controller will typically be a computer implemented control system and may include suitable hardware and/or software elements. In some examples the controller incorporates machine learning algorithms, e.g. artificial neural networks, for processing data such as that received according to (i) and for determining how to control the energy production and storage system in respect of one or more of (ii)
- 30 and/or (iii), or other control processes. The controller may be configured (e.g. using machine learning algorithms) to track and anticipate trends, e.g. in relation to one or more of the actual or potential energy production from the renewable energy source, the amount of stored energy in the electrical energy storage device, the balancing requirements for the external grid and/or the effect on the grid of the
- 35 operation of the energy production and storage system as a balancing service provider. The controller may additionally or alternatively be configured to track external events such as weather patterns and to take this into account when controlling the system. The controller may also be configured to identify patterns and use the identified patterns to control the system to optimise energy efficiency
- 40 and/or to optimise the amount of renewable energy that is produced and used either

locally or via export to the grid. The control of the system may include taking account of a forecast of future trends when deciding to increase or decrease one or more of energy storage at the electrical energy storage device, energy usage by the electrolyser, power drawn from the external electrical grid or power supplied to the external electrical grid. Thus, the controller, which is advantageously implemented using machine learning systems, may effectively predict and prepare for future events.

Grid power systems are exposed to supply and demand variations challenging its balance. To always ensure balance, reserve capacities are required. Different types of reserves are used in different territories depending on the characteristics of the power system. Different reserves typically in use are primary, secondary, and tertiary reserves as well as fast reserves. These all have different purposes, response times and characteristics.

The frequency stability of the power system is typically dependent on rotating mass/ rotational energy/ rotational inertia in synchronous machines connected to the power grid. Most of the rotating mass is found in hydropower plants and thermal power plants (e.g. fossil fuel plants), and a smaller proportion is found in power consumption. The energy production and storage system of the first aspect advantageously contributes to frequency stability without the need for inclusion of a rotating mass of the type found in synchronous machines. In some implementations the renewable energy sources may also not include any rotating mass that contributes to stability for the grid. For example there may be no generators having a synchronous connection. In example embodiments the energy production and storage system of the first aspect does not include any form of thermal power plant, e.g. it may be absent any form of steam turbine and/or gas turbine. Omitting such power plants can also avoid situations where there is added environmental impact from the energy production and storage system. This advantage can be extended by avoiding or minimising the use of gas phase combustion, even if this may use “green” hydrogen, so that in some examples the energy production and storage system does not include any gas phase combustion of hydrogen, or optionally wherein there is no gas phase combustion of any fuel. Thus, the hydrogen consumption within the energy production and storage system of the first aspect may be restricted to non-gas phase combustion and may, for example, include a fuel cell and/or a catalytic burner.

Renewables such as solar power and wind power do not contribute to stability via rotating mass as there are no generators in use, or the generators are not synchronously connected to the grid. The need for frequency balancing thus becomes greater in situations with low load and production, combined with a high proportion of renewable imports to the grid.

The immediate reaction to a change/outage of production or consumption is captured by the conversion of the rotating mass (rotating energy) in the power system into electrical energy. In turn, the frequency will change, activating primary reserves often divided into normal operations reserves (FCR-N) and disturbance reserves (FCR-D).

Secondary reserves (automatic Frequency Restoration Reserve (aFRR sometimes also referred to as Load Frequency Control)) is activated to bring the frequency back to 50.00 Hz and thereby releasing the activated primary reserve so that it is available to handle new faults and imbalances.

After secondary reserves have returned the frequency to the normal band, tertiary reserves are activated to maintain the balance in the system until a new balance is reached in the energy market. In addition to this frequency regulation, tertiary reserves are also used to manage regional congestion and imbalance flows.

Fast Frequency Reserves (FFR) are activated very quickly to prevent frequency drops below 49.0 Hz in the event of major faults or disturbances in the power system. FFR is activated within approximately one second when the system frequency drops below a certain level. Different activation frequencies are possible, typically from 49.5 Hz to 49.7 Hz. When selecting a low activation frequency, the response must be delivered faster to achieve the desired effect.

The system of the first aspect may be configured to operate as a secondary reserve, i.e. aFRR, or as a Fast Frequency Reserve (FFR). It will be appreciated that the switching needed to release electrical power from an electrical energy storage device such as a battery can be done quickly, within the time period needed for FFR. Likewise, the response time for increasing the load on the grid by operating the electrolysis device can be quick, as it is possible to keep this in a standby condition where it can be turned on swiftly.

The power input connection is for receiving electrical power from a renewable energy source, which may be provided as AC power or DC power. The power input connection may also act as a part of the grid connection, e.g. for input of electrical energy from the grid. In that case there may also be a power export connector as another part of the grid connection, or the power input connection could be implemented as a combined import/export connection. The optimal implementation may be selected based on the electrical power output from the renewable energy source, e.g. if this is AC or DC and if the voltage is similar to the grid voltage or not. The energy production and storage system may comprise an AC/DC converter, for example in order to allow for AC power from the renewable energy source to be converted and provided to the electrical energy storage device or the electrolysis device as DC power. The energy production and storage system may include the renewable energy source (or multiple renewable energy sources), which may

advantageously be provided by a local renewable energy production facility. Using a local energy source enhances efficiency.

The renewable energy source may include one or more of solar power, wind power, hydroelectricity, tidal power and/or wave power, for example.

