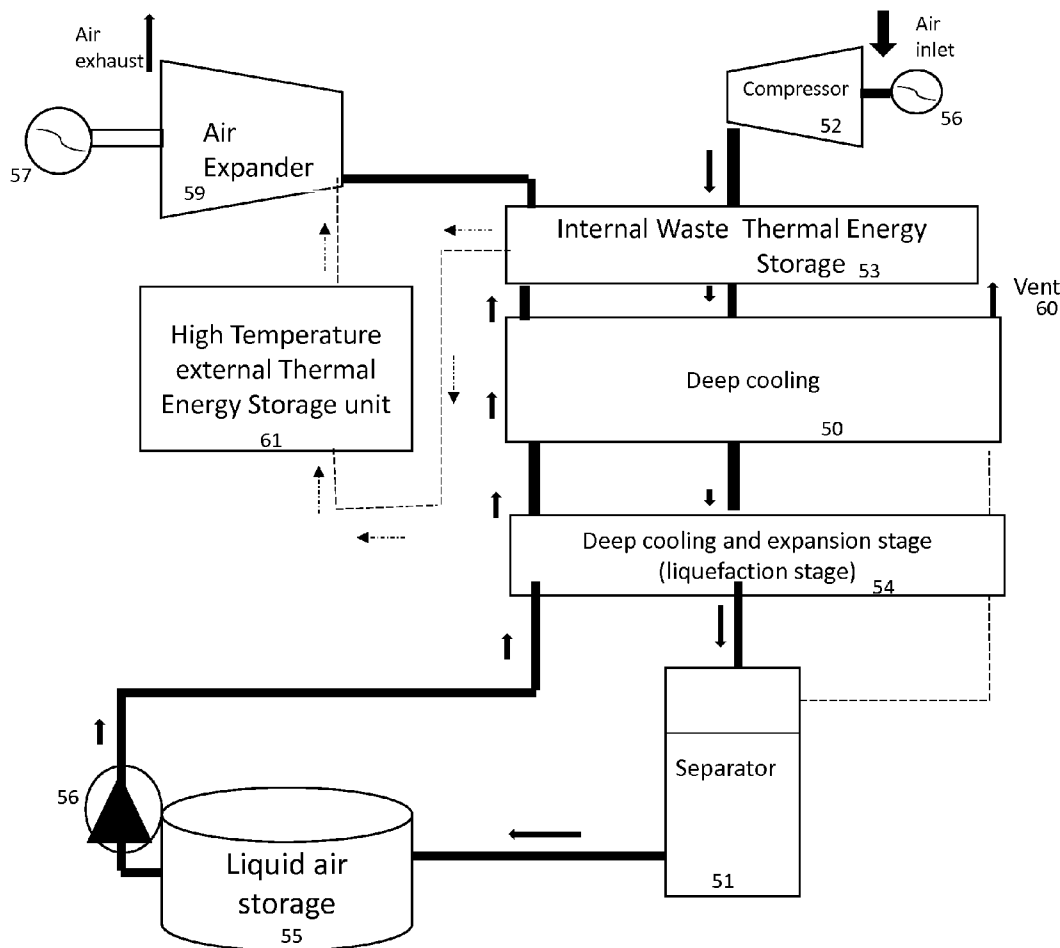




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POWER STORAGE, RECOVERY, AND
BALANCING***F01K 15/00* (2006.01)*F01K 3/08* (2006.01)(52) **U.S. Cl.**CPC ... *F01K 3/02* (2013.01); *F01K 3/08* (2013.01);
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F01K 7/16 (2006.01)**ABSTRACT**

An energy processing apparatus includes an energy input unit, a bulk storage unit, an auxiliary unit, and an energy output unit. The energy input unit can include conduits/devices for the input of electrical/thermal energy sources. The bulk storage unit can include a system, conduits/devices for electrical/thermal energy storage/release. The auxiliary unit can include a system, conduits/devices for the production of material products. The energy output unit can contain conduits/devices for the output of electrical energy. The energy input unit can be connected to the bulk storage unit, auxiliary unit, and energy output unit by conduits/devices for the transfer of electrical/thermal energy. The bulk storage unit and auxiliary unit can be connected by conduits/devices for the transfer of material products and/or thermal energy. The energy output unit can be connected to the energy input unit and/or bulk storage unit by conduits/devices for the transfer of electrical energy.



