(12) UK Patent Application (19) GB (11) 2619700 (13) A

(43) Date of A Publication 20.12.2023

(21) Application No: **2208261.4**

(22) Date of Filing: **06.06.2022**

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(51) INT CL:
H02J 15/00 (2006.01)

(56) Documents Cited:

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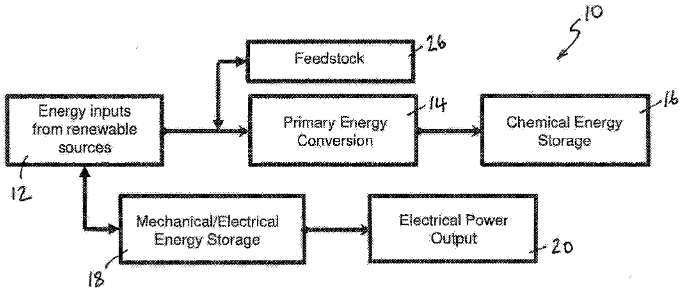
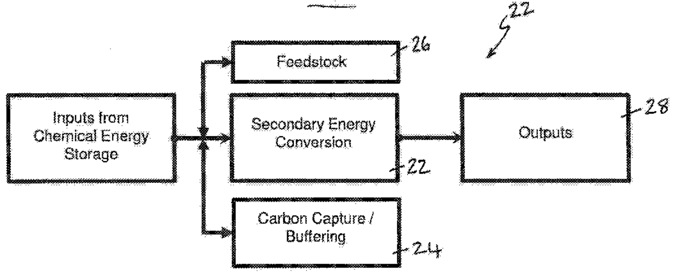
(58) Field of Search:
INT CL **H02J**
Other: **WPI, EPODOC**

(54) Title of the Invention: **Renewable energy capture, conversion and storage system**
Abstract Title: **An energy conversion and storage system**

(57) The system receives energy generated from renewable energy sources. The system comprises primary energy conversion means for converting input energy into at least one primary reaction product e.g., hydrogen, synthesis gas, or hydrocarbon liquids or gases. It further comprises secondary conversion means for converting primary reaction products into secondary reaction products e.g., methanol, ammonia, biofuel, or synthetic fuel, and energy storage means.
A control system that may be AI-based controls distribution of input energy amongst the primary energy conversion means, secondary conversion means, and energy storage means. The control system is configured to match an energy demand of the energy conversion and storage system to an available input energy from the renewable energy sources such that all the available input energy is consumed by the system.



FIG·1



FIG·2

GB 2619700 A

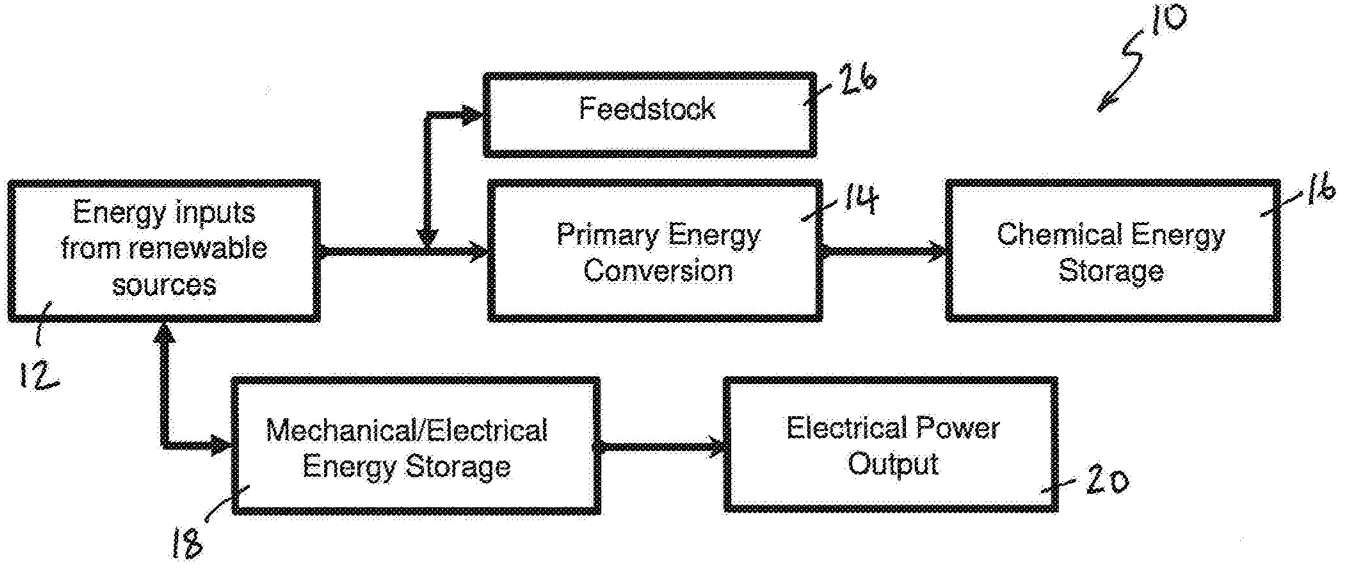

10
Feedstock
26
Energy inputs from renewable sources
12
Primary Energy Conversion
14
Chemical Energy Storage
16
Mechanical/Electrical Energy Storage
18
Electrical Power Output
20

FIG. 1

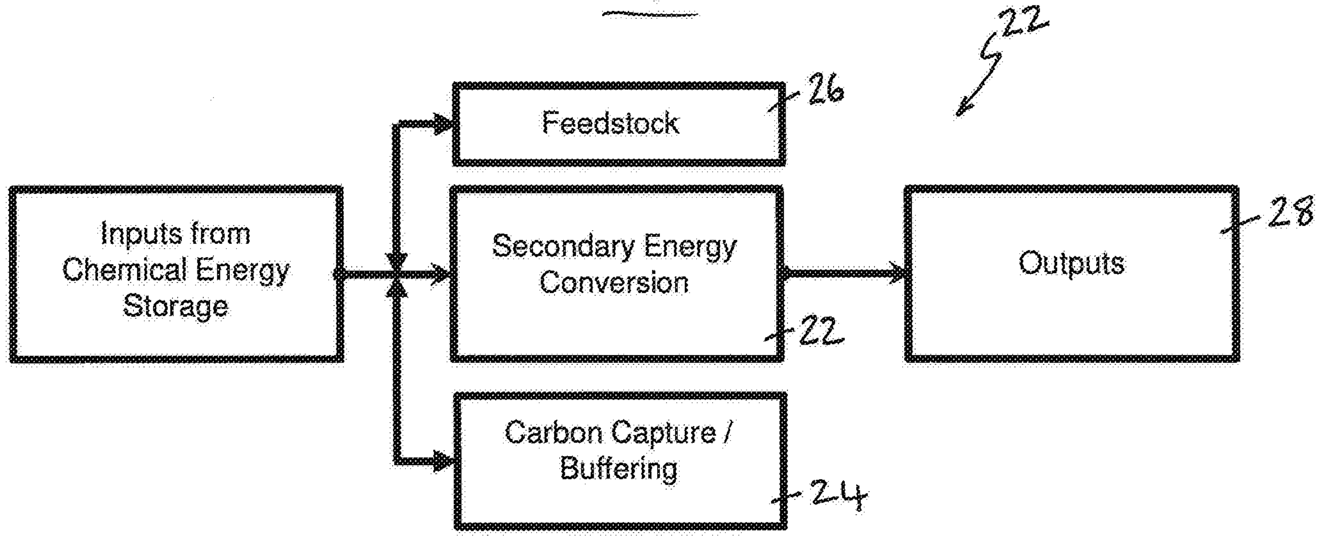

22
Feedstock
26
Inputs from Chemical Energy Storage
Secondary Energy Conversion
22
Outputs
28
Carbon Capture / Buffering
24

FIG. 2

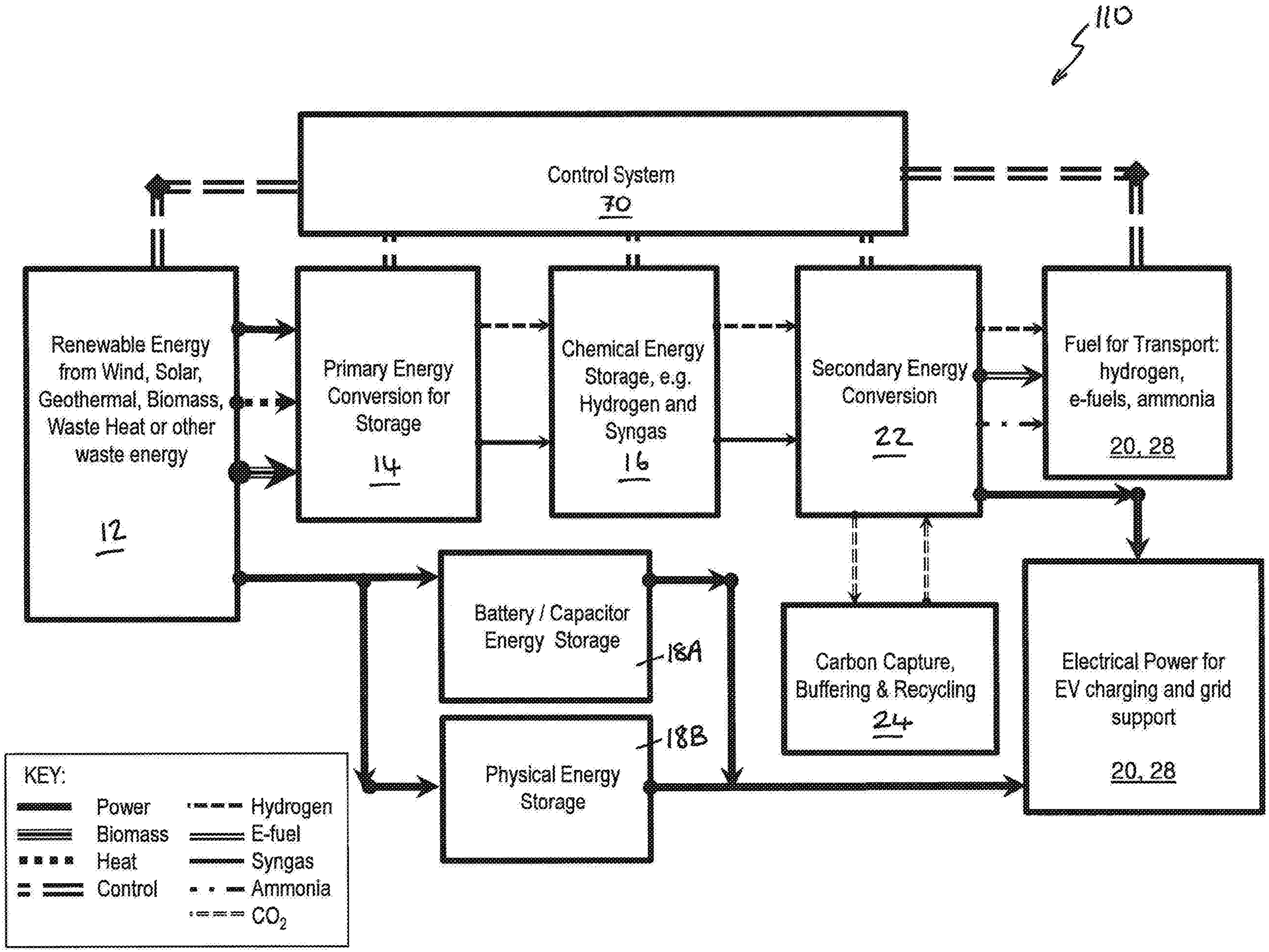

110
Control System
70
Renewable Energy from Wind, Solar, Geothermal, Biomass, Waste Heat or other waste energy
12
Primary Energy Conversion for Storage
14
Chemical Energy Storage, e.g. Hydrogen and Syngas
16
Secondary Energy Conversion
22
Fuel for Transport: hydrogen, e-fuels, ammonia
20, 28
Battery / Capacitor Energy Storage
18A
Physical Energy Storage
18B
Carbon Capture, Buffering & Recycling
24
Electrical Power for EV charging and grid support
20, 28
KEY:
Power
Biomass
Heat
Control
Hydrogen
E-fuel
Syngas
Ammonia
CO2