5 The renewable energy source may supply energy to the electrolysis device directly or indirectly, such as via elements of the grid connection and/or via the electrical energy storage device. In some examples, the electrical energy storage device may be used as primary power supply for the electrolysis device, with electrical energy from external sources being routed via the electrical energy storage device. Thus, 10 the renewable energy source may be used to charge the electrical energy storage device and the power for the electrolysis device may be drawn from the electrical energy storage device. If energy import from the grid is required then the grid connection may be connected via an AC/DC converter and charger to charge the electrical energy storage device. The electrical energy storage device may then 15 power the electrolyser via a DC/DC converter. Advantageously, by indirect supply of electrical power via the electrical energy storage device it becomes possible to utilise AC/DC and/or DC/DC conversion systems that are already present in the system. It will also be possible to redirect energy stored in the electrical energy storage device to export to the grid. DC power may be supplied directly to the 20 electrolysis device from the electrical energy storage device via the control unit, which has the advantage of avoiding the need for a rectification device to be integrated into the electrolysis system.

It is required that the storage capacity and discharge rate of the electrical energy storage device enables the supply of a peak power that is at least equivalent to the 25 power needed to operate the electrolysis device. Thus, at least for a short period of time, e.g. at least 5 minutes, at least 10 minutes or at least 15 minutes, the electrical energy storage device should be able to discharge power to the grid (e.g. for balancing) at the same level that the electrolysis device draws power, or higher. Advantageously the electrical energy storage device may be of sufficient size to 30 power the electrolysis device, e.g. to aid in maintaining a continuous power supply when switching from the renewable energy source to the grid, or to allow for the electrical energy storage device to act as a standalone power source for the electrolysis device, which can be beneficial to allow for “green” hydrogen production using stored renewable energy in times when renewable energy 35 production is not available, e.g. due to weather conditions. This may involve the full capacity of the energy storage device being able to power the electrolysis device for a minimum time period, such as 5 minutes, 15 minutes, at least one hour, or at least two hours, or in some cases at least five hours. This enables the energy storage device to be used to smooth over the variable power production from the 40 renewable energy source, by storing power when the renewable energy source

provides more power than is needed by the electrolysis device and by discharging power when the renewable energy source provides less power than is needed by the electrolysis device.

5 The electrical energy storage device may also be used to reduce the costs of powering the electrolysis production e.g. by storing energy from the grid and/or from the renewable energy source when electricity prices are low and drawing electricity from the energy storage device when prices of electricity delivered by the grid is high.

10 The electrolysis device may for example require 1 MW or more, for example 2 MW or more, optionally 15 MW or more. It may thus be a relatively large device. The electrolysis device could be provided by multiple devices in parallel, e.g. multiple 5 MW devices that together require a higher combined power input. In some examples the electrolysis device may require up to 100 MW and in some cases even more. The electrical energy storage device may have a storage capacity allowing
15 for at least 5 minutes, 15 minutes, at least 30 minutes, one hour or more, or for several hours use to power the electrolysis device as noted above. Thus, for example, in the case of a 1 MW or 50 MW power supply requirement for the electrolysis device then the electrical energy storage device may have a total storage capacity of 2 MWh or of 100 MWh, or above, allowing for two hours of operation
20 of the electrolysis device. It is typical for electrical energy storage devices to be able to discharge power at a rate that may be about half of the storage capacity, e.g. taking two hours to fully discharge at the peak discharge rate.

As well as the overall storage capacity requirement the electrical energy storage device may be capable of a large discharge rate as noted above, e.g. at least
25 equivalent to a tenth, a quarter, or a half of the power requirement of the electrolysis device, or in some cases greater than this.

The electrical energy storage device may comprise one or more batteries, e.g. using lithium based chemistries such as lithium ion or any other chemistry reflecting the desired characteristics such as charging and discharging. The electrical energy
30 storage device may be provided by a plurality of batteries or cells, being connected in series and/or in parallel as required to provide the necessary voltage and power output.

The electrical energy storage device may be a battery energy storage system, which may comprise batteries, control electronics, power converter systems, and/or
35 interface appliances. Such interface appliances are designed to provide interface system protection. Batteries store electricity by means of electro-chemical processes which convert electricity into chemical energy and back into electricity when required. The electric energy used in batteries are DC rather than AC. Different chemistries may be applied depending on the application and its

surrounding circumstances and may include the use of nickel, lithium, vanadium, graphite, magnesium, cobalt, silicon, cadmium, carbon black, lead, polyvinylidene fluoride and others. Considerable efforts are invested in battery technology development including the finding/ development of alternative sustainable chemistries including the materials it will require.

The chemical energy stored in batteries of the electrical energy storage device may be transformed by DC/DC transformers or to AC by DC/AC transformers. High-capacity or high-energy batteries are designed to store and deliver a large amount of energy and are typically used in consumer electronics as well as in electric vehicles. Typical battery cell voltage is currently 3.2 VDC and maximum continuous charge and discharge rates are 1C (meaning that a fully charged battery rated at 1 Ah should provide 1 Ah for one hour). Batteries consists of cells that are typically connected in series but may be connected parallelly dependent upon desired resultant voltage and current. Typical battery module/stack voltage may lie between 500VDC and 1500VDC.

Electrical energy storage in batteries can be configured to serve different industrial or grid standards/ requirements and may include DC/DC – DC/ AC interfaces in the range of 400VAC to 33/ 132 kV via the use of a transformer. Available electrical energy storage capacities in batteries are typically higher than its supply rate. For example a 2.7 MWh battery may have a 1.5 MW output capacity. This may be paired with an electrolysis device rated at 3.2 MW, for example, and typically used with a lower power input than its rated power (e.g. 2MW).