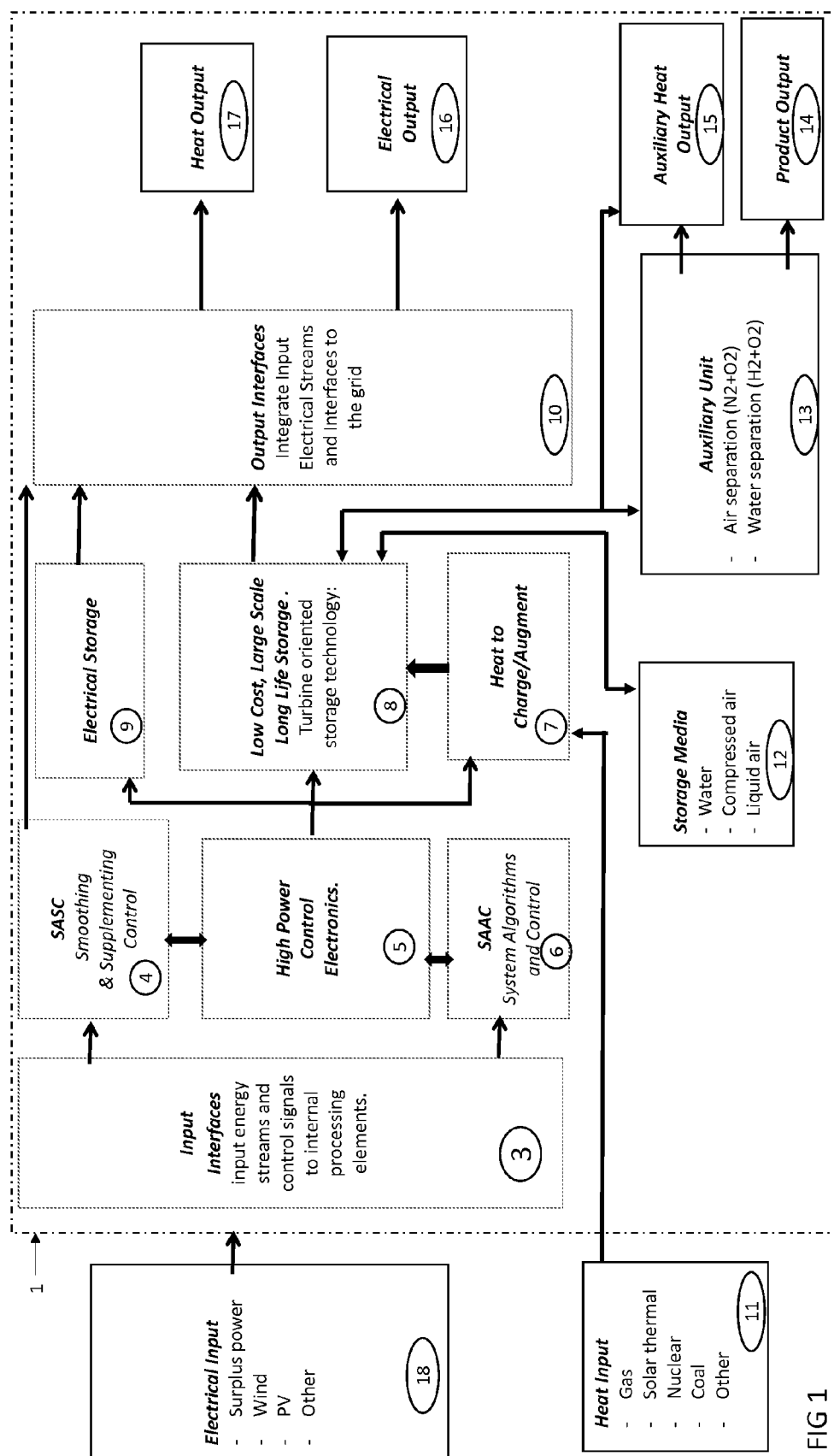


FIG 1