FIG. 3

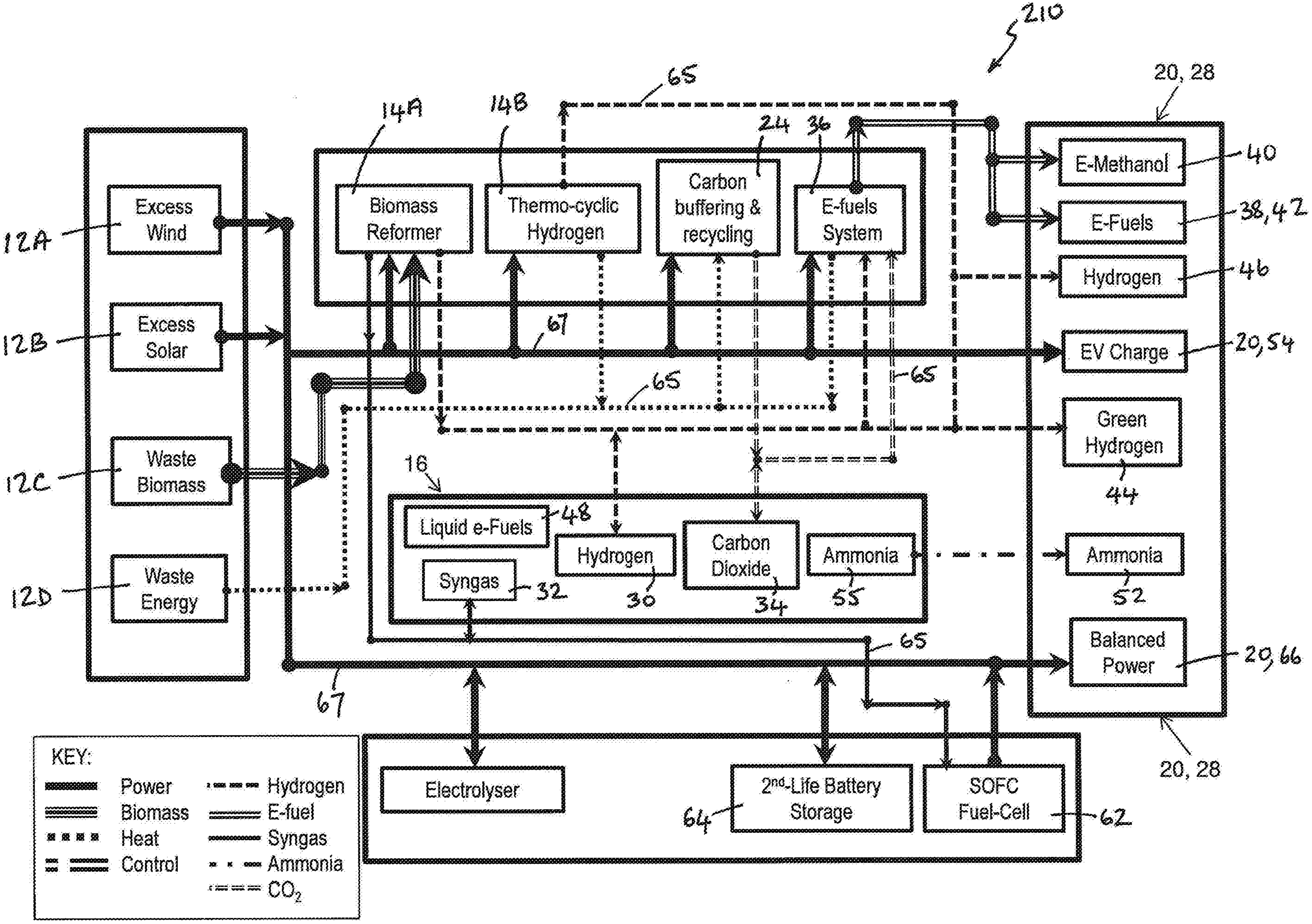

210
12A
Excess Wind
12B
Excess Solar
12C
Waste Biomass
12D
Waste Energy
14A
Biomass Reformer
14B
Thermo-cyclic Hydrogen
24
Carbon buffering & recycling
36
E-fuels System
65
67
16
Liquid e-Fuels
48
Syngas
32
Hydrogen
30
Carbon Dioxide
34
Ammonia
55
20, 28
E-Methanol
40
E-Fuels
38,42
Hydrogen
46
EV Charge
20,54
Green Hydrogen
44
Ammonia
52
Balanced Power
20,66
Electrolyser
2nd-Life Battery Storage
64
SOFC Fuel-Cell
62
KEY:
Power
Biomass
Heat
Control
Hydrogen
E-fuel
Syngas
Ammonia
CO2

FIG. 4

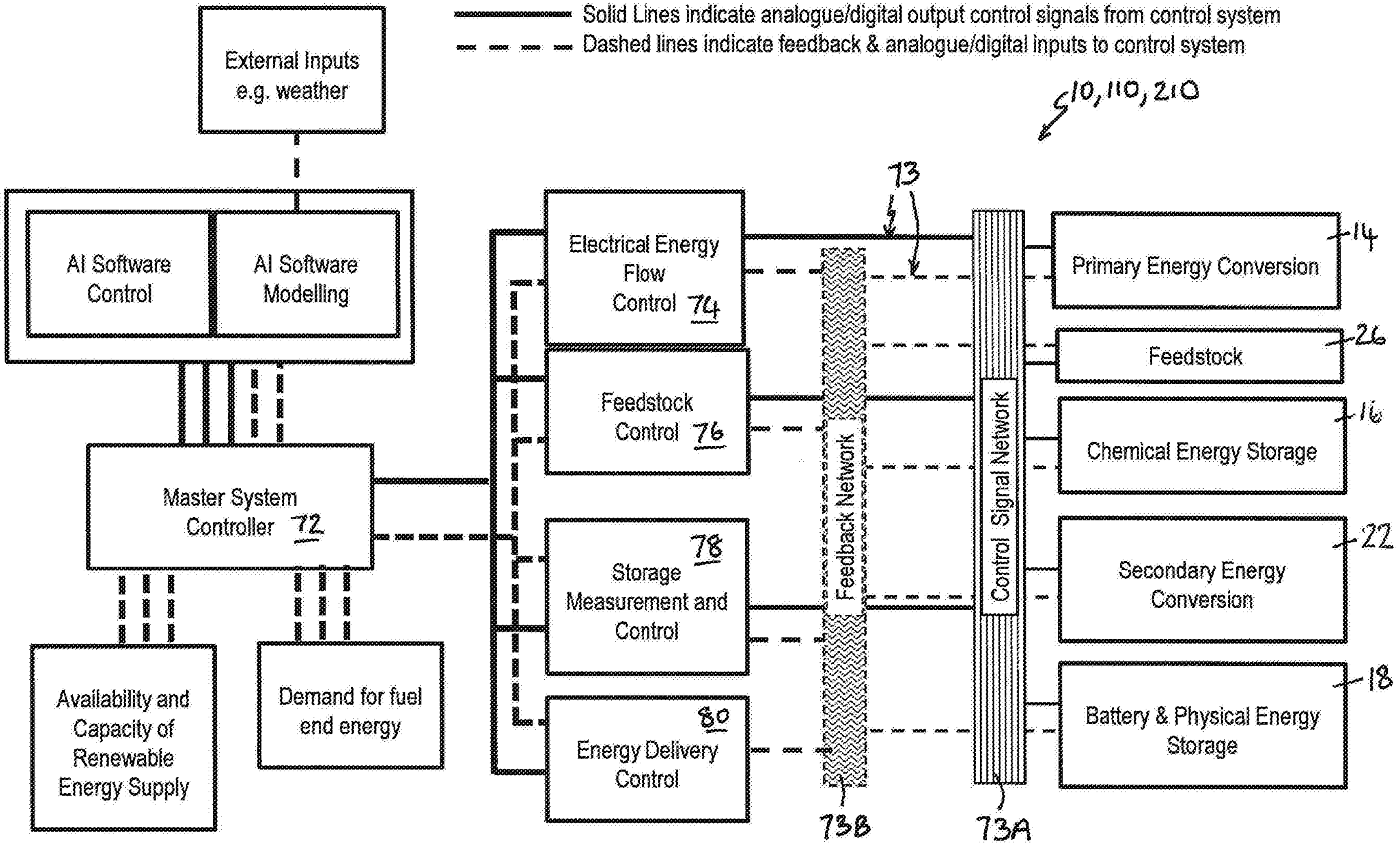

Solid Lines indicate analogue/digital output control signals from control system
Dashed lines indicate feedback & analogue/digital inputs to control system
10,110,210
External Inputs e.g. weather
AI Software Control
AI Software Modelling
Master System Controller 72
Availability and Capacity of Renewable Energy Supply
Demand for fuel end energy
Electrical Energy Flow Control 74
Feedstock Control 76
Storage Measurement and Control 78
Energy Delivery Control 80
73
Feedback Network
73B
Control Signal Network
73A
Primary Energy Conversion
14
Feedstock
26
Chemical Energy Storage
16
Secondary Energy Conversion
22
Battery & Physical Energy Storage
18

FIG. 5

FIG. 6A

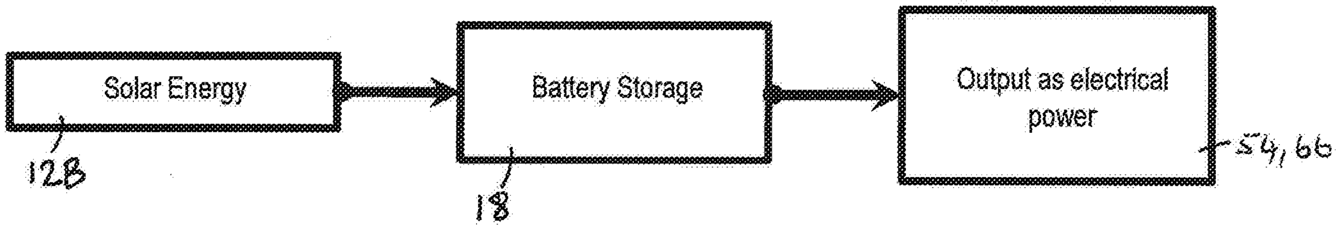


FIG. 6B

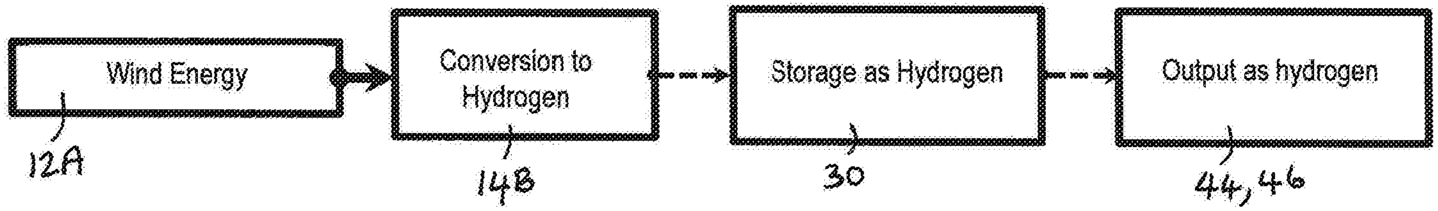
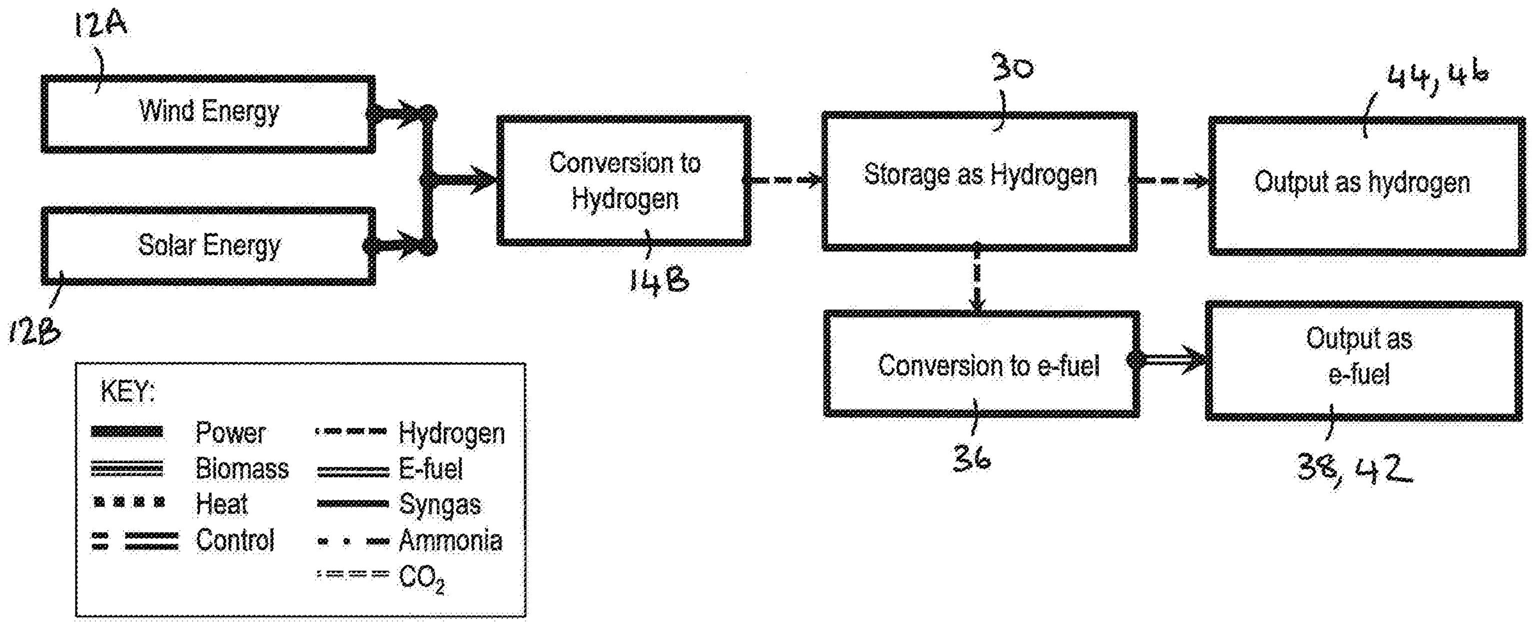