The electrolysis device may be powered from directly from the renewable energy source or from the grid which may also provide renewable energy via the electrical energy storage device, which may be a battery. Suppliers of electrolysis devices provide complete systems comprising all necessary subsystems to ensure safe and reliable electrolysis operations over time. Typically included are systems for water treatment ensuring that water used are suitable, cooling systems ensuring that maximum allowable cell stack temperatures are not exceeded, control systems monitoring performance and reporting any issues requiring attention as well as power supply system's ensuring sufficient and correct electric power supply. Electrolysis applies DC power, thus the power supply system assumes power delivered from the grid and consequently transforms AC to DC power using one or several rectifiers. The introduction of an electrical energy storage device such as a battery enables the electrolysis device to be simplified in the situation where the power supplied, via the battery, is already DC. This gives rise to an advantage from use of the electrical energy storage device for indirect supply of power to the electrolysis device.

The renewable energy source may be provided with an average energy production capacity that is similar to the power requirements of the electrolysis device, or may be higher, and thus the peak power production capacity of the renewable energy source will be higher than the power demand of the electrolysis device. For
5 example, with a wind power production facility as the renewable energy source the mean average power production may be 2 MW or 50 MW to match a 2 MW or 50 MW power supply requirement for the electrolysis device, but the rated power production could be twice that and the peak power production may be higher still. The capacity of the renewable energy source may also be lower than the
10 requirement of the electrolysis device. In such cases, the power input connection system must have the capability to import the additional capacity required from the grid in order to power the electrolysis device. As the energy production and storage system includes an electrical energy storage device then there is no waste of the excess power production, and also no waste of energy in the event that the
15 electrolysis device is not needed to be operated or must be shut down for whatever reason, e.g. for maintenance.

The grid connection is configured for two-way connectivity with the external electrical grid, and advantageously can receive power from and supply power to the external electrical grid at a suitably high rate to provide at least 100% of the power
20 requirement of the electrolysis device or draw an equivalent amount or power from the electrical energy storage device. The grid connection may for example be a three-phase configuration, which suitable further connections to the electrolysis device, the electrical energy storage device, and optionally the renewable energy source. These connections may take a suitable form as known in the art.

25 The controller may receive information and control the flow of electricity to and from the grid using conventional means. This may include information about the electricity cost that can be used to increase efficiency by reference to the market forces that influence supply/demand, e.g. optimising the use of the energy storage device and/or optimising production of hydrogen from a cost point of view. The
30 controller may comprise separate hardware/software modules for performing different functions and/or it may be distributed over several processors or sub-controllers at different parts of the system. For example, there may be an energy storage management system at the energy storage device and/or a local control system for the renewable energy source.

35 The electrolysis device is for electrolysis of water to produce hydrogen, oxygen and heat and all of those products may be captured for storage and/or for use. Hydrogen may be stored for later use. The hydrogen produced by the electrolysis device is a commodity product and may be used as a fuel/energy source either locally or remotely, after onward transport to some other system. It may be stored under
40 pressure at the energy production and storage system, which may hence comprise a

- hydrogen storage device, e.g. a tank. The hydrogen production and/or storage may be done with parameters (i.e. temperature, pressure) configured for onward transport and/or use as a fuel. For example, the hydrogen may be output from the electrolysis device at 5 -90 °C and 1-5 MPa and stored at ambient – 80 °C and 1-90 MPa. The energy production and storage system may include a compressor for compression of the hydrogen before storage. Hydrogen produced may also be stored using metal oxides via solid state diffusion or as liquid hydrogen or further it may be stored transformed in a carrier such as ammonia or in a liquid organic hydrogen carrier (LOHC) that can absorb or release hydrogen through chemical reactions.
- 10 In order to make local use of the hydrogen, for example to further increase the efficiency of the local energy system, then the energy production and storage system may comprise a fuel cell and/or a catalytic burner to use hydrogen for local electricity and/or heat demands. As noted above it is preferred that the energy production and storage system does not include any gas phase combustion of
- 15 hydrogen. There may also be an absence of gas phase combustion of any type.

Hydrogen, and preferably green hydrogen generated from electrolysis powered by renewable energy, is particularly suited as an energy carrier for thermal/ heat applications due to its high gravimetric energy density and its reactivity. An alternative way to use hydrogen to allow for stored energy is that the system may

20 include a heater configured to generate heat from hydrogen by e.g. catalytic combustion and to store the heat in a heat store such as a geothermal well.

In hydrogen electrolysis, oxygen is generated at a rate of 8 kg for every single kg of hydrogen produced. Oxygen accumulated in electrolysis may be stored and/or used locally such as for aquaculture in an aquaculture facility that may be onshore or

25 offshore or for alternative usage. Thus, the system may include an oxygen storage device, such as a tank, and/or an oxygen outlet for transfer of oxygen to an oxygen consumer. The relatively low purity requirements for oxygen used in aquaculture in comparison with e.g. medical use, may avoid the need for use of resources and time for added processing for purifying the oxygen from the electrolysis device, and/or

30 this may allow for a less complex or more energy efficient electrolysis device to be used. The energy production and storage system may include a dryer for the removal of moisture/water from the oxygen and/or a compressor for compression of the oxygen before storage.