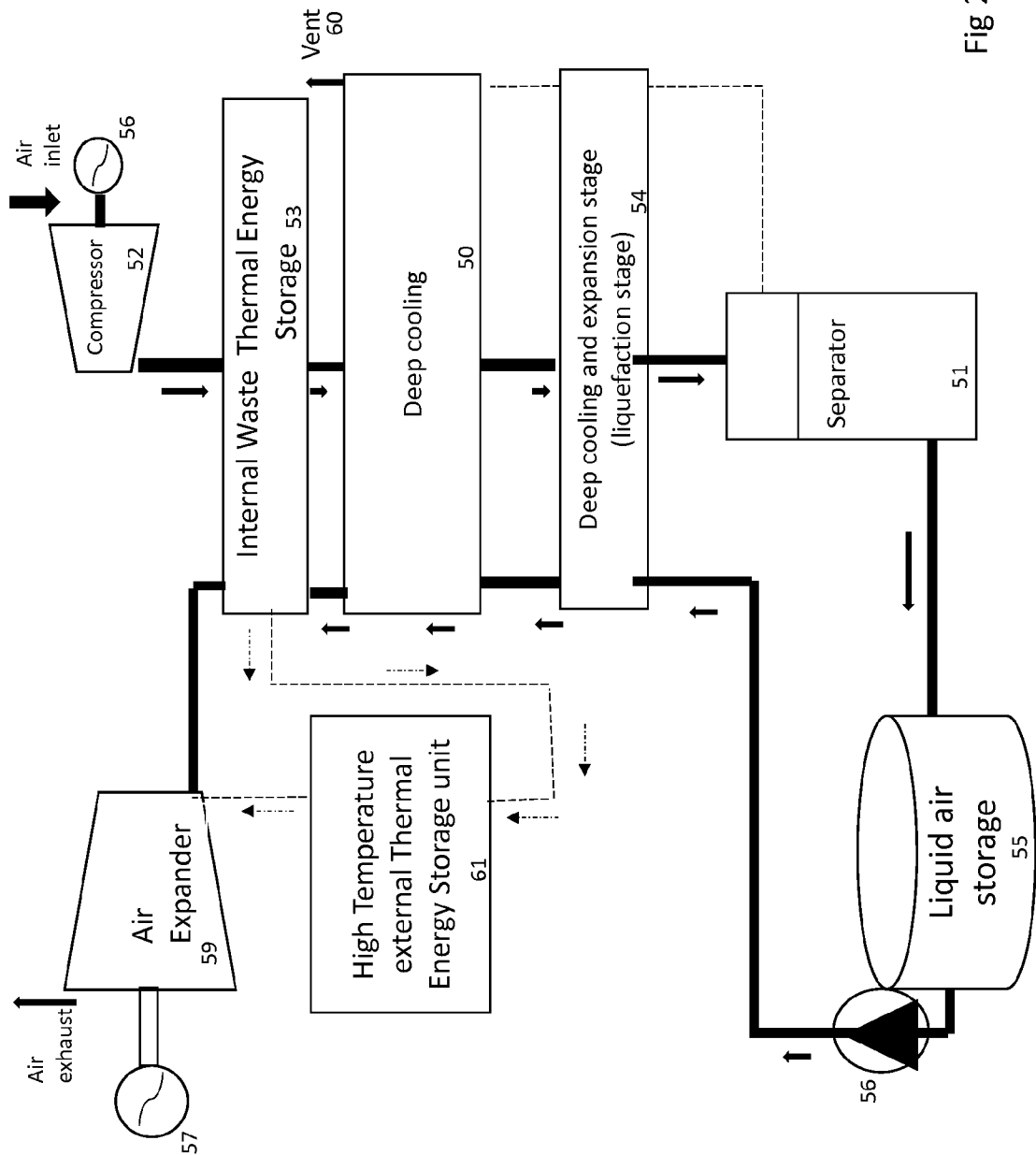


Fig 2