FIG. 6C



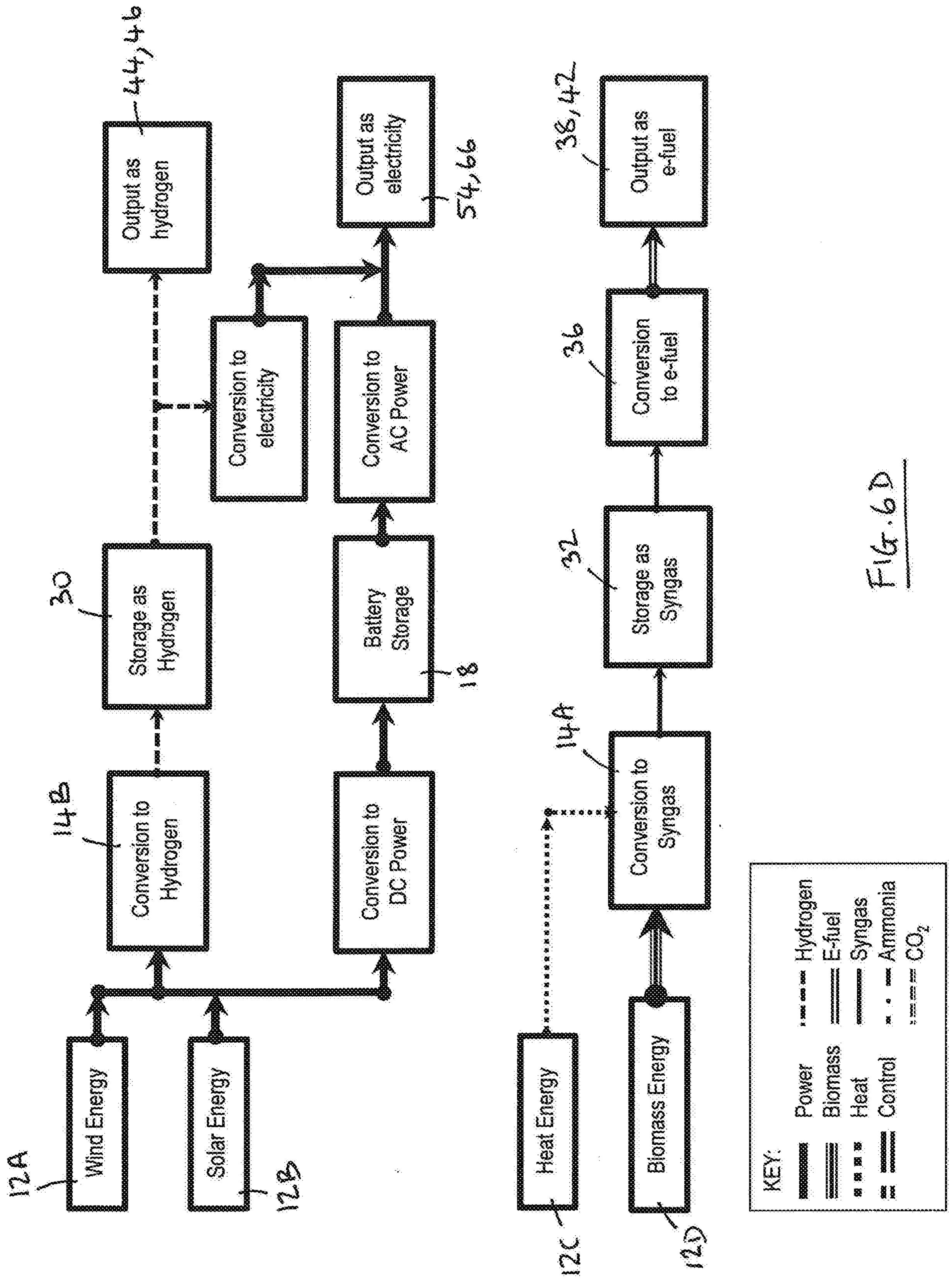

Wind Energy
12A
Solar Energy
12B
Conversion to Hydrogen
14B
Storage as Hydrogen
30
Output as hydrogen
44,46
Conversion to electricity
Conversion to DC Power
Battery Storage
18
Conversion to AC Power
Output as electricity
54,66
Heat Energy
12C
Biomass Energy
12D
Conversion to Syngas
14A
Storage as Syngas
32
Conversion to e-fuel
36
Output as e-fuel
38,42
KEY:
Power
Biomass
Heat
Control
Hydrogen
E-fuel
Syngas
Ammonia
CO_2

FIG. 6D

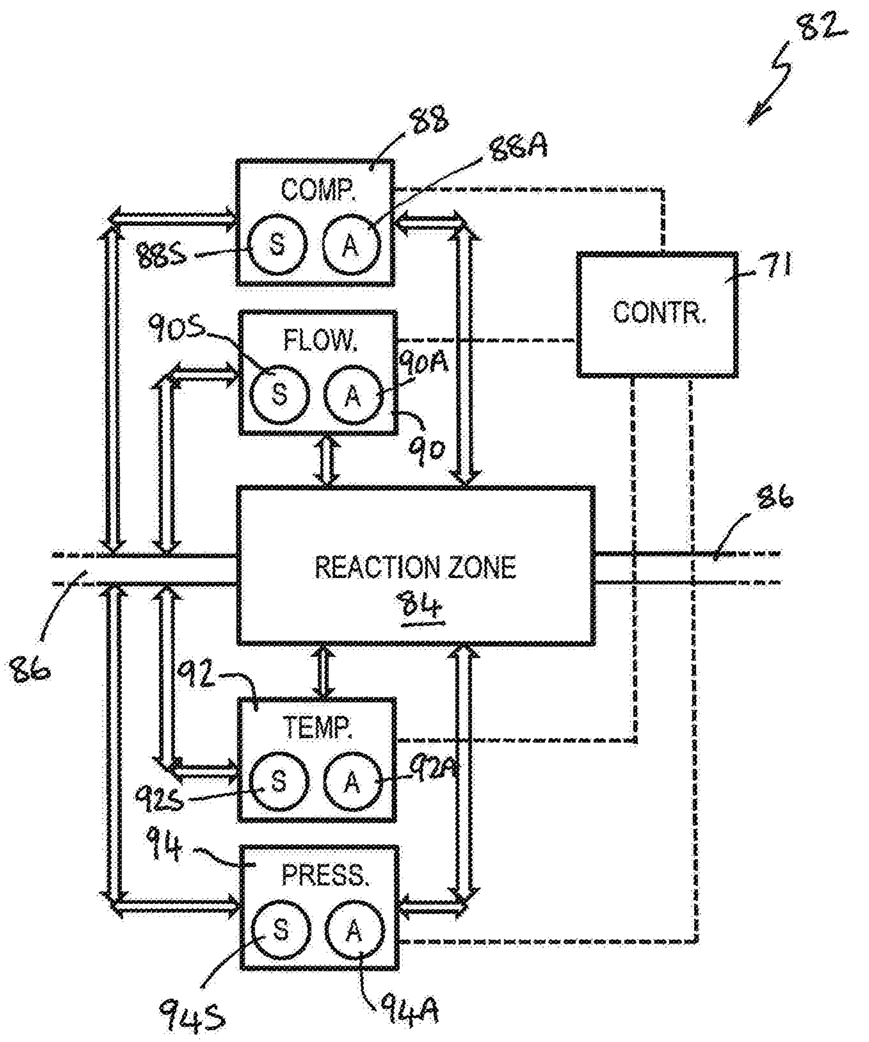

82
88
88A
COMP.
88S
S
A
71
CONTR.
90S
FLOW.
90A
S
A
90
86
REACTION ZONE
84
86
92
TEMP.
92S
S
A
92A
94
PRESS.
S
A
94S
94A

FIG. 7

Renewable Energy Capture, Conversion and Storage System

Field of the Invention

This invention relates to systems for storing energy, in particular excess energy, from energy sources, especially renewable energy sources. The invention relates especially to systems for capturing, storing and delivering energy from renewable energy sources in particular.

Background to the Invention

Renewable energy sources are variable in nature, and their energy output may depend on multiple factors such as weather, climate, location, season, time of day and the availability of feedstock. As a result, the power or energy generated by any renewable technology is variable minute-to minute, day-to-day, season-to-season. Not only is the power (kW) output variable, but so too are key power quality parameters such as voltage, amperes, harmonics and so on. In addition, the amount of excess energy that requires storage at any given time can vary depending on energy usage demand.

Known methods for storing unused energy include storage in batteries or by conversion to green hydrogen using hydrolysis of water or a chemical process. These methods can be relatively inefficient and do not make most effective use of renewable resources since inputs and outputs are not well matched to instantaneous requirements for power or fuels, which can lead to wastage of renewable energy resources.

It would be desirable to provide a more efficient and responsive system and method to optimise the storage, use and/or application of renewable resources.

Summary of the Invention

From one aspect the invention provides an energy conversion and storage system configured to receive input energy from at least one renewable energy source, the energy storage system comprising: primary energy conversion means for converting said input energy into at least one primary reaction product; at least one of: secondary conversion means for converting at least one of said at least one primary reaction product into at least one secondary reaction product; and energy storage means. The system includes a control system configured to control distribution of input energy amongst said primary energy conversion means, said secondary conversion means and/or said energy storage means and/or to control the operation of said energy conversion and storage system to match an energy demand of the energy conversion and storage system to an available input energy from said at least one renewable energy source.

Preferably, said control system is configured to control the operation of said energy conversion and storage system such that all, or substantially all, of said available input energy is consumed by said energy conversion and storage system.

Typically, said energy demand comprises an internal energy demand, preferably comprising at least an internal electrical power consumption and/or heat energy consumption, of the energy conversion and storage system, and wherein, typically, said internal energy demand comprises the respective energy demand, preferably comprising at least a respective electrical power consumption and/or heat energy consumption, of any one or more of said primary energy conversion means, said secondary energy conversion means and/or said energy storage means.

The energy conversion and storage system is optionally connected to at least one external load, and wherein said energy demand comprises an external energy demand, preferably comprising an external electrical power consumption, of said at least one external load.

The control system may be configured to control the operation of said energy conversion system by allocating a respective amount of said available input energy, especially the available input electrical power and/or heat energy, to any one or more of said primary energy conversion means, said secondary energy conversion means and/or said energy storage means.

The control system may be configured to control the operation of said energy conversion system by controlling the operation of any one or more of said primary energy conversion means, said secondary energy conversion means and/or said energy storage means, in particular to control the respective energy consumption and/or heat energy consumption, especially the respective electrical power consumption of and/or heat energy consumption or, the primary energy conversion means, said secondary energy conversion means and/or said energy storage means.

Advantageously, the control system is configured to perform computer modelling of the input energy from said at least one renewable energy source to predict the available input energy, and is configured to perform computer modelling of the energy conversion and storage system to predict the energy demand of the energy conversion and storage system. The control system may be configured to perform computer modelling of any one or more of said primary energy conversion means, said secondary energy conversion means and/or said energy storage means to predict said internal energy demand. The control system may be configured to perform computer modelling of said external energy demand to predict said external energy demand. The control system may be configured to perform said computer modelling continuously, or substantially continuously, and to correspondingly control the operation of the energy conversion and storage system continuously or substantially continuously. The control system may be configured to perform said computer modelling using at least one mathematical model, and wherein, preferably, said control system is configured to train and/or optimize said at least one mathematical model using one or more Artificial Intelligence (AI) technique, optionally by implementing said at least one mathematical model using one or more Artificial Neural Network (ANN) and training and/or optimizing the, or each, ANN using supervised and/or unsupervised machine learning.

In preferred embodiments, said primary energy conversion means comprises at least one energy conversion system configured to use said input energy to perform at least one chemical reaction with at least one reactant to produce at least one of said at least one primary reaction product. The energy conversion and storage system may be configured to provide said at least one reactant to said at least one energy conversion system from at least one of said at least one renewable energy source, or from at least one feedstock source. Optionally, said at least one energy conversion system is configured to use input electrical power from said at least one energy source to perform said at least one chemical reaction.

In preferred embodiments, said primary energy conversion means comprises at least one hydrogen producing system configured to produce hydrogen using input electrical power from said at least one energy source, and wherein, preferably, said at least one hydrogen producing system comprises at least one thermo-cyclic hydrogen production system and/or at least one hydrogen electrolyser.

Optionally, said input energy from at least one of said at least one energy source comprises biomass, and wherein said primary energy conversion means comprises at least one biomass conversion system for converting said biomass into at least one reaction product, wherein, preferably, said at least one reaction product comprises hydrogen and/or synthesis gas.

In preferred embodiments, the energy conversion and storage system includes at least one carbon capturing system configured to capture carbon dioxide, preferably from air or seawater, and means for storing the captured carbon dioxide, wherein said at least one carbon capturing means may be included in, or connected to, said primary energy conversion means and/or said secondary conversion means.

In preferred embodiments, the energy conversion and storage system includes at least one fuel synthesizing system configured to produce synthesized fuel, and which may be included in said primary conversion means and/or said secondary conversion means. Said at least one fuel synthesizing system is preferably configured to synthesize a fuel precursor from synthesis gas, and to catalytically synthesize the fuel precursor to produce synthesized fuel, and wherein, preferably, said synthesis gas is a reaction product of said primary energy conversion means. Optionally, said synthesis gas is a reaction product of said at least one biomass conversion system.

Said at least one fuel synthesizing system may be configured react carbon dioxide with hydrogen to produce carbon monoxide and water, and to mix said carbon monoxide with hydrogen to produce said synthesis gas. Preferably, said carbon dioxide is said captured carbon dioxide.

In preferred embodiments, said secondary conversion means comprises one or more conversion system configured to convert at least one of said primary reaction product into at least one output comprising at least one of said at least one secondary reaction product and/or electrical power.

Optionally, said secondary conversion means comprises at least one fuel cell for producing electrical power from at least one of said primary reaction product.

Optionally, said secondary conversion means comprises an ammonia production system configured to produce ammonia from nitrogen and hydrogen.

Optionally, said energy storage means comprises any one or more of: means for storing electrical energy, for example comprising at least one battery and/or at least one capacitor; means for storing mechanical energy, for example comprising any one or more of a compressed air energy storage system, a flywheel energy storage system, a pumped hydroelectric energy storage system, a gravity battery and/or any other conventional mechanical energy storage system or device; and/or thermal energy storage means (TES).

In some embodiments, any one or more of said at least one primary reaction product and/or any one or more of said at least one secondary reaction product, preferably hydrogen and/or synthesized fuel, are provided as an output product of the energy conversion and storage system, and wherein said energy conversion and storage system may include at least one respective vessel, preferably at least one portable vessel, for storing the, or each output product, and/or may include a respective dispensing apparatus for dispensing the, or each, output product.

Optionally, the energy conversion and storage system comprises at least one electrical outlet for delivering electrical power from said energy conversion and storage system.

In preferred embodiments, the energy conversion and storage system includes storage means, typically comprising at least one vessel and/or reservoir, for storing any one or more of said at least one primary reaction product, said at least one secondary reaction product, and/or feedstock for said primary energy conversion and/or for said secondary conversion means.

In typical embodiments, said primary conversion means comprises at least one primary conversion system comprising a chemical reactor, and/or said secondary conversion means comprises at least one secondary conversion system comprising a chemical reactor, and wherein said control system is configured to control the operation of the, or each, chemical reactor in order to control any one or more of: the energy consumption of the respective chemical reactor, preferably the electrical power consumption and/or the heat energy consumption; the consumption of feedstock; and/or the production of reaction product(s). Typically, the, or each, reactor comprises any one or more of fluid composition control means for controlling the composition of reactant(s) in the reactor; fluid flow control means for controlling the flow of fluid in the reactor; fluid temperature control means for controlling the temperature of fluid in the reactor; and/or fluid pressure control means for controlling the pressure of fluid in the reactor, and wherein said control system is configured to control the operation of the, or each, chemical reactor by controlling the operation of any one or more of the fluid composition control means, the fluid flow control means, the fluid temperature control means and/or the fluid pressure control means.