An alternative usage for offset of oxygen accumulated from electrolysis may be that

35 of oxyfuel combustion for simplifying carbon capture when combusting fossil fuels. Thus, the energy production and storage system may comprise an oxyfuel combustor that receives oxygen from the electrolysis device directly or indirectly. In this way the energy production and storage system may be integrated with, or connected to, an industrial process that applies or requires an oxyfuel combustor or

oxygen generated by the electrolysis device may be transported to the oxyfuel combustion site. Whilst gas phase combustion has some disadvantages, this can be mitigated by use of oxyfuel combustion and so the energy production and storage system may usefully have an absence of gas fuel combustion of hydrogen whilst oxygen is used for oxyfuel combustion to reduce the adverse impact of industrial processes in which combustion is a necessary part. In some examples the energy production and storage system may include no gas phase combustion aside from oxyfuel combustion. Oxyfuel combustion provides oxygen or a mixture of oxygen and recirculated flue gas instead of air to the combustion process. The bulk nitrogen is avoided and the resulting combustion can be more efficient and/or create fewer pollutants. In oxyfuel-combustion, processes related to the bulk nitrogen in air is avoided as air is replaced by primarily oxygen. The resulting combustion products will have CO₂ content up to about 90 per cent (dry basis). The flue gas impurities (predominantly O₂, N₂, and Ar) may be removed by reducing the flue gas (at moderate pressure) to a temperature at which the CO₂ condenses whilst the impurities do not.

Oxyfuel-combustion may be employed with solid fuels (such as coal, petroleum coke, and biomass), as well as liquid and gaseous fuels.

The heat from electrolysis, which can be 20-30% of the energy input to the electrolysis device, might in some cases be referenced as waste heat. However, in the present system this is treated as a beneficial product of the electrolysis device. This heat may be captured and stored, e.g. in a geothermal well/thermal battery, or may be used locally for district heating and/or for industrial or agricultural requirements, such as heating water for fish farming or other aquaculture system. The electrolysis device may produce heat at a temperature of around 40-80°C, for example in the form of a heated fluid, such as hot water, which may be a heated fluid that passes through the electrolysis device (i.e. a coolant fluid) or may be a heated fluid that undergoes heat exchange with a coolant fluid loop of the electrolysis device. The heated fluid can be used directly at the temperature emitted by the electrolysis device, or stored at that temperature, or alternatively it may be heated/cooled to obtain a specific temperature for a required purpose. Hydrogen from the electrolysis device may be used as fuel to boost the temperature of the heated fluid, e.g. by means of a catalytic burner. As set out above in some embodiments there is no gas phase combustion of hydrogen. The heat may be stored in a geothermal well/thermal battery or other type of heat store, so that the energy production and storage system can store heat energy as well as electrical energy, and also store hydrogen as an energy carrier. For example, the heat may be stored in a phase change material, in a geothermal heat store, or in a sand battery.

The controller may control distribution of the heat from the electrolysis device, e.g. in the case that there is more than one consumer of heat for the energy production

and storage system. Alternatively, there may be a separate heat distribution control system.

As noted above there are particular synergies with aquaculture, e.g. fish farming, since this can be a consumer for both of the oxygen and the heat from the electrolysis device. Thus, the invention extends to a combined aquaculture and energy production facility comprising an energy production and storage system as discussed above along with an aquaculture facility, which may for example comprise an aquaculture tank for fish farming and/or for growing aquatic plants or algae. In the case of such a combined aquaculture and energy production facility the controller may also control the aquaculture facility, e.g. by monitoring and controlling water temperature and/or water oxygen level with use of heat and oxygen from the electrolysis device.

Viewed from a second aspect the present invention provides a method of controlling energy production and storage using an energy production and storage system as discussed above in relation to the first aspect, the method comprising:

- (i) receiving information relating to: actual or potential energy production from the renewable energy source, the amount of stored energy in the electrical energy storage device, and balancing requirements for the external electrical grid;
- (ii) using the energy from the renewable energy source to power the electrolysis device and/or for storage in the energy storage device; and
- (iii) based on the received information, operating the energy production and storage system as a balancing service provider by either: drawing power from the external electrical grid to supply the electrolysis device, or supplying power to the external electrical grid from the energy storage device, thereby acting as a switch to aid in balancing for the external electrical grid.

These steps may be carried out at the controller, which may be configured as discussed above. The method may include receiving electrical power from a renewable energy source at the power input connection. The method may include using the grid connection for two-way connectivity to receive power from and supply power to an external electrical grid, for example to allow for export of surplus energy and/or to “top-up” when the renewable energy source does not produce enough power to satisfy local demand. The method may include using (only) renewable energy from the external electrical grid, e.g. to ensure that the method is a method of controlling a renewable energy production and storage system in order to produce green hydrogen amongst other things. The various features of the energy production and storage system may be as set out above in connection with optional features linked to the first aspect.

Certain example embodiments will now be described by way of example only and with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of an energy production and storage system; and

Figure 2 shows a variation of the energy production and storage system.

5 As seen in Figure 1, an energy production and storage system is provided for receiving electrical energy from one or more renewable energy source 2, such as wind, solar, hydro, waves, tidal or others, and for two-way connectivity to an electrical grid 4, e.g. a national grid 4. An electrical switching system 6 with a controller 8 is used to control the flow of power. The renewable energy is provided
10 via a power input connection. The electrical grid 4 is connected via a grid connection 12. The electrical switching system 6 can also receive power from, or send power to, an electrical energy storage device 14, which is typically provided by rechargeable batteries such as lithium ion batteries. It will be understood that both of the electrical grid 4 and the electrical energy storage device 14 can act as
15 either a source of power or a consumer of power. The energy production and storage system may comprise a DC/DC converter or an AC/DC converter, for example in order to allow for AC power from the renewable energy source 2 to be converted and provided to the electrical energy storage device 14 as DC power.