From another aspect the invention provides an energy conversion and storage method comprising:
receiving input energy from at least one renewable energy source;
converting at least some of said input energy into at least one primary reaction product;
converting at least one of said at least one primary reaction product into at least one secondary reaction product, and/or storing at least some of said input energy; and
controlling the distribution of said input energy amongst said converting into at least one primary reaction product, said converting into at least one secondary product and/or said storing.

Preferred embodiments of the system are relatively efficient and responsive, optimising the storage, use and/or application of renewable resources. Advantageously, the system captures variable renewable energy output, and transforms the energy to form(s) which are available and ready for use when energy demand requires it. Advantageously, preferred embodiments are configured to predict, control and optimise multiple energy vectors to convert multiple sources of renewable energy and provide multiple sources of energy supply.

Preferred embodiments provide an efficient and responsive system and method for optimizing the use and application of renewable resources by balancing energy usage amongst different forms of energy conversion and/or energy storage as required, preferably while ensuring zero carbon impact in real-time from energy generation through to consumption.

In preferred embodiments, the system comprises a plurality of inter-connected energy conversion systems controlled by a master control system, which is preferably configured to support modelling of any one or more of: the operation of the system (including the operation of any component thereof), energy demand (or system output), and energy availability (or system input). The control system may be configured to control the operation of the (overall) system to match, or balance, the storage and/or use of energy to the available supply from renewable (and/or other) energy sources. Preferably, the control system is configured to perform the modelling and/or control using artificial intelligence (AI), e.g. using supervised and/or unsupervised machine learning algorithm(s). Preferred embodiments provide flexibility and control to optimise use of energy resources, including any one or more of: the capture, transformation (or conversion), storage, transportation and/or use or energy, advantageously with a real time net zero carbon impact on the environment.

In preferred embodiments, the control system and more particularly the master controller is configured to implement system modelling logic, e.g. by supporting mathematical modelling software or firmware, for enabling the control system to mathematically model the behaviour of the overall system and/or individual components thereof, typically depending on process settings and/or on feedback signals received from one or more system components during operation of the overall system and/or system component.

Optionally, the control system is configured to implement Model Predictive Control (MPC). Using MPC, the control system may cause the operation of one or more of the system components to be adjusted before a corresponding deviation from a relevant process set point actually occurs. This predictive ability, when combined with traditional feedback operation, enables the control system to make adjustments that are smoother and closer to the optimal control action values than would otherwise be obtained. A control model for the equipment nodes can be written in Matlab, Simulink, or Labview by way of example and executed by the master controller. Advantageously, MPC can handle MIMO (Multiple Inputs, Multiple Outputs) systems. The control system may include an artificial intelligence (AI) based model controller configured to optimize operation of the overall system and/or any one or more of the system components in real time in order to making best use of available energy, reactant levels and so on.

In some embodiments, the system is configured to receive energy produced from multiple different renewable energy sources, and to store the energy in one or more forms suitable for immediate consumption, for transport or distribution and/or for conversion into other form(s). Advantageously, the system is flexible and is available to receive and store input energy that would otherwise be lost. For example curtailed wind energy, unused solar energy, waste biomass and/or waste heat energy can be stored as chemical energy, which may be used or converted, e.g. into electrical power. Advantageously, preferred embodiments of the system are configured to capture curtailed or transient peaks of instantaneous power generation.

In preferred embodiments, the system includes an artificial intelligence modelling and control system configured to control a plurality of fluctuating renewable energy inputs that are typically modular. The preferred system is configured to convert the variable energy inputs, advantageously using computer-implemented AI algorithms, into any one or more of a plurality of outputs by converting the energy into a form that is suitable for onward energy consumption and/or energy storage medium/media.

In preferred embodiments, the system, in particular the control system, is configured to predict and/or monitor one or more parameters (preferably comprising one or more power quality parameter(s)) associated with one or more system components (or sub-systems), and/or the, or each, energy input. The control system is configured to control, preferably instantaneously, how the available input energy is used by the overall system. Operation of the overall system (e.g. with respect to how input energy is processed) is flexible, and may be determined by the control system in response to one or more measured parameters, and/or or more predicted parameters, relating to the energy input(s) and/or the energy demand of the, or each, system component (or sub-system). This assists the system to make use of energy that would otherwise be lost, such as curtailed wind, unused solar, waste biomass and waste heat, by conversion and storage as chemical energy, which may be used or converted to electrical energy. Advantageously, the system is configured so that its operation, in particular its energy conversion cycle, delivers zero carbon impact on the environment in real-time.

In preferred embodiments, the control system is configured to perform computer modelling to predict input energy from one or more energy source, and also to predict the energy consumption requirements of the overall system, and to perform predictive load matching between the input energy and energy consumption in order to determine how to control the operation of the system.

In preferred embodiments the control system is configured to monitor inputs and outputs (which may for example include any one or more of flow rate, fluid temperature, fluid pressure, power input, power output and/or any other monitored parameter of the overall system or of any component or sub-system included in the overall system). The control system may adjust the control algorithms in response to the inputs and outputs, and/or provide over-arching control of individual sub-systems, or components, within the overall system.

Advantageously, the control system is configured to control operation of the system depending on recorded and/or predicted data indicating energy input availability and energy demand, and/or past performance of sub-system inputs, and/or one or more other factors such as weather predictions, time of day, week and year; rate of change of inputs and outputs (e.g. wind speed, percentage cloud cover, concentration of sun, demand for e-fuel, contents or fill-level of storage vessels, pressure in storage vessels and so on). Advantageously, by using AI the control system is able to continually learn and adapt to optimise energy utilisation based on any one or more of the foregoing parameters.

In preferred embodiments, the control system is configured to control operation of the system by controlling any one or more of the following aspects of the system: which renewable energy sources are in operation, which energy conversion system(s) are in operation (e.g. turned on or off); how the available input energy is distributed amongst the energy conversion system(s) (e.g. determining which energy conversion system(s) receive input energy, and how much energy each energy conversion system receives); the individual operation of the, or each, relevant conversion system (e.g. controlling one or more operating parameters of the conversion system in order to control its energy consumption, wherein the operating parameters may include any one or more of: electrical input power, electrical output power, chemical reaction rate(s), as applicable, wherein controlling a chemical reaction rate may involve controlling any one or more of the quantity, flow rate, temperature, pressure and/or composition of one or more chemical reactants).

The control system is preferably configured to optimise its operation, preferably using AI, to ensure that the energy inputs are utilised optimally to operate the conversion system(s). The control system is preferably configured to control the operation of conversion system(s) that require continuous operation such that they are stable and optimised from an energy conversion perspective.

The control system is advantageously configured to determine which conversion system(s) are prioritised based on the amount of energy input available at any given time, and/or on the demand profile(s) of the respective conversion system(s).

Advantageously, the system may be operated such that the overall energy conversion cycles within the system deliver net-zero carbon impact on the environment in real-time, within the energy generation and power usage output cycles.

Further advantageous aspects of the system will be apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments and with reference to the accompanying drawings.

Brief Description of the Drawings

Embodiments of the invention are now described by way of example and with reference to the accompanying drawings in which like numerals are used to denote like parts an in which:

Figure 1 is a block diagram of an energy conversion and storage system embodying one aspect of the invention;

Figure 2 is a block diagram of a secondary energy conversion system being suitable for use with, or inclusion in, the energy storage system of Figure 1;

Figure 3 is a block diagram of an embodiment of the energy conversion and storage system including the secondary energy conversion system;

Figure 4 is a block diagram of the system of Figure 3 illustrating an exemplary configuration of the system;

Figure 5 is an alternative block diagram of the system of Figure 3, illustrating a control system included in the energy conversion and storage system;

Figure 6A is a block diagram of a first exemplary system configuration having a single renewable energy input, a single energy storage means, and a single energy output;

Figure 6B is a block diagram of a second exemplary system configuration having a single renewable energy input, a single primary energy conversion means, a single energy storage means, and a single energy output;

Figure 6C is block diagram of a third exemplary system configuration having multiple renewable energy inputs, a single primary energy conversion means, a single energy storage means, a secondary energy conversion means, and multiple energy outputs;

Figure 6D is block diagram of a fourth exemplary system configuration having multiple renewable energy inputs, multiple primary energy conversion means, multiple energy storage means, multiple secondary energy conversion means, and multiple energy outputs; and

Figure 7 is a block diagram of a chemical reactor suitable for use in systems embodying the invention.

Detailed Description of the Drawings

Referring now to Figure 1 of the drawings, there is shown an energy conversion and storage system 10 embodying one aspect of the invention. Figure 2 shows a system comprising secondary conversion means 22, which may be referred to as secondary energy conversion means in preferred embodiments, that is configured to convert chemically stored energy into one or more output product and/or into electrical power (illustrated generally as “outputs” in Figure 2). In preferred embodiments, the secondary conversion means 22 is included in the energy storage system 10, wherein energy stored by and/or otherwise received by, the system 10 is provided as the input to the secondary conversion means 22. Figure 3 shows a preferred embodiment of the energy conversion and storage system, generally indicated as 110, in which the secondary conversion means 22 is included. The system 110 is similar to the system 10 and the same or similar description applies as would be apparent to a skilled person, with like numerals being used to denote like parts.

The system 10, 110 is configured to receive input energy from one or more energy sources 12, preferably renewable energy sources, the number and type of which may vary depending on the embodiment as is described in more detail hereinafter. The system 10, 110 may connectable to the energy sources 12. Alternatively, the energy sources 12 may be part of the system 10, 110, in which case the system 10, 110 may be described as an energy generation, conversion and storage system. As is described in more detail hereinafter, the system 10, 110 may be configured to deliver output energy in one or more forms, and may therefore be described as an energy delivery system.

The system 10, 110 includes primary energy conversion means 14 configured to convert energy received (preferably directly) from any one or more of the energy source(s) 12 from one energy form to another energy form for the purpose of energy storage. In particular, the primary energy conversion means 14 comprises means for converting received energy into chemically storable energy, preferably in the form of Hydrogen (H_2), Syngas (synthesis gas) and/or other hydrocarbon (in liquid or gaseous form as is convenient). In preferred embodiments (for example the embodiment of Figure 3), the primary energy conversion means 14 comprises means for converting electrical energy, heat energy and/or biomass into Hydrogen and/or Syngas. The primary energy conversion means 14 typically comprises one or more energy conversion system or apparatus configured to use the received energy (which may for example comprise electrical energy, heat energy and/or biomass) to perform one or more chemical reaction with one or more reactant to produce one or more reaction product. The, or each, reactant may be obtained from the energy source(s) 12 (e.g.

biomass), or may be obtained from a suitable feedstock source 26, as required. The, or each, reaction product (e.g. H_2 or syngas) is the medium (typically in fluid form) in which the converted energy is stored. The reaction product(s), or other output product(s) of the, or each, primary conversion system is typically fluid (i.e. liquid and/or gas) but may alternatively, or in addition, comprise solid matter. For example a primary conversion system may be configured to convert biomass to block of fuel, or methane to solid carbon.

The system 10, 110 includes chemical energy storage means 16 for storing any one or more of: the, or each, product produced by the primary energy conversion means 14; any product(s) derived therefrom; any other product produced or obtained by the system 16 (in particular carbon dioxide obtained by carbon capture); the, or each, product produced by the secondary conversion means 22. The chemical energy storage means typically comprises one or more vessel for storing liquid and/or gas, as applicable.

In typical embodiments, the system 10, 110 includes means 18 for storing electrical energy (18A in Figure 3) and/or for storing mechanical energy (18B in Figure 3) received from the, or any one or more of, the energy source(s) 12. The electrical energy storage means 18A may comprise one or more battery and/or one or more capacitor. The mechanical energy storage means 18B may for example comprise a compressed air energy storage system, a flywheel energy storage system, a pumped hydroelectric energy storage system, a gravity battery and/or any other conventional mechanical energy storage system or device, preferably but not necessarily being electrically powered. In some embodiments, the primary energy conversion means 14 may include means for converting energy received from the energy source(s) 12 into electrical energy, in which case such electrical energy may be stored using the electrical energy storage means 18.

The system 10, 110 may include, or be connectable to, one or more electrical power output or outlet 20 by which stored electrical power and/or electrical power generated from stored mechanical power can be delivered to an electrical load (not shown), e.g. an electrical grid, a electrical vehicle (EV) charging point. The system 10, 110 may include one or more electrical generator (not shown) for converting stored mechanical energy into electrical power. Any suitable conventional electrical generator may be used for this purpose. Alternatively, or in addition, electrical power received from one or more of the energy sources 12A, 12B may be provided directly to the output 20.

In preferred embodiments, the secondary conversion means 22 comprises means for producing one or more fuel, especially e-fuel and/or biofuel, and/or one or more chemical substance, e.g. ammonia, preferably from one or more product stored in the chemical energy storage means 16. As such, the stored product(s) may be said to comprise feedstock for the secondary energy conversion means 22.

The reaction product(s), or other output product(s) of the, or each, secondary conversion system is typically fluid (i.e. liquid and/or gas) but may alternatively, or in addition, comprise solid matter or electrical power. For example a secondary conversion system may comprise one or more fuel cell for generating electrical power.

The secondary conversion means 22 may include means for converting one or more product stored in the chemical energy storage means 16 into electrical energy. Any suitable conventional transducer may be used for this purpose, e.g. one or more fuel cell, one or more thermoelectric transducer and/or other chemical-to-electrical and/or heat-to-electrical transducer. The conversion means 22 may include, or be connectable to, one or more electrical power output or outlet (e.g. the output/outlet 20 of the system 10, 110) by which stored electrical power and/or electrical power generated from stored mechanical power can be delivered to an electrical load (not shown), e.g. an electrical grid and/or an electrical vehicle (EV) charging point 54 (Figure 4).

The system 10, 110 optionally includes one or more thermal energy storage (TES) means (not shown), which may comprise one or more conventional TES system of any convenient type, e.g. comprising a reservoir containing a liquid or gaseous mass. The, or each, TES system may be electrically heated or heated by heat exchanger(s). The TES system(s) may be used to store heat energy from the relevant energy source(s) 12, or to generate and store heat energy from electrical power from the relevant energy source(s) 12, and/or or store heat energy generated during operation of the secondary conversion means 22. Advantageously, stored thermal energy may be used by the secondary conversion means 22 in any convenient manner, e.g. to perform one or more chemical reactions.

In preferred embodiments, the system 10, 110 includes carbon capturing means 24 preferably configured to capture carbon dioxide (CO_2) from the environment, e.g. from air and/or from seawater. Any conventional carbon capturing apparatus or system, e.g. a conventional direct air capture (DAC) system or direct ocean capture (DOC) system, may be provided in the system. More generally, any conventional carbon capturing and/or sequestering apparatus or system may be used, e.g. apparatus for capturing carbon, or more particularly carbon dioxide, by any conventional process (e.g. by absorption or scrubbing or by membrane(s)) from any available source, for example, flue gas, seawater or air. Carbon dioxide produced by the carbon capturing means 24 may be stored, or buffered, in the system 10, 110, 210 (for example in a suitable vessel included in the storage means 16) or elsewhere) and/or may be used by other component(s) or subsystems of the system 10, 110, 210 as required. In typical embodiments, the secondary conversion means 22 is configured to receive CO_2 from or obtained by the carbon capturing means 24 for use in one or more energy conversion process. Alternatively, or in addition, the secondary conversion means 22 may be connected to a tank or other source of CO_2. The carbon capturing means 24 may be considered to be part of the primary conversion means 14 in that it consumes electrical energy from the energy sources 12A, 12B and produces CO2, which may be stored in the storage means 16 for use by the secondary conversion means 22. Optionally, at least some of the captured CO2 may be recycled or used in applications such as fire suppression systems, fire extinguishers, food packaging, carbonating beverages and so on. As such, CO2 may be considered as an output of the system 10, 110, 210.

In typical embodiments, the system 10, 110 includes, or is connectable to, one or more feedstock source 26. The number and type(s) of feedstock required by the system 10, 110 may very depending on the embodiment, in particular depending on what process(es) are performed by the primary energy conversion means 14 and/or the secondary conversion means 22. In typical embodiments, a respective feedstock source 26 may be provided for any one or more of: water, iodine (I_2), sulphur dioxide (SO_2), carbon dioxide (CO_2) and hydrogen (H_2). The, or each, feedstock 26 may be provided in any suitable form (solid, liquid or gas) and in any suitable tank or other container, preferably with means (e.g. pump(s), fan(s), injector(s) and/or valve(s)) for controlling the delivery of the respective feedstock to the relevant part(s) of the primary or secondary conversion means 14, 22.

The system 10, 110 is configured to produce one more output 20, 28, optionally including electrical power output as described above. In typical embodiments, the output 28 comprises one or more product produced by the secondary conversion means 22 and/or by the primary conversion means 14. As described above, product(s) of the energy storage means 16, e.g. hydrogen and syngas, may be stored in the chemical energy storage means 16. Such products may be output from the system 10, 110 from the storage means 16. The system 10, 110 may include storage means (not shown in Figures 1 or 2) for storing the, or each, product of the secondary conversion means 22, and which may comprise one or more vessel for storing liquid and/or gas. The product(s) of the secondary conversion means 22 may be output from the system 10, 110 in any convenient manner, e.g. from the respective storage means or directly from the secondary conversion means 22. The product(s) may be output in container(s) for transport and distribution, and/or may be dispensed via any suitable dispensing system (not shown), e.g. a fuel dispenser.

The primary energy conversion means 14, secondary conversion means 22, energy storage means 16, 18, carbon capturing means 24 and/or output means 20, 28 may be referred to as components or sub-systems of the overall system 10, 110, 210.

Figure 4 shows an exemplary embodiment of the energy storage system 210 in more detail. The system 210 is similar to the systems 10, 110 and the same or similar description applies as would be apparent to a skilled person, with like numerals being used to denote like parts.

In preferred embodiments, the system 10, 110, 210 is configured to receive input energy from a plurality of energy sources 12A-12D, typically comprising more than one type of energy source. At least one of, and preferably all of, the energy sources 12 are sources of renewable energy, typically including any one or more of wind energy, solar energy, wave energy, tidal energy biomass or waste heat. Accordingly, in use the system 10, 110, 210 may be connected to one or more renewable energy source 12, each comprising one or more respective energy power generator (for example one or more wind turbine, one or more solar power generator, one or more wave turbine and/or one or more tidal power turbine (not shown)) and/or may be configured to receive feedstock (such as biomass material) and/or heat energy (e.g. via one or more heat exchanger (not shown). In this regard, the specific configuration of the system 10, 110, 210 may vary from embodiment to embodiment depending on, for example, the location of the system 10, 110, 210. In some embodiments, the system 10, 110, 210 is connected to at least one instance of multiple different types of energy source, preferably at least one instance of multiple different types of energy source.

The form(s) in which the energy is received by the system 10, 110, 210 depends on the type of the energy source(s) 12. For example, wind turbines, solar generators, wave turbines and tidal turbines may supply energy in the form of electrical power, whereas other forms of energy (e.g. biomass) may be provided in the form of solid, liquid and/or gaseous matter, or heat energy may be provided. Heat energy may for example be received from a geothermal system (not shown) or a nuclear power plant. In preferred embodiments the system 10, 110, 210 is configured to receive electrical energy, or electrical power, from at least one type, and preferably more than one type, of renewable energy source. The renewable energy source(s) 12 may be conventional and may comprises any conventional respective apparatus, e.g. suitable renewable energy generator(s), and/or any other equipment, for example power converter(s) or heat exchanger(s). For example, in cases where a renewable energy source 12 comprises an electrical generator, one or more electrical power converter (e.g. an AC-DC converter and/or DC-AC converter as required) may be included in the energy source 12. Alternatively, or in addition, the system 10, 110, 210 may include one or more electrical power converter (e.g. an AC-DC converter and/or DC-AC converter as required) for converting electrical power received from one or more of the energy sources 12 and/or for converting electrical power within the system 10, 110, 210 itself. Such converters may be considered to be primary conversion means or secondary conversion means. For example, as illustrated in Figure 6D, the system 10, 110, 210 may include an AC-DC power converter for converting AC power received from renewable source(s) 12 into DC power for battery storage (other storage as applicable), and/or may include a DC-AC converter for converting battery stored (or otherwise stored) energy to AC power. Each renewable energy source 12 may include a controller for controlling its operation. As is described in more detail below, the respective controller of each energy source 12 may be controlled by the control system 70 of the system 10, 110, 210, which control system 70 may be referred to as a master control system.

Although not shown for reasons of clarity, the system 10, 110, 210 may be provided with any suitable conventional means for receiving energy from the relevant energy source(s) 12, e.g. electrical power converter(s), heat exchanger(s), and/or storage tanks as applicable. The system 10, 110, 210 preferably also includes any suitable conventional means for measuring the amount of energy received from each source 12. By way of example, suitable measuring means may include any one or more of electrical power meter(s), voltage sensor(s), current sensor(s), flow sensor(s), density sensor(s), pressure sensor(s), temperature sensor(s) and feedstock measurements (e.g. a calorific value for biomass feedstock).

In preferred embodiments, the energy received from the, each or any one or more of the, energy source(s) 12 is excess or waste energy. In this connection, each energy source 12 may be part of another system (not shown) to which the system 10, 110, 210 is connected or with which it is associated. For example, the system 10, 110, 210 may be connected to one or more renewable energy electrical power generation system (not shown), e.g. a wind farm or solar farm, which supplies electrical power to the electrical grid or other variable load (e.g. local machinery or plant), and may be configured to receive excess power from the system when its generated power exceeds the load demand. Waste energy may for example take the form of waste biomass or waste heat.

Advantageously, received electrical power from one or more of the sources 12 may be used to provide electrical power to operate the system 10, 110, 210 although the system 10, 110, 210 may be connectable to or provided with an alternative power supply as required.

Referring in particular to Figure 2, the primary energy conversion means 14 comprises at least one, preferably more than one, energy conversion system 14A, 14B (which may generally be referred to as a component or sub-system of the system 10, 110, 210) for converting energy received from one or more of the energy source(s) 12 into one or more product, typically in gaseous or liquid form, preferably comprising hydrogen and/or syngas, for storage. In preferred embodiments, at least one biomass conversion system 14A is provided for producing hydrogen and/or syngas from the received biomass. As such, the biomass received from the respective energy source 12C may be said to comprise feedstock for the biomass conversion system 14. The, or each, biomass conversion system 14A may be of any conventional type, i.e. configured to convert biomass using any suitable conventional process e.g. gasification, torrefaction or pyrolysis. In the illustrated embodiment, the system 14A is a biomass reformer. The conversion system 14A may use electrical power received from one or more of the energy sources 12A, 12B to perform the conversion process. The output of the biomass conversion system 14 may be stored in the chemical energy storage means 16, which in the example of Figure 4 comprises one or more vessel or reservoir 30 for storing Hydrogen, and one or more vessel or reservoir 32 for storing syngas.

In preferred embodiments, at least one hydrogen production system 14B is provided. In the illustrated embodiment, the hydrogen production system 14B comprises a thermo-cyclic Hydrogen production system, i.e. a system configured to produce Hydrogen from water by a thermochemical cycle such as the Sulphur-iodine cycle or iron oxide cycle, or a hybrid thermochemical cycle such as the Copper-chlorine cycle or hybrid Sulphur cycle. The system 14B may include one or more chemical reactor configured to perform the, or each, chemical reaction of the relevant cycle, and may take any conventional form. The system 14B advantageously receives electrical power from one or more of the energy sources 12A, 12B to perform the relevant cycle. The hydrogen production system 14B may receive water from a respective feedstock source 26. The hydrogen production system 14B may receive any other required reactant or feedstock, e.g. sulphur dioxide and iodine in cases where the sulphur-iodine cycle is being implemented, from a respective feedstock source 26. The hydrogen produced by the system 14B may be stored in the reservoir 30, or in a separate hydrogen reservoir (especially if it is desired to keep separate hydrogen produced using renewable electrical power from hydrogen produced using other received energy), preferably as part of the storage means 16. Other reaction products may be stored and/or recycled as is convenient.

Typically, the thermochemical cycle is exothermic and in preferred embodiments heat energy generated by the system 14B may be stored and/or recycled for use in one or more other process performed by the system 10, 110, 210. For example the system 10, 110, 210 may be configured to provide heat energy produced by the system 14B to the carbon capturing means 24.

Alternatively, or in addition, the hydrogen production system 14B comprises an electrolyser, i.e. a system configured to produce hydrogen by electrolysis of water, and may take any conventional form. The system 14B advantageously receives electrical power from one or more of the energy sources 12A, 12B to perform the electrolysis. The hydrogen production system 14B may receive water from a respective feedstock source 26.

More generally, the preferred primary energy conversion means 14 comprises one or more energy conversion system or apparatus configured to use the received energy (which may for example comprise electrical energy, heat energy and/or biomass) to perform one or more chemical reaction with one or more reactant to produce one or more reaction product. The, or each, reactant may be obtained from the energy source(s) 12 (e.g. biomass), or may be obtained from a suitable feedstock source 26, as required. The, or each, reaction product (e.g. H_2 or syngas) is the medium (typically in fluid form) in which the converted energy is stored. In some embodiments, the reaction product(s) may comprise products other than hydrogen or syngas.

Hydrogen (which may in in liquid or gaseous form) produced by the, or each, hydrogen producing system 14A, 14B of the primary conversion means 14 may be stored in the reservoir 30 and/or in one or more respective vessel 44. The, or each, vessel 44 may be portable and removable from the system 10, 110, 210, and/or may be used to fill one or more portable vessel, in order to facilitate transport and distribution of the hydrogen. Alternatively, or in addition, the produced hydrogen may be provided to a respective dispensing apparatus 46 for dispensing to end users (not shown), e.g. as a fuelling station for vehicles, tankers or the like. Hydrogen may be stored in the vessel(s) 44 or provided to the dispensing apparatus 46 directly from the hydrogen producing system 14A, 14B and/or from the reservoir 30. The reservoir 30 may be used as a buffer for storing hydrogen when production exceeds demand.

Another example of a primary conversion system is an ammonia production system (not shown) configured to produce ammonia from nitrogen (N_2) and hydrogen (H_2) using the Haber-Bosch process. The hydrogen may be obtained from the reservoir 30, or other hydrogen source provided by the system 10, 110, 210. The produced ammonia may be stored in a respective vessel or reservoir 55 that may be part of the storage means 16.

The carbon capturing means 24 may comprise any conventional carbon capturing system. The carbon capturing system 24 advantageously receives electrical power from one or more of the energy sources 12A, 12B to perform carbon capturing. Carbon dioxide produced by the carbon capturing system 24 may be stored in a vessel or reservoir 34 for storing carbon dioxide, preferably being part of the storage means 16. In order to perform carbon capturing, system 10, 110, 210 may be configured to provide heat energy to the carbon capturing system 24 from one or more heat energy source 12D (if present) and/or from one or more energy conversion system included in the primary energy conversion means 14 and/or the secondary conversion means 22.

In typical embodiments, carbon dioxide is used by the secondary conversion means 22, in particular by one or more fuel synthesizing system 36, which may be considered to be part of the secondary conversion means 22. The fuel synthesizing system(s) 36 may receive carbon dioxide directly from the carbon capturing system 24, and/or from the reservoir 34 (which may serve as a buffer between the carbon capturing system 24 and the fuel synthesizing system(s) 36. Alternatively, or in addition, the fuel synthesizing system(s) 36 may receive carbon dioxide from a feedstock source 26 of carbon dioxide.

The fuel synthesizing system 36 is configured to produce synthesized fuel, or synthetic fuel, preferably electro-fuel (or e-fuel). The fuel synthesizing system 36 is configured to synthesize a fuel precursor (typically a methyl precursor) from a mixture of carbon monoxide and hydrogen (i.e. syngas) by a process commonly referred to as the Fischer-Tropsch process. The fuel precursor is catalytically synthesized to produce fuel, which may be in liquid or gaseous form. Different types of fuel (i.e. comprising a respective different hydrocarbon) can be produced depending on how the synthesis is controlled, in particular by controlling the amount of H_2 that is present during the catalytic synthesis of the fuel precursor to produce the fuel.