An electrolysis device 16 is provided for electrolysis of water to produce oxygen
20 (O_2), hydrogen (H_2), and heat. The electrolysis device receives power via the electrical switching system 6 and the controller 8 can determine if this is to be power taken from the electrical grid 4, from the renewable energy source 2 or from the electrical energy storage device 14. When power is taken from the electrical grid 8 then it is preferred that this is renewable power. The water may be sourced
25 from a river or lake, with suitable filtering and purification. Alternatively, a mains water source may be used. The electrolysis device may include additional water treatment if required. The hydrogen from the electrolysis device 16 can be sent to a hydrogen storage device 18, e.g. a tank. This hydrogen can be stored for later use as a fuel, either locally or after onward transport to some other system. Oxygen
30 produced by the electrolysis device may be compressed and prepared for export for usage elsewhere or stored and/or used locally such as by delivery to an aquaculture facility 20. Advantageously, the relatively low purity requirements for oxygen used in aquaculture and other alternative processes can mesh well with the purity of oxygen produced by electrolysis.

35 One option to make local use of the hydrogen, for example to further increase the efficiency of the local energy system, is for the energy production and storage system to comprise a fuel cell and/or a catalytic burner to use hydrogen for local electricity and/or heat demands. In this example there is no gas phase combustion of hydrogen and also no gas phase combustion of any other type.

5 The heat from the electrolysis device 16, which can be 20-30% of the electrical energy input to the electrolysis device 16, can be used locally for district heating 22 and/or for industrial or agricultural requirements, such as heating water for fish farming in an aquaculture facility 20. Alternatively, or additionally, the heat can be captured and stored in a heat store 24 such as a geothermal well/ thermal battery.

10 The controller 8 and the electrical switching system are in communication with the power input connection 10, the electrolysis device 16, the electrical energy storage device 14 and the grid connection 12. The controller 8 can receive information, via those connections, from the electrical grid 4 (i.e. from the operator of the electrical grid 4), from the renewable energy source (such as from a control/monitoring system thereof) and also from the electrical energy storage device 14. The controller 8 can therefore receive information relating to: actual or potential energy production from the renewable energy source 2, the amount of stored energy in the electrical energy storage device 14, the power requirement of the electrolysis device 15 including its sub-systems and balancing requirements for the external electrical grid 4. The controller 8 may also receive information about the market for electricity in the external electrical grid 4, e.g. cost/price that varies as a representation of supply/demand.

20 This means that, as well as controlling the energy supply to the electrolysis device 16 and controlling the local distribution of power from the renewable energy source 2, then the controller 8 can also operate the energy production and storage system as a balancing service provider for the electrical grid 4. Thus, the controller 8 may operate the energy production and storage system by drawing power from the grid to supply the electrolysis device 16, thereby increasing the load on the grid. 25 Alternatively, the controller 8 may supply power to the grid from the energy storage device 14, decreasing the load on the grid. The controller 8 can also turn the electrolysis device 16 on/off giving another switching effect even without sending power to the grid 4. Moreover, the controller 8 may direct power from the renewable energy source 2 to the grid or use power from the grid to recharge the energy storage device 14. There is thus a readily controllable variation in the load 30 on the grid 4 that may be used to aid in meeting the balancing requirements of the operator of the external electrical grid 4.

35 The storage capacity and discharge rate of the electrical energy storage device 14 might advantageously be sufficient to operate the electrolysis device 16 for 5 minutes, 15 minutes or 30 minutes, e.g. aid in keeping a continuous supply when switching between renewable energy and power from the grid. In some implementations the electrical energy storage device 14 is of sufficient size to operate the electrolysis device 16 for at least one hour or for a number of hours, e.g. two hours or five hours. This allows the system to cope with gaps in power 40 production from the renewable energy source 2 without the need to constantly draw

power from the grid 4. The controller 8 can operate the system to store power at the electrical energy storage device 14 when the renewable energy source 2 provides more power than is needed by the electrolysis device 16. It can also operate the system to discharge power from the electrical energy storage device 14 when the renewable energy source 2 provides less power than is needed by the electrolysis device 16. The electrolysis device 16 may for example require 1 MW, 50 MW or up to 100 MW, in which case the electrical energy storage device 14 may have a 2 MWh, 100 MWh or 200 MWh capacity, or more, allowing for it to power the electrolysis device for two hours. Alternatively, the energy storage device 14 can have a smaller capacity so that it is used primarily for balancing purposes, e.g. using stored renewable energy, without the secondary function of powering the electrolysis device 16. In one example implementation the electrical energy storage device has a capacity of 2.7 MWh and a discharge rate of 1.5 MW, whilst the electrolysis device draws 3.2 MW at full power. This can then allow for a switching/balancing effect of -3.2 MW to +1.5 MW.

The renewable energy source 2 can be a combination of different energy sources or it may be just one type of energy source, e.g. an array of wind turbines or an area of solar panels. The renewable energy source 2 may be provided with an average energy production capacity that is similar to the power requirements of the electrolysis device 16, such that over a given time period there is on average sufficient renewable power produced to operate the electrolysis device 16 as needed for hydrogen, heat and oxygen production. The electrical energy storage device 14 and the ability to draw power from the electrical grid 4 allows for variability in renewable energy production. For example, with a wind power production facility the mean average power production may be 100 MW to match a 100 MW power supply requirement for the electrolysis device 16, but the rated power production for the renewable energy source 2 could be twice that and the peak power production may be higher still. Any excess in renewable power production can be sold back to the grid. The mean average energy production may in some cases be less than the power supply requirement of the electrolysis. Any deficit of energy may be imported from the electrical grid 4, preferably drawing from renewable energy sources on the grid 4.