In preferred embodiments, fuel synthesizing system 36 is configured to chemically react carbon dioxide (CO_2) with hydrogen (H_2) through the Reverse Water-Gas Shift (RWGS) reaction to produce carbon monoxide and water. The carbon monoxide may then be mixed with hydrogen to produce the syngas for use in producing the fuel precursor. Advantageously, the CO_2 and H_2 used for the RWGS reaction are obtained using renewable energy, in particular renewable electrical energy to enable the resultant fuel to be designated as e-fuel. Preferably, therefore, the CO_2 used in the RWGS reaction is obtained from the carbon capture system 24. The H_2 for use in the RWGS reaction, and preferably also for the production of the fuel precursor and the fuel itself, may be obtained from the hydrogen production system 14B. The hydrogen used by the system 36 may be obtained from other source(s), e.g. the reservoir 30 or other part of the storage means 16, the system 14A, one or more other hydrogen producing system included in the primary conversion means 14, or a hydrogen feedstock source 26. However, it is preferred the hydrogen provided to the fuel synthesizing system 36 is produced by renewable electrical energy (e.g. by the thermo-cyclic hydrogen production system 14B and/or an hydrogen electrolysing system) to allow the resultant fuel to be designated as e-fuel. By way of example, the fuel synthesizing system 36 may be configured or be configurable to produce any one or more of the following fuels (without limitation) e-methanol, e-petrol, e-diesel, e-kerosene, e-jet fuel, e-methane. It will be understood that other e-fuels and non-e-fuels may be produced alternatively or in addition to those mentioned. The fuel synthesizing system 36 typically comprises a chemical reactor configured to perform the relevant chemical reactions to produce the fuel. It will be understood that the same reactor may produce different fuels depending on its configuration as outlined above. In alternative embodiments, more than one fuel synthesizing system 36 may be provided. The, or each, fuel synthesizing system 36 advantageously receives electrical power from one or more of the energy sources 12A, 12B to perform fuel synthesis.

In alternative embodiments, syngas produced by one or more energy conversion system included in the primary energy conversion means 14, e.g. the biomass conversion system 14A, may be provided to the fuel synthesizing system 36 for production of the fuel precursor. In such cases it is not necessary for the fuel synthesizing system 36 to support performance of the RWGS reaction. It is however preferred that the syngas is produced using the RWGS reaction as this supports the production of e-fuels.

The, or each, fuel (which may in in liquid or gaseous form) produced by the fuel synthesizing system 36 may be stored in one or more respective vessel 38 for output from the system 10, 110, 210. The, or each, vessel 38 may be portable and removable from the system 10, 110, 210, and/or may be used to fill one or more portable vessel, in order to facilitate transport and distribution of the respective fuel. Alternatively, or in addition, the, or each, fuel produced by the fuel synthesizing system 36 may be provided to a respective dispensing apparatus 40, 42 for dispensing to end users (not shown), e.g. as a fuelling station for vehicles, tankers or the like. Optionally, the, or each, fuel produced by the fuel synthesizing system 36 may be stored in a respective reservoir 48 that is part of the storage means 16. The system 10, 110, 210 may be configured to provide heat energy produced by the fuel synthesizing system to the carbon capturing means 24.

The secondary conversion means 22 may comprise one or more conversion system or apparatus (which may generally be referred to as a component or sub-system of the system 10, 110, 210) configured to convert one or more product stored in the storage means 16 into one or more output product, typically one or more liquid and/or one or more gas. The fuel synthesizing system 36 is a preferred example of such a system or apparatus, particularly when it uses products (H_2, CO_2 or syngas as applicable) stored in the storage means 16. Another example is an ammonia production system (not shown) configured to produce ammonia from nitrogen (N_2) and hydrogen (H_2) using the Haber-Bosch process. The hydrogen may be obtained from the reservoir 30, or other hydrogen source provided by the system 10, 110, 210. The nitrogen may be provided by one of the feedstock sources 26. The secondary conversion means 22 may include one or more other system, for example an e-gas reformer 60, for producing output product(s), in particular chemical commodities such as ammonia, H_2, CO_2 or fertilizer, from the products stored in the storage means 16. Such system may be conventional in configuration.

The produced ammonia, or other product(s) as applicable, may be stored in one or more respective vessel 52 for output from the system 10, 110, 210. The, or each, vessel 52 may be portable and removable from the system 10, 110, 210, and/or may be used to fill one or more portable vessel, in order to facilitate transport and distribution of the respective product. Optionally, the ammonia, or other product(s), may be stored in a respective reservoir 55 that is part of the storage means 16.

In the embodiment of Figure 4, the secondary conversion means 22 includes one or more fuel cell 62 for converting syngas stored in the chemical energy storage means 16 into electrical energy. The, or each, fuel cell 62 may for example be a solid oxide fuel cell (SOFC) or a hydrogen fuel cell. In the example of Figure 4, an SOFC fuel cell is provided and so receives syngas from the primary conversion means 14A and/or storage means 16/32. In embodiments where hydrogen fuel cell(s) are provided, the hydrogen fuel cell(s) may be provided with hydrogen from the primary conversion means 14A, 14B and/or storage means 16/30 as is convenient. Electrical power produced by the, or each, fuel cell 62 may be provided to the electrical outlet 20 of the system 10, 110, 210.

More generally, the preferred secondary conversion means 22 comprises one or more conversion system or apparatus configured to convert one or more of the product(s) produced by the primary conversion means 14 into one or more output 28, the output comprising one or more product and/or electrical power. Typically, at least one of the secondary conversion system(s) is configured to perform one or more chemical reaction with at least one reactant to produce at least one reaction product, wherein the at least one reactant comprises any one or more of: one or more of the product(s) produced by the primary conversion means 14; one or more product stored in the storage means 16; one or more product obtained from one or more of the feedstock source(s) 26. The or each reaction product may be provided as an output of the system 10, 110, 210. The or each secondary conversion system may use the received energy (which may for example comprise electrical energy, heat energy and/or biomass) to perform the relevant chemical reaction(s) or otherwise to perform the respective conversion process. Any of the secondary conversion systems 36, 62, 64 that use energy directly received from the energy source(s) 12 may be considered to be part of the primary energy conversion means 14, especially if they do not use feedstock produced by the primary energy conversion means 14.

In the embodiment of Figure 4, the electrical energy storage means 18A comprises one or more battery 64, e.g. one or more second-life battery, for storing electrical power received from one or more of the energy sources 12A, 12B. Electrical power from the, or each, battery 64 may be provided to the electrical outlet 20 as required.

The electrical power output of the system 10, 110, 210 may include an electrical outlet 66 for supplying power to an electrical grid and/or one or more electrical outlet 54 for use as a charging point, in particular an EV charging point. Any of the electrical outlets 66, 54 may be supplied by the energy storage means 18, the fuel cell(s) 62 and/or directly from the relevant energy source(s) 12A, 12B as desired. In the embodiment of Figure 4, the electrical power outlet 66 is supplied by the energy sources 12A, 12B, the battery(s) 18A and the fuel cell(s) 62, whereas the outlet 54 is supplied directly by the energy sources 12A, 12B.

The components of the system 10, 110, 210, in particular the components of the primary energy conversion means 14, the chemical energy storage means 16, the secondary conversion means 22, carbon capturing system 24, the electrical/mechanical energy storage means 18 and the feedstock sources 26, are interconnected as required by conduits 65, e.g. pipes, for delivering solids, liquids and/or gases (as required) to and/or from the relevant components, and/or between components as required, which may be referred to as a feedstock delivery network. The components of the system 10, 110, 210 are also interconnected as required by electrical power lines 67 (e.g. electrical wires or electrical cables), communication links (e.g. analogue, digital, multi cores, profibus, cat 6, and/or other wired or wireless communication links) for delivering electrical power and control signals to and/or from the relevant components, and/or between components, and/or from the relevant energy source 12A, 12B as required, which may be described as an electrical power and communications network.

As shown in Figures 3 and 5, the energy storage system 10, 110, 210 includes a control system 70 for controlling operation of the system 10, 110, 210, in particular the operation of the primary energy conversion means 14, the chemical energy storage means 16, the secondary conversion means 22, carbon capturing system 24, the electrical/mechanical energy storage means 18 and the feedstock sources 26.

Referring to Figure 5 in particular, a preferred embodiment of the control system 70 is shown. The control system 70 comprises a master controller 72 in communication with the relevant components of the system 10, 110, 210 by a control network 73, which may comprise a network of wired and/or wireless connections as is convenient, and which is capable of sending control signals from the controller 72 to the relevant components of the system 10, 110, 210, and receiving feedback signals from the relevant components of the system 10, 110, 210 as required.

Each component of the system 10, 110, 210, in particular the components of the primary energy conversion means 14, the chemical energy storage means 16, the secondary conversion means 22, the electrical/mechanical energy storage means 18, carbon capturing system 24 and the feedstock sources 26, may include one or more electrically powered and/or electrically operable device, e.g. one or more controller (e.g. PLC), sensor, fan, blower, pump, heater, furnace, fluid injector, valve and/or actuator, that is used during operation of the respective component. In this regard, the particular configuration of any given component depends on its type. For example, a liquid or gas storage vessel may include one or more electrically operable valve, level controller and/or pressure sensor, while the hydrogen production system 14B or fuel synthesizing system 36 may comprise one or more controller, sensor, fan, blower, pump, heater, furnace, fluid injector, level controller and/or valve for performing the relevant chemical reaction(s). For some components, e.g. any one or more the primary and/or secondary conversion systems 14A, 14B, 36 and/or the carbon capture system

24, there may be a respective minimum electrical power requirement to enable the component to operate. For some components, e.g. any one or more the primary and/or secondary conversion systems 14A, 14B, 36 and/or the carbon capture system 24, the electrical power consumption of the component and/or the rate at which the component consumes feedstock, may be adjustable by adjusting the operation of one or more of the respective electrical devices and/or by otherwise controlling the component. For example, the operation of any component that implements one or more chemical reaction (e.g. any one or more the primary and/or secondary conversion systems 14A, 14B, 36 and/or the carbon capture system 24) can be controlled to speed up or slow down one or more reaction, thereby increasing or decreasing the electrical power consumption of the system and/or increasing or decreasing the rate at which feedstock is used and/or increasing or decreasing the rate at which reaction product(s) are produced. Controlling the speed of reaction(s) may be achieved by adjusting any one or more of: the temperature in the reaction zone, the pressure in the reaction zone, the fluid flow rate in the reaction zone, the quantity and/or composition of the reactant(s) in the reaction zone.

Primary or secondary conversion systems that perform chemical reaction(s) (e.g. the hydrogen production system 14B and the fuel synthesizing system 36) typically comprise a chemical reactor. The configuration of the respective chemical reactor depends on the respective reaction(s) to be performed. Figure 7 shows a block diagram of a simple chemical reactor 82. The reactor 82 comprises one or more reaction zone 84 (only one shown) in which one or more relevant chemical reactions are performed depending on the purpose of the reactor 82. The reaction zone(s) 84 are incorporated into a fluid flow system comprising one or more fluid conduits 86 by which fluid enters and exits the reaction zone 84. The reactor 82 may include fluid composition control means 88 configured to control the composition of reactant(s) in the reaction zone 84, e.g. the quantity of the reactant(s) and/or ratio of reactant(s) or in the fluid flow system. The fluid composition control means 88 may include one or more sensor 88S for sensing the composition of the fluid in the reaction zone 84 and/or the fluid flow system, and/or one or more actuator or other device 88A (e.g. a valve or fluid injector) for controlling the composition of the fluid in the reaction zone 84 and/or the fluid flow system. The reactor 82 may include fluid flow control means 90 configured to control the flow of fluid in or to the reaction zone 84. The fluid flow control means 90 may include one or more sensor 90S for sensing the rate of fluid flow in or to the reaction zone 84, and/or one or more actuator or other device 90A (e.g. a pump, fan or blower) for controlling the fluid flow rate in or to the reaction zone 84. The reactor 82 may include fluid temperature control means 92 configured to control the temperature of fluid in the reaction zone 84 or fluid flow system. The fluid temperature control means 92 may include one or more sensor 92S for sensing the temperature of fluid in the reaction zone 84 or fluid flow system, and/or one or more actuator or other device 92A (e.g. heater) for controlling the fluid temperature in the reaction zone 84 or fluid flow system. The reactor 82 may include fluid pressure control means 94 configured to control the pressure of fluid in the reaction zone 84 or fluid flow system. The fluid pressure control means 94 may include one or more sensor 94S for sensing the pressure of fluid in the reaction zone 84 or fluid flow system, and/or one or more actuator or other device 94A (e.g. valve, pump, fluid injector) for controlling the fluid pressure in the reaction zone 84 or fluid flow system. The reactor 82 typically includes at least one local controller 71 for controlling the operation of the reactor 82, advantageously in conjunction with the master controller 72. Optionally, the conduit(s) 86 of the fluid flow system are arranged to create a recirculating fluid circuit around which the fluid in the reactor is recirculated.

Each component of the system 10, 110, 210, in particular the components of the primary energy conversion means 14, the chemical energy storage means 16, the secondary conversion means 22, carbon capturing system 24, the electrical/mechanical energy storage means 18, may include a local controller 71 for controlling the operation of the respective component. Each local controller may be controlled by the master controller 72 as required.

In preferred embodiments, the control network 73 includes a control signal network 73A for delivering control signals from the master controller 72 to the relevant components of the system 10, 110, 210, e.g. to the respective local controller and/or to controllable devices such as valves or switches.

In preferred embodiments, the control network 73 includes a feedback network 73B by which feedback signals can be sent from the relevant components of the system 10, 110, 210 to the master controller 72. The feedback signals may be sent from the respective local controller and/or from one or more measurement device or other sensor associated with the respective system component. In this connection, in preferred embodiments, each electrically powered component of the system 10, 110, 210, including the relevant energy sources 12A, 12B, includes at least one electrical power measurement device for measuring the electrical power consumed by and/or produced by the respective component. The electrical power measurement devices preferably measure one or more parameters that are indicative of power quality, e.g. voltage level, current level, harmonics and so on. Each component of the system 10, 110, 210 may include one or more other sensor for sensing one or more parameter that is indicative of the status of the respective system component. For example, for components that implement one or more chemical reaction, one or more sensors may be provided to detect the temperature in the reaction zone, the pressure in the reaction zone, the fluid flow rate in the reaction zone, the quantity and/or composition of the reactant(s) in the reaction zone. For storage components, e.g. reservoirs, vessels, tanks and so on for storing feedstock 26 or products of the primary or secondary conversion means, one or more sensors may be provided to detect the current available capacity of the storage component to store the respective product and/or to deliver or dispense the respective product. For electrical or mechanical energy storage apparatus 18A, 18B, and fuel cells 62, one or more sensor may be provided for detecting the current available capacity to store and/or deliver energy.