In some cases the controller 8 may assess the relative pricing of renewable energy from the grid 4 compared to non-renewable energy from the grid 4 and the controller may be designed to aid achieving a target price and/or availability for renewable energy on the external electrical grid 4, thereby maximising usages/availability of renewable energy. In this way the decision about how to power the electrolysis device 16 or how to charge the electrical energy storage device 14 can be based on environmental considerations (e.g. environmental “cost”) as well as on financial considerations.

Combining the use of electrolysis with aquaculture, e.g. fish farming, has particular advantages since this can be a consumer for both of the oxygen and the heat from the electrolysis device. The system of Figure 1 may also be considered as a combined aquaculture and energy production facility comprising an energy production and storage system as discussed above along with the aquaculture facility 20, which can be a complete aquaculture plant comprising aquaculture tank(s) for fish farming and/or for growing aquatic plants or algae. It is often the case that sites suited for on-shore fish farming can also have a water source for electrolysis as well as being of the right character for installation of a renewable energy source such as a solar park or a wind farm. In the case of such a combined aquaculture and energy production facility then the controller 8 may also control heat and oxygen distribution as well as electrical power for the aquaculture facility.

In another example, as illustrated in Figure 2, the oxygen from the electrolysis device 16 may be used locally (or stored and transported) as oxyfuel for an oxyfuel combustor 26. The other parts of the system can be as discussed above in relation to Figure 1. Alternatively (or additionally) it may be used in other oxygen demanding processes and/or in a combination of such processes, e.g. in a system with both an oxyfuel combustor 26 and an aquaculture facility 20. Where oxyfuel combustion is used then there may advantageously be no other gas phase combustion within the system, and in particular the hydrogen from the electrolysis device 16 may not be used as fuel for gas phase combustion (it may instead be consumed by a fuel cell or catalytic burner, for example).

CLAIMS:

1. An energy production and storage system comprising:
 - a power input connection for receiving electrical power from a renewable energy source;
 - 5 - an electrolysis device for electrolysis of water to produce oxygen, hydrogen, and heat;
 - an electrical energy storage device;
 - a grid connection configured for two-way connectivity to receive power from and supply power to an external electrical grid; and
 - 10 - a controller in communication with the power input connection, the electrolysis device, the electrical energy storage device and the grid connection, wherein the controller is configured to
 - (i) receive information relating to: actual or potential energy production from the renewable energy source, the amount of
15 stored energy in the electrical energy storage device, and balancing requirements for the external electrical grid;
 - (ii) use the energy from the renewable energy source to power the electrolysis device and/or for storage in the energy storage device; and
 - 20 (iii) based on the received information, operate the energy production and storage system as a balancing service provider by either: drawing power from the external electrical grid to supply the electrolysis device, or supplying power to the external electrical grid from the electrical energy storage
25 device, thereby acting as a switch to aid in balancing for the external electrical grid.
2. An energy production and storage system as claimed in claim 1, wherein the controller is configured to: store power from the external electrical grid in the electrical energy storage device at the same time as drawing power from the
30 external electrical grid to supply the electrolysis device in order to increase the peak power drawn from the grid, and/or provide power from the renewable energy storage device to the grid at the same time as supplying power to the external electrical grid from the energy storage device in order to increase the peak power supplied to the grid.
- 35 3. An energy production and storage system as claimed in claim 1 or 2, wherein the controller is configured to track and anticipate trends and thereby predict and prepare for future events.
4. An energy production and storage system as claimed in claim 1, 2 or 3, wherein the energy production and storage system comprises an electrical switching

system that can receive electrical energy from various power sources and provide electrical energy to various power consumers, wherein the controller is a part of the electrical switching system, wherein the power sources include the power input connection for power from the renewable energy sources, the grid connection, and the electrical energy storage device, and wherein the power consumers include the electrolysis device, the grid connection, and the electrical energy storage device.

5 5. An energy production and storage system as claimed in any preceding claim, wherein the electrical energy storage device has a storage capacity and discharge rate enabling the supply of a peak power that is at least equivalent to a quarter of the power needed to operate the electrolysis device.

10 6. An energy production and storage system as claimed in any preceding claim, wherein the electrical energy storage device has a storage capacity and discharge rate enabling the supply of a peak power that is at least equivalent to the power needed to operate the electrolysis device, and wherein the energy storage device can power the electrolysis device for at least 5 minutes.

7. An energy production and storage system as claimed in any preceding claim, wherein the electrical energy storage device has a total storage capacity of at least 1 MWh and the electrolysis device requires a power supply of at least 1 MW.

20 8. An energy production and storage system as claimed in any preceding claim, wherein the energy from the external electrical grid is renewable energy.

9. An energy production and storage system as claimed in any preceding claim, wherein in step (ii) energy from the renewable energy source is used to power the electrolysis device indirectly via the electrical energy storage device, and/or wherein in step (iii) energy from the external electrical grid is used to power the electrolysis device indirectly via the electrical energy storage device.

10. An energy production and storage system as claimed in any preceding claim, wherein there is no gas phase combustion of hydrogen.

30 11. An energy production and storage system as claimed in claim 10, comprising hydrogen consumption to produce heat and/or electricity without gas phase combustion, such as through use of a fuel cell and/or a catalytic burner.

12. An energy production and storage system as claimed in any preceding claim, comprising a hydrogen storage device for storing hydrogen from the electrolysis device.

35 13. An energy production and storage system as claimed in claim 12, wherein hydrogen production at the electrolysis device and/or hydrogen storage at the

hydrogen storage device is done at a temperature of ambient - 80 °C and a pressure of 1- 90 MPa.

14. An energy production and storage system as claimed in any preceding claim, comprising an oxygen storage device and/or an oxygen outlet for transfer of oxygen to an oxygen consumer.
15. An energy production and storage system as claimed in any preceding claim, wherein the heat from the electrolysis device is captured and stored and/or is made available for local use.
16. An energy production and storage system as claimed in claim 15, wherein the controller is configured to control distribution of the heat from the electrolysis device to one or more heat consumers selected from district heating, industrial processes, and/or agriculture such as heating water for aquaculture.
17. An energy production and storage system as claimed in any preceding claim, wherein the electrolysis device produces heat at a temperature of 40-80°C, and wherein hydrogen from the electrolysis device is used as fuel to boost the temperature of the heated fluid.
18. An energy production and storage system as claimed in any preceding claim, comprising an oxyfuel combustor that receives oxygen from the electrolysis device.
19. A combined aquaculture and energy production facility comprising an energy production and storage system as claimed in any preceding claim along with an aquaculture facility, wherein the aquaculture facility receives oxygen and heat from the electrolysis device.
20. A method of controlling energy production and storage using an energy production and storage system as claimed in any preceding claim, the method comprising:
- (i) receiving information relating to: actual or potential energy production from the renewable energy source, the amount of stored energy in the electrical energy storage device, and balancing requirements for the external electrical grid;
 - (ii) using the energy from the renewable energy source to power the electrolysis device and/or for storage in the energy storage device; and
 - (iii) based on the received information, operating the energy production and storage system as a balancing service provider by either: drawing power from the external electrical grid to supply the electrolysis device, or supplying power to the external electrical grid from the energy storage device, thereby acting as a switch to aid in balancing for the external electrical grid.