In preferred embodiments, the control system 70 is configured to perform electrical energy flow control 74, which may involve controlling the supply of electrical energy, or electrical power, to each electrically powered component of the system 10, 110, 210, in particular the components of the primary energy conversion means 14, the chemical energy storage means 16, the secondary conversion means 22, carbon capturing system 24, the electrical/mechanical energy storage means

18, via the control signal network 73A depending on feedback signals received via the feedback network 73B, in particular feedback signals relating to electrical power consumption, electrical power delivery and/or electrical power quality of the relevant system components, and/or depending on the electrical power or energy available from the relevant energy sources 12.

In preferred embodiments, the control system 70 is configured to perform feedstock control 76, which may involve controlling the supply of feedstock (e.g. from any one or more of the feedstock sources 26 and/or storage means 16) to the relevant components of the system 10, 110, 210, in particular the primary energy conversion means 14, the chemical energy storage means 16, the secondary conversion means 22, and/or the carbon capturing system 24, via the control signal network 73A depending on feedback signals received via the feedback network 73B, and/or depending on the electrical power or energy available from the relevant energy sources 12.

In preferred embodiments, the control system 70 is configured to perform storage control 78, which may involve controlling the storage of products in the relevant components of the system 10, 110, 210, in particular the chemical energy storage means 16 and/or other vessels or reservoirs included in the system 10, 110, 210, via the control signal network 73A depending on feedback signals received via the feedback network 73B, and/or depending on the electrical power or energy available from the relevant energy sources 12.

In preferred embodiments, the control system 70 is configured to perform energy delivery control 80, which may involve controlling the delivery of product(s) and/or electrical power to the outputs 20, 28 of the system 10, 110, 210 as applicable, via the control signal network 73A depending on feedback signals received via the feedback network 73B, and/or depending on the electrical power or energy available from the relevant energy sources 12.

In preferred embodiments, the control system 70 is configured to control operation of the system 10, 110, 210 by controlling any one or more of the following aspects of the system 10, 110, 210:
which components of the system 10, 110, 210 (in particular any one or more of the primary and/or secondary conversion systems 14A, 14B, 26, 62, the mechanical, electrical or other (e.g. heat) energy storage systems 18A, 18B, 64 and/or the carbon capture apparatus 24) are in operation (e.g. turned off or on);
how the available electrical input power and/or other available energy (e.g. heat energy) from the energy sources 12 is distributed amongst the operational components of the system 10, 110, 210, in particular any one or more of the primary and/or secondary conversion systems 14A, 14B, 26, 24, 62, the mechanical, electrical or other (e.g. heat) energy storage systems 18A, 18B, 64 and/or the carbon capture apparatus 24, e.g. by determining which of the components of the system 10, 110, 210 receive the input power or energy, and how much power or energy each component receives;
the operation of the, or each, component of the system 10, 110, 210, in particular any one or more of the primary and/or secondary conversion systems 14A, 14B, 26, 24, 62 the mechanical, electrical or other (e.g. heat) energy storage systems 18A, 18B, 64 and/or the carbon capture apparatus 24, e.g.

by controlling one or more operating parameters of the respective component order to control its energy consumption, in particular its electrical power consumption, wherein the operating parameters may include any one or more of: electrical input power, electrical output power, feedstock supply, chemical reaction rate(s), as applicable, and wherein controlling a chemical reaction rate may involve controlling any one or more of the quantity, flow rate, temperature, pressure, density, concentration, and/or composition of one or more chemical reactants;
the quantity of the, or each, product (e.g. hydrogen and/or syngas) of the primary conversion system(s) to store in the chemical energy storage means 16;
the quantity of the, or each, product (e.g. hydrogen and/or syngas) to supply to the relevant secondary conversion system(s);
the quantity of carbon dioxide to store in the storage means 16;
the quantity of carbon dioxide to support to the fuel synthesizing system 26;
the quantity of the, or each, product (e.g. hydrogen, fuel and/or ammonia) of the primary or secondary conversion systems to provide for the system outputs 20, 28;
the amount of electrical power to provide at the, or each, electrical output 54, 66 of the system.

The control system 70 is preferably configured to control the system 10, 110, 210, including controlling any one or more of the aspects listed above, based on any one or more of:
the input energy, preferably at least the available electrical power, available from the energy source(s) 12;
the internal demand for energy by the system 10, 110, 210 (which may comprise the energy consumption requirements (typically including electrical power consumption) of one or more components of the system 10, 110, 210, in particular any one or more of the primary and/or secondary conversion systems 14A, 14B, 26, 24, 22, 62 the mechanical, electrical or other (e.g. heat) energy storage systems 18A, 18B, 64 and/or the carbon capture apparatus 24);
the external demand for output energy from the system 10, 110, 210 (which may comprise the demand for any one or more of the available outputs 20, 28, e.g. electrical power, fuel(s) and/or other chemical product(s));
the operation and/or status of any one or more of the components of the system 10, 110, 210.

Relevant aspects of the operation or status of the components may include any one or more of:
the available storage capacity in the relevant storage means (e.g. the relevant vessel(s) or reservoir(s) of the storage means 16 or elsewhere in the system 10, 110, 210, and/or in the storage means 18A, 18B, 64);
the availability of the relevant feedstock(s);
the available operating capacity of the relevant component(s).

Preferably, the control system 70 assigns a priority level to at least some of the components of the system 10, 110, 210, and is configured to allocate energy to components depending on their respective priority level. In particular, a respective priority level may be assigned to any one or more of: the or each primary energy conversion system; the or each secondary conversion system; the or each carbon capture apparatus; the or each mechanical and/or electrical storage system. Optionally, the control system may be configured to adjust the priority levels depending on one or more system inputs, e.g. the available input energy and/or the demand for output energy, and/or a user-input). For example, any conversion system that requires or benefits from continuous operation, or which produces an output that is in relatively high demand, may be assigned a relatively high priority. Conversely, any conversion system that does not require or benefit from continuous operation, or which produces an output that is in relatively low demand, may be assigned a relatively low priority.

In preferred embodiments, the control system 70 is configured to control the operation of the system 10, 110, 210 to match the demand for energy (or at least the demand for electrical power and/or heat energy) by the system 10, 110, 210 to the available input energy (or at least the available electrical power and/or heat energy), wherein the demand for energy by the system 10, 110, 210 comprises the internal demand and optionally also the external demand. Advantageously, the control system 70 is configured to control the operation of the system 10, 110, 210 such that all of, or substantially all of, or otherwise as much as possible of, the available input energy (or at least all of the available electrical and/or thermal energy) is consumed by the system 10, 110, 210. Optionally, the control system 70 is configured to control the operation of the system 10, 110, 210 to match the output energy of the system 10, 110, 210 (e.g. the production of output(s) 20, 28 by the system 10, 110, 210) to the external demand for output energy from the system 10, 110, 210. In preferred embodiments, the control system 70 is configured to perform load matching between the available input energy (in particular the amount of input energy, and especially the amount of input electrical power and/or heat energy) and the energy demand (especially the electrical power demand, or consumption, and/or heat energy consumption) of the system 10, 110, 210, wherein the energy demand preferably comprises the internal energy (in particular electrical power and/or heat energy) demand and optionally also the external energy demand (in particular for electrical power and/or relevant fluid output(s)). For output products (typically liguids or gases) that are stored in reservoirs or vessels as part of the storage means 16 or output means 20, 28, the control system 70 may monitor the demand for the product by monitoring the fill level of the respective reservoir/vessel. If the control system 70 determines that more or less of any given output product is required (i.e. as a result of internal or external demand for the product), the control system 70 may allocate energy to, and/or otherwise control the operation of, the relevant system components (e.g. the relevant primary and/or secondary conversion system(s)) in order to produce more or less, respectively, of the relevant product.

In preferred embodiments, the control system 70 is configured to support computer modelling of any one or more of: the operation of the system 10, 110, 210; energy demand (i.e. the demand for energy from the or each component of the system 10, 110, 210 and/or the demand for the system output 20, 28); and energy availability (i.e. availability of energy input from the energy source(s) 12).

The preferred control system 70 supports computer modelling of the components of the system 10, 110, 210 (in particular any one or more of the primary and/or secondary conversion systems 14A, 14B, 26, 24, 62, the mechanical, electrical or other (e.g. heat) storage systems 18A, 18B, 64 and/or the carbon capture apparatus 24) in order to predict the energy consumption (or at least the electrical power consumption) of the components of the system 10, 110, 210 (in particular any one or more of the primary and/or secondary conversion systems 14A, 14B, 26, 24, 62, the mechanical, electrical or other (e.g. heat) storage systems 18A, 18B and/or the carbon capture apparatus 24), i.e. the internal energy demand of the system. To this end, the control system 70 may receive external input data, for example data relating to the availability or quantity of feedstock, and/or data relating to the processing of feedstock.

The preferred control system 70 supports computer modelling of the input energy produced by the energy source(s) in order to predict the available input energy for the system 10, 110, 210. To this end, the control system 70 may receive external input data, for example weather forecast data.

The preferred control system 70 may support computer modelling of the demand for output energy from the system 10, 110, 210 in order to predict the output energy demand, i.e. the external energy demand. To this end, the control system 70 may receive external input data, for example electricity grid operator data, and/or data relating to economic/procurement criteria of energy inputs.

Advantageously, the control system 70 is configured to control the operation of the system 10, 110, 210 to match the predicted energy demand of the system 10, 110, 210 with the predicted available input energy from the energy source(s), wherein the predicted energy demand comprises the predicted internal demand and optionally also the predicted external demand.

Optionally, the control system 70 is configured to control the operation of the system 10, 110, 210 to match the predicted output energy of the system 10, 110, 210 to the predicted demand for output energy from the system 10, 110, 210.

In order to support the computer modelling, the control system 70 is configured to use at least one respective mathematical model of the relevant system component(s), the input energy and/or the output energy demand as applicable. Preferably, the control system 70 is configured to use Artificial Intelligence (AI) techniques, e.g. by means of one or more Artificial Neural Network (ANN), to train and/or optimise the mathematical model(s), e.g. the mathematical model(s), or algorithms, may be trained and/or optimized using supervised and/or unsupervised machine learning techniques, preferably using internal or external data obtained by the system during use, and/or historical data..

The control system 70 typically comprises one or more suitably programmed or configured hardware, firmware and/or software controllers (which may include the master controller 72 and local controllers), e.g. comprising one or more suitably programmed or configured microprocessor, microcontroller, PLC or other processor, for example an IC processor such as an ASIC, DSP or FPGA (not illustrated). The master controller 72 and local controllers may be implemented in any convenient manner, for example as one or more separate hardware, firmware and/or software components of the overall control system 70. The local controllers 71 may act as slaves to the master controller 72, or may act as stand-alone controllers with interface signals to the master controller 72.

In preferred embodiments, the control system 70, and more particularly the master controller 72 is configured to implement system modelling logic, e.g. by supporting mathematical modelling software or firmware, for enabling the control system 70 to mathematically model the behaviour of the system 10, 110, 210, input energy and energy demand as described above. The control system 70 may be configured to implement Model Predictive Control (MPC). Suitable mathematical models can be written in Matlab, Simulink, or Labview by way of example and executed by the master controller 72.

In preferred embodiments, the control system 70 is configured to model and continuously update future energy inputs from the renewable sources 12. The preferred control system 70 is configured to model and continuously update the components of the system 10, 110, 210 to predict energy demand within the system 10, 110, 210. Energy demand within the system primarily comprises the energy demand from operation of the conversion means and storage means within the system. However, optionally, the total energy demand associated with the system 10, 110, 210 may include external energy demand from, for example, another manufacturing facility to which the system 10, 110, 210 is connected, or energy demand from an electrical grid. The control system 70 may be configured to use the external energy demand (such as from the grid) to ensure that time-limited peaks in renewable energy availability are productively utilised, especially when system storage is full to capacity and surplus input energy still exists.

In preferred embodiments, input energy (in particular input electrical power) and energy demand (in particular electrical power consumption) are measured continuously (or at least regularly) using power-quality meters (or other suitable power measurement devices) which accurately measure instantaneous power flowing through the relevant electrical supply cables. The measurement devices of the system 10, 110, 210 supply the relevant measurement data to the control system 70. As a result, the control system 70 is able to make continuous (or at least regular) adjustments to the operation of the system 10, 110, 210 as required.

By way of simple example, assume that the renewable energy source 12A is a wind turbine which historically over a given time period (e.g. 24 hours) has a measured power output that is variable but which does not drop below a baseline level (e.g. 10,000kWh). Also assume that the system 10, 110, 210 includes a conversion system, e.g. a primary energy conversion system 14A, 14B, that has a maximum power consumption that is below the baseline level (e.g. 9000kWh), and which it is desirable to run continuously and which has a relatively high priority. The foregoing information is included in the relevant model(s) supported by the control system 70, and the control system 70 may decide to allocate the required maximum power (e.g. 9000kWh) to the exemplary conversion system for the duration of the time period. The control system 70 then determines how to allocate the surplus power (which is variable and peaks at 1000kWh in this example) amongst the other components of the system 10, 110, 210, e.g. to run, or adjust the running of, another conversion system 14, 22, 26, and/or or direct the surplus energy input to storage means 18A, 18B, and/or to supply the external demand.

More generally, the preferred control system 70 is similarly able to optimally manage several variable energy inputs from different energy sources simultaneously, and to configure, manage and control the energy conversion systems/processes to ensure energy inputs match demand requirements, advantageously optimising for performance, preferably to achieve net zero or carbon neutral operation.

Advantageously, the variable energy input from the, or each renewable energy source 12 can be forecast, measured, captured and effectively utilised by the preferred control system 70 since it predictively models the processes performed within the system 10, 110, 210, and can enable, disable or adjust the operation of each process (or system) as required, preferably according to priorities incorporated into the control logic. Some of the priority settings may be fixed, others may be set by the control system 70 during use, and others may be set via a user-interface.

In preferred embodiments, the system 10, 110, 210 provides a user-interface (not shown) for monitoring operation of the system 10, 110, 210 and/or to allow user inputs concerning system operation, e.g. configuring software to allow for off-line maintenance of individual demand-side processes or energy generation side fault notification /management.

The system 10, 110, 210 may be provided with parameter values which determine the priority of how the conversion systems are used (and optionally in what order if more than one are to operate together), and optionally also what energy storage output is used. Standard business economic key performance indicators / set points may be input via the user interface or automatically downloaded from AI configured price indexes or the like. For instance, values for the price of a unit of grid electricity, a litre of oil, a cubic meter of gas or other commodities, e.g. carbon, may be continuously updated and used by the control system 70, and may be used in determining how to prioritise operation of the system.

The control system 70 may control the system in accordance with a prioritisation matrix that allows optimisation of the system’s inputs and outputs based on the location of the system and the configuration of input and output processes/systems. The carbon footprint of the system 10, 110, 210 may be determined by the prioritisation matrix, ensuring that net zero carbon is a true measure of how the energy is generated, converted, stored and ultimately used across the whole life cycle of energy generation to consumption.

In preferred embodiments, the system 10, 110, 210 is flexible, or modular, to accommodate a range of different renewable energy inputs depending, for example, on where in the world the system 10, 110, 210 is located. In some embodiments, the system 10, 110, 210 may have only one input energy source (such as a single wind turbine or a PV array), while in other embodiments there are two or more different input energy sources such (as a wind farm, PV array, biomass and/or geothermal system). The flexibility advantageously extends to the configuration and operation of the system 10, 110, 210. For example in some embodiments there is no secondary conversion means, or no electrical/mechanical storage means 18, or no connection to an external load. The primary and secondary conversion means 14, 22, storage means 18 and carbon capture apparatus 24 may operate independently of each other. For example, one or more secondary conversion system may be running while the primary conversion system(s) are not running, and vice versa. For instance, depending on the requirements of the application, the primary conversion and subsequent chemical energy storage may be the final output of the system 10, 110, 210. Alternatively, the secondary energy conversion means may be operational without the requirement of the interim chemical storage, or at least the interim chemical store may just be a buffering arrangement between primary and secondary conversion to smooth out peaks and troughs in process cycles.

Each renewable energy source is variable in nature. Power generated by any renewable technology is variable; minute-to minute, day-to-day, season-to-season. Not only is the power (kW) output variable, but so too are the key power quality parameters of voltage, amperes, harmonics and so on. In preferred embodiments, the control system 70 measures, via the relevant sensors or measurement devices, the instantaneous power quality parameters of each renewable input energy source, modelling and correcting and optimising the individual parameters. Individual power input streams may be assimilated and used to enable and control the downstream conversion processes.

In preferred embodiments, the system 10, 110, 210 facilitates the capture, storage and conversion of renewable energy in any location regardless of whether a grid connection is available. The conversion and storage of the renewable energy in-situ allows net zero energy fuels to be produced, and to be used economically in economic sectors such as transportation, which cannot technically nor economically use battery alternatives.

In preferred embodiments, the control system 70 is configured to operate the system 10, 110, 210 to deliver net-zero carbon impact on the environment in real-time, within the energy generation and power usage output cycles.

Preferred embodiments of the system 10, 110, 210 have the ability to provide an electricity grid optimising solution via the provision of controlled power storage and output. Preferably, the system 10, 110, 210 can provide a source of green-hydrogen and hydrogen energy carrier solutions such as green-Ammonia and e-methanol. The system 10, 110, 210 may integrate CO_2 recycling, as well as being a source for e-fuels (liquid and gas), synthetic biofuels and electrical grid support services. Preferred embodiments may provide a transport fuelling solution delivering green-hydrogen and e-fuels at point of use.

Figures 6A to 6D illustrate examples of possible configurations of the system, without limitation. In each of Figures 6A to 6C, the system is configured to receive a single form of input energy, in this case electrical power from one or renewable energy source 12A, 12B. Figure 6A illustrates a system configured to capture solar energy as electrical power and store the electrical power in one or more battery 18. The system of Figure 6B is configured to convert wind energy into hydrogen, the hydrogen being stored and subsequently provided as the system output. The system of Figure 6C is configured to convert both solar and wind energy into hydrogen. The hydrogen is stored and can further be converted into e-fuels, via system 36, and/or provided as a system output. The system of Figure 6D is configured to receive multiple forms of input energy, in this case electrical power from wind and solar energy sources 12A, 12B, heat energy 12C and biomass energy 12D. In this example the system is configured for hydrogen production with energy input from solar and wind renewable energy, and for the production of syngas from heat energy and biomass energy. The produced hydrogen is converted into electricity (e.g. by one or more hydrogen fuel cell) which may be provided as a system output. The syngas may be converted to e-fuel which may be provided as a system output.

The invention is not limited to the embodiment(s) described herein but can be amended or modified without departing from the scope of the present invention.

CLAIMS:

1. An energy conversion and storage system configured to receive input energy from at least one renewable energy source, the energy storage system comprising:
primary energy conversion means for converting said input energy into at least one primary reaction product;
at least one of:
secondary conversion means for converting at least one of said at least one primary reaction product into at least one secondary reaction product; and
energy storage means; and
a control system configured to control distribution of input energy amongst said primary energy conversion means, said secondary conversion means and/or said energy storage means.

2. The system of claim 1, wherein said control system is configured to control the operation of said energy conversion and storage system to match an energy demand of the energy conversion and storage system to an available input energy from said at least one renewable energy source, and wherein, preferably, said control system is configured to control the operation of said energy conversion and storage system such that all, or substantially all, of said available input energy is consumed by said energy conversion and storage system.

3. The system of claim 2, wherein said energy demand comprises an internal energy demand, preferably comprising at least an internal electrical power consumption and/or heat energy consumption, of the energy conversion and storage system, and wherein, typically, said internal energy demand comprises the respective energy demand, preferably comprising at least a respective electrical power consumption and/or heat energy consumption, of any one or more of said primary energy conversion means, said secondary energy conversion means and/or said energy storage means.

4. The system of claim 2 or 3, wherein said energy conversion and storage system is connected to at least one external load, and wherein said energy demand comprises an external energy demand, preferably comprising an external electrical power consumption, of said at least one external load.

5. The system of any one of claims 2 to 4, wherein said control system is configured to control the operation of said energy conversion system by allocating a respective amount of said available input energy, especially the available input electrical power and/or heat energy, to any one or more of said primary energy conversion means, said secondary energy conversion means and/or said energy storage means.

6. The system of any one of claims 2 to 5, wherein said control system is configured to control the operation of said energy conversion system by controlling the operation of any one or more of said primary energy conversion means, said secondary energy conversion means and/or said energy

storage means, in particular to control the respective energy consumption and/or heat energy consumption, especially the respective electrical power consumption of and/or heat energy consumption or, the primary energy conversion means, said secondary energy conversion means and/or said energy storage means.

7. The system of any preceding claim, wherein said control system is configured to perform computer modelling of the input energy from said at least one renewable energy source to predict the available input energy, and is configured to perform computer modelling of the energy conversion and storage system to predict the energy demand of the energy conversion and storage system, and wherein, preferably, said control system is configured to perform computer modelling of any one or more of said primary energy conversion means, said secondary energy conversion means and/or said energy storage means to predict an internal energy demand of said energy conversion and storage system, and/or to perform computer modelling of one or more external energy demand to predict the external energy demand.

8. The system of claim 7, wherein said control system is configured to perform said computer modelling continuously, or substantially continuously, and to correspondingly control the operation of the energy conversion and storage system continuously or substantially continuously.

9. The system of claim 7 or 8, wherein said control system is configured to perform said computer modelling using at least one mathematical model, and wherein, preferably, said control system is configured to train and/or optimize said at least one mathematical model using one or more Artificial Intelligence (AI) technique, optionally by implementing said at least one mathematical model using one or more Artificial Neural Network (ANN) and training and/or optimizing the, or each, ANN using supervised and/or unsupervised machine learning.

10. The system of any preceding claim, wherein said primary energy conversion means comprises at least one energy conversion system configured to use said input energy to perform at least one chemical reaction with at least one reactant to produce at least one of said at least one primary reaction product, and wherein, preferably, the energy conversion and storage system is configured to provide said at least one reactant to said at least one energy conversion system from at least one of said at least one renewable energy source, or from at least one feedstock source.

11. The system of claim 12, wherein said at least one energy conversion system is configured to use input electrical power from said at least one energy source to perform said at least one chemical reaction.

12. The system of any preceding claim, wherein said primary energy conversion means comprises at least one hydrogen producing system configured to produce hydrogen using input electrical power from said at least one energy source, and wherein, preferably, said at least one hydrogen producing

system comprises at least one thermo-cyclic hydrogen production system and/or at least one hydrogen electrolyser.

13. The system of any preceding claim, wherein said input energy from at least one of said at least one energy source comprises biomass, and wherein said primary energy conversion means comprises at least one biomass conversion system for converting said biomass into at least one reaction product, wherein, preferably, said at least one reaction product comprises hydrogen and/or synthesis gas.

14. The system of any preceding claim, further including at least one carbon capturing system configured to capture carbon dioxide, preferably from air or seawater, and means for storing the captured carbon dioxide, wherein said at least one carbon capturing means may be included in, or connected to, said primary energy conversion means and/or said secondary conversion means.

15. The system of any preceding claim, further including at least one fuel synthesizing system configured to produce synthesized fuel, and which may be included in said primary conversion means and/or said secondary conversion means, and wherein, typically, said at least one fuel synthesizing system is configured to synthesize a fuel precursor from synthesis gas, and to catalytically synthesize the fuel precursor to produce synthesized fuel, and wherein, preferably, said synthesis gas is a reaction product of said primary energy conversion means.

16. The system of claim 15, when dependent on claim 13, wherein said synthesis gas is a reaction product of said at least one biomass conversion system.

17. The system of claim 15 or 16, wherein said at least one fuel synthesizing system is configured react carbon dioxide with hydrogen to produce carbon monoxide and water, and to mix said carbon monoxide with hydrogen to produce said synthesis gas, and wherein, preferably, said carbon dioxide is captured carbon dioxide.

18. The system of any preceding claim, wherein said secondary conversion means comprises one or more conversion system configured to convert at least one of said primary reaction product into at least one output comprising at least one of said at least one secondary reaction product and/or electrical power.

19. The system of any preceding claim, wherein said secondary conversion means comprises at least one fuel cell for producing electrical power from at least one of said primary reaction product, and/or an ammonia production system configured to produce ammonia from nitrogen and hydrogen.

20. The system of any preceding claim, wherein said energy storage means comprises any one or more of:

means for storing electrical energy, for example comprising at least one battery and/or at least one capacitor;
means for storing mechanical energy, for example comprising any one or more of a compressed air energy storage system, a flywheel energy storage system, a pumped hydroelectric energy storage system, a gravity battery and/or any other conventional mechanical energy storage system or device;
thermal energy storage means (TES).

21. The system of any preceding claim, wherein any one or more of said at least one primary reaction product and/or any one or more of said at least one secondary reaction product, preferably hydrogen and/or synthesized fuel, are provided as an output product of the energy conversion and storage system, and wherein said energy conversion and storage system may include at least one respective vessel, preferably at least one portable vessel, for storing the, or each output product, and/or may include a respective dispensing apparatus for dispensing the, or each, output product.

22. The system of any preceding claim, further including at least one electrical outlet for delivering electrical power from said energy conversion and storage system.

23. The system of any preceding claim, further including storage means, typically comprising at least one vessel and/or reservoir, for storing any one or more of said at least one primary reaction product, said at least one secondary reaction product, and/or feedstock for said primary energy conversion and/or for said secondary conversion means.

24. The system of any preceding claim, wherein said primary conversion means comprises at least one primary conversion system comprising a chemical reactor, and/or said secondary conversion means comprises at least one secondary conversion system comprising a chemical reactor, and wherein said control system is configured to control the operation of the, or each, chemical reactor in order to control any one or more of: the energy consumption of the respective chemical reactor, preferably the electrical power consumption and/or the heat energy consumption; the consumption of feedstock; and/or the production of reaction product(s), and wherein, typically, the, or each, reactor comprises any one or more of fluid composition control means for controlling the composition of reactant(s) in the reactor; fluid flow control means for controlling the flow of fluid in the reactor; fluid temperature control means for controlling the temperature of fluid in the reactor; and/or fluid pressure control means for controlling the pressure of fluid in the reactor, and wherein said control system is configured to control the operation of the, or each, chemical reactor by controlling the operation of any one or more of the fluid composition control means, the fluid flow control means, the fluid temperature control means and/or the fluid pressure control means.

25. An energy conversion and storage method comprising:
receiving input energy from at least one renewable energy source;
converting at least some of said input energy into at least one primary reaction product;

converting at least one of said at least one primary reaction product into at least one secondary reaction product, and/or storing at least some of said input energy; and

controlling the distribution of said input energy amongst said converting into at least one primary reaction product, said converting into at least one secondary product and/or said storing.

Intellectual
Property
Office

Application No: GB2208261.4
Claims searched: 1 to 25
Examiner: Peter Easterfield
Date of search: 21 October 2022

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	at least 1,12,19,23,25	EP 1657409 A1 (ELSAM) see paras [0053]-[0056]
X	at least 1,12,19,23,25	GB 2539700 A (ITM) see abstract
X	at least 1,12,19,23,25	US 2016/006066 A1 (ROBERTSON) see abstract
X	at least 1,12,19,23,25	US 2015/377211 A1 (OCHIELLO) see paras [0030]-[0033]
X	at least 1,12,19,23,25	US 2015/311703 A1 (BOUASSEAU et al) see abstract
X	at least 1,12,19,23,25	US 2011/237839 A1 (WALSTEIN) see paras [0043]-[0045]
X	at least 1,12,19,23,25	WO 2015/192877 A1 (SIEMENS) see abstract
X	at least 1,12,19,23,25	WO 2009/104820 A1 (TOYOTA) see abstract

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

H02J

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
H02J	0015/00	01/01/2006