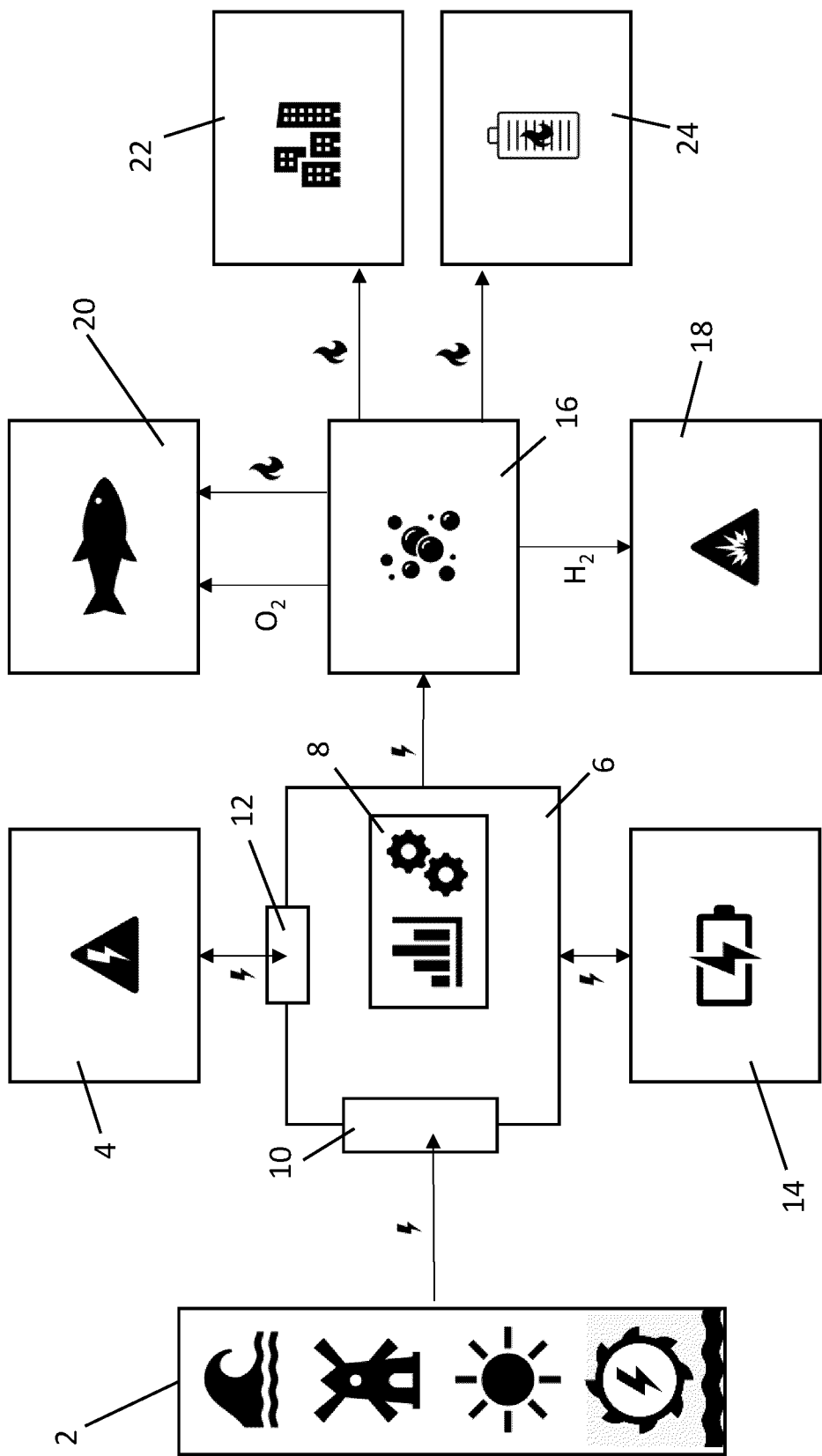


Fig. 1

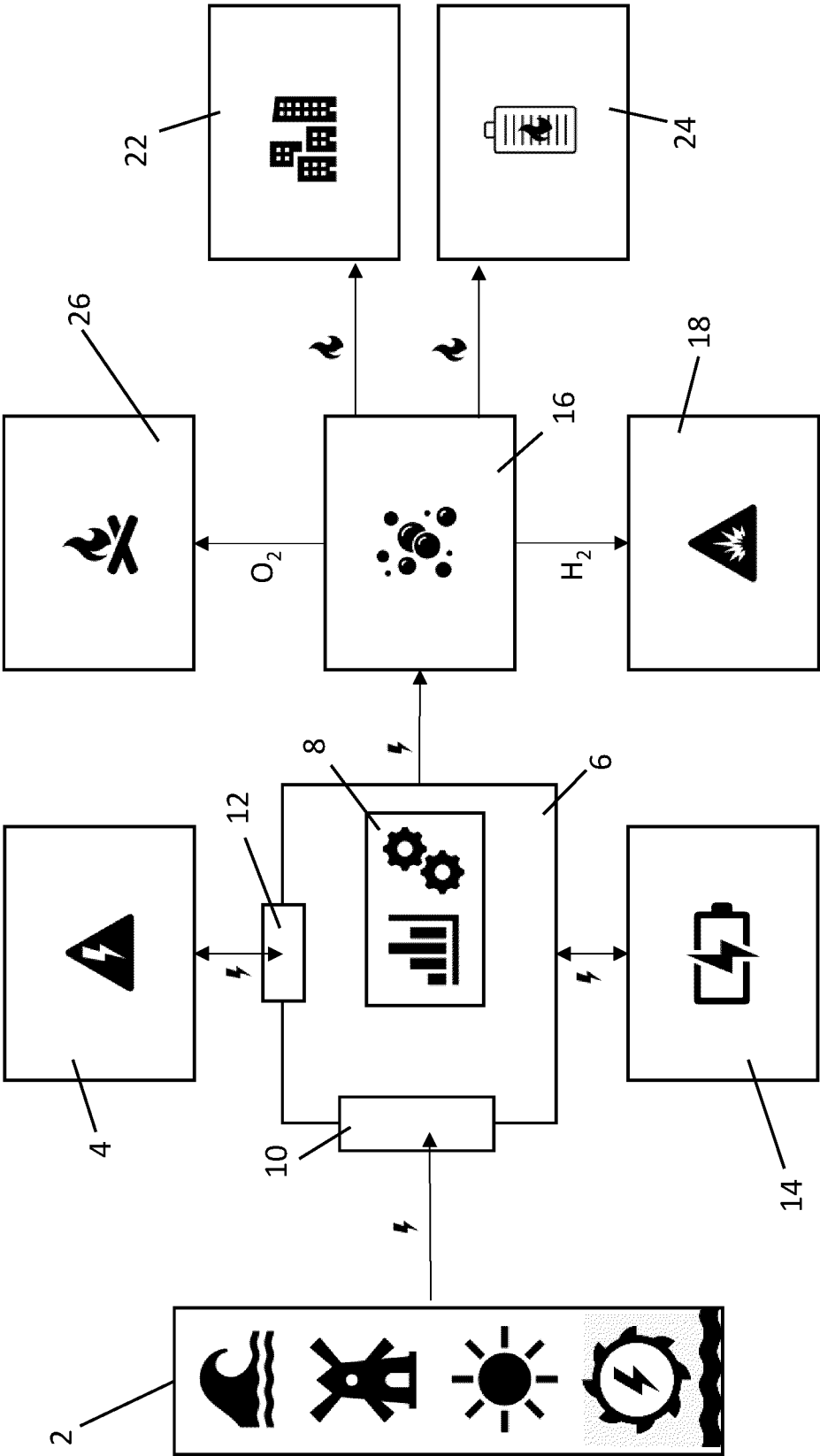


Fig. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/078530

A. CLASSIFICATION OF SUBJECT MATTER		
INV.	H02J7/32	A01K61/00
		C25B1/04
		H02J7/00
		H02J3/32
ADD.	H01M8/00	
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)		
H02J A01K C25B H01M H02S		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2023/175144 A1 (BALLANTINE ARNE [US]) 8 June 2023 (2023-06-08)	1-13,17, 20
Y	paragraphs [0006], [0017], [0031], [0053], [0057], [0059], [0061]; figures 1,4,5	14-16, 18,19

Y	US 2009/189445 A1 (STRIZKI MICHAEL [US]) 30 July 2009 (2009-07-30)	14,18
A	paragraphs [0043], [0059], [0060]; figure 2	8

	-/-	
☒ Further documents are listed in the continuation of Box C.		
☒ See patent family annex.		
* Special categories of cited documents :		
"A" document defining the general state of the art which is not considered to be of particular relevance		
"E" earlier application or patent but published on or after the international filing date		
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"O" document referring to an oral disclosure, use, exhibition or other means		
"P" document published prior to the international filing date but later than the priority date claimed		
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention		
"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone		
"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art		
"&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
22 January 2025		13/02/2025
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Varela Fraile, Pablo

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2024/078530

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Korpås Magnus: "Distributed Energy Systems with Wind Power and Energy Storage", , 31 March 2004 (2004-03-31), XP093242202, Retrieved from the Internet: URL:https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/249683/122023_FULLTEXT01.pdf [retrieved on 2025-01-22] page 157, section titled "Small-scale niche application for hydrogen" -----	15,16,19

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/078530

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2023175144	A1	08-06-2023	NONE
US 2009189445	A1	30-07-2009	NONE