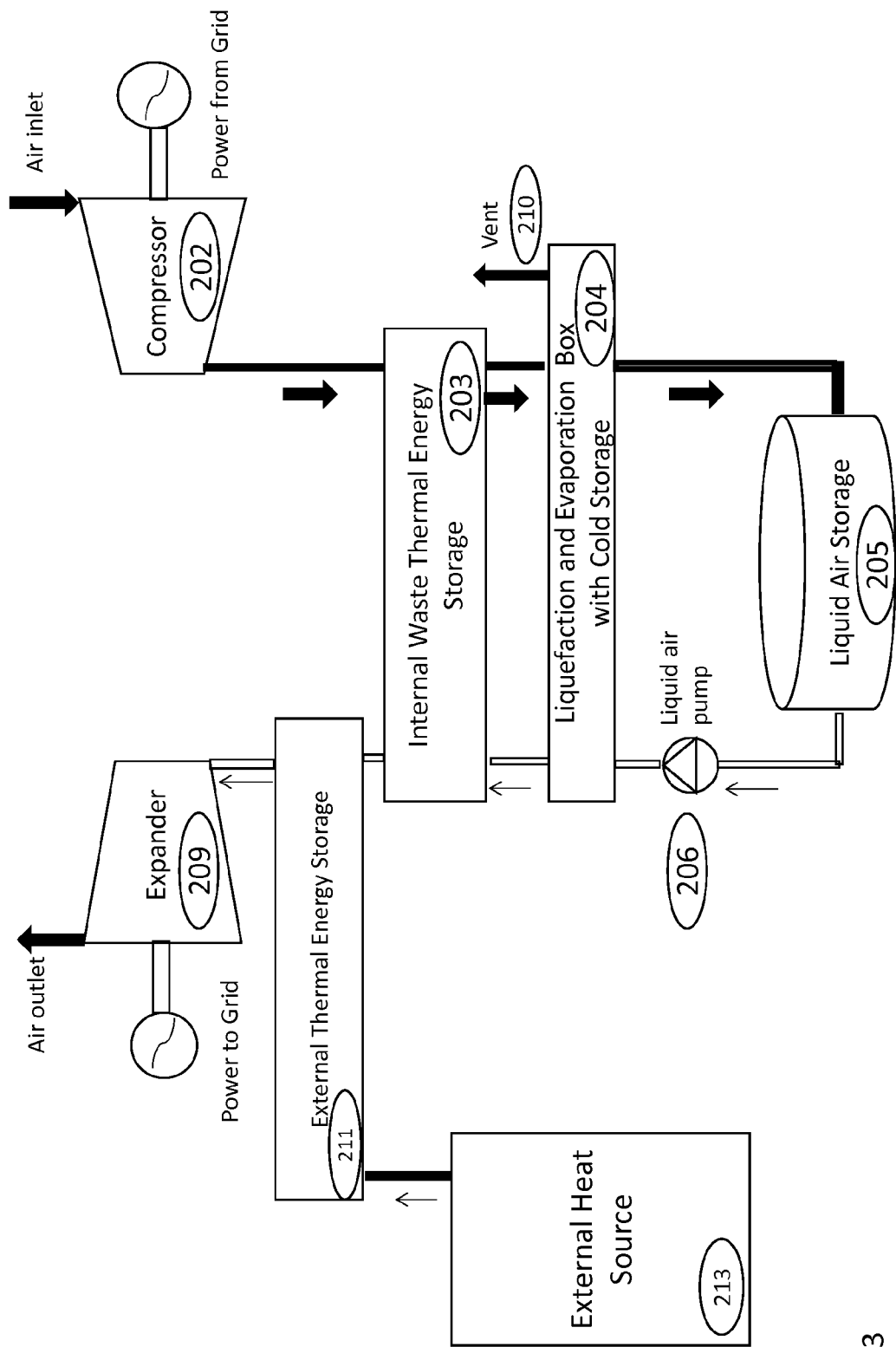


FIG 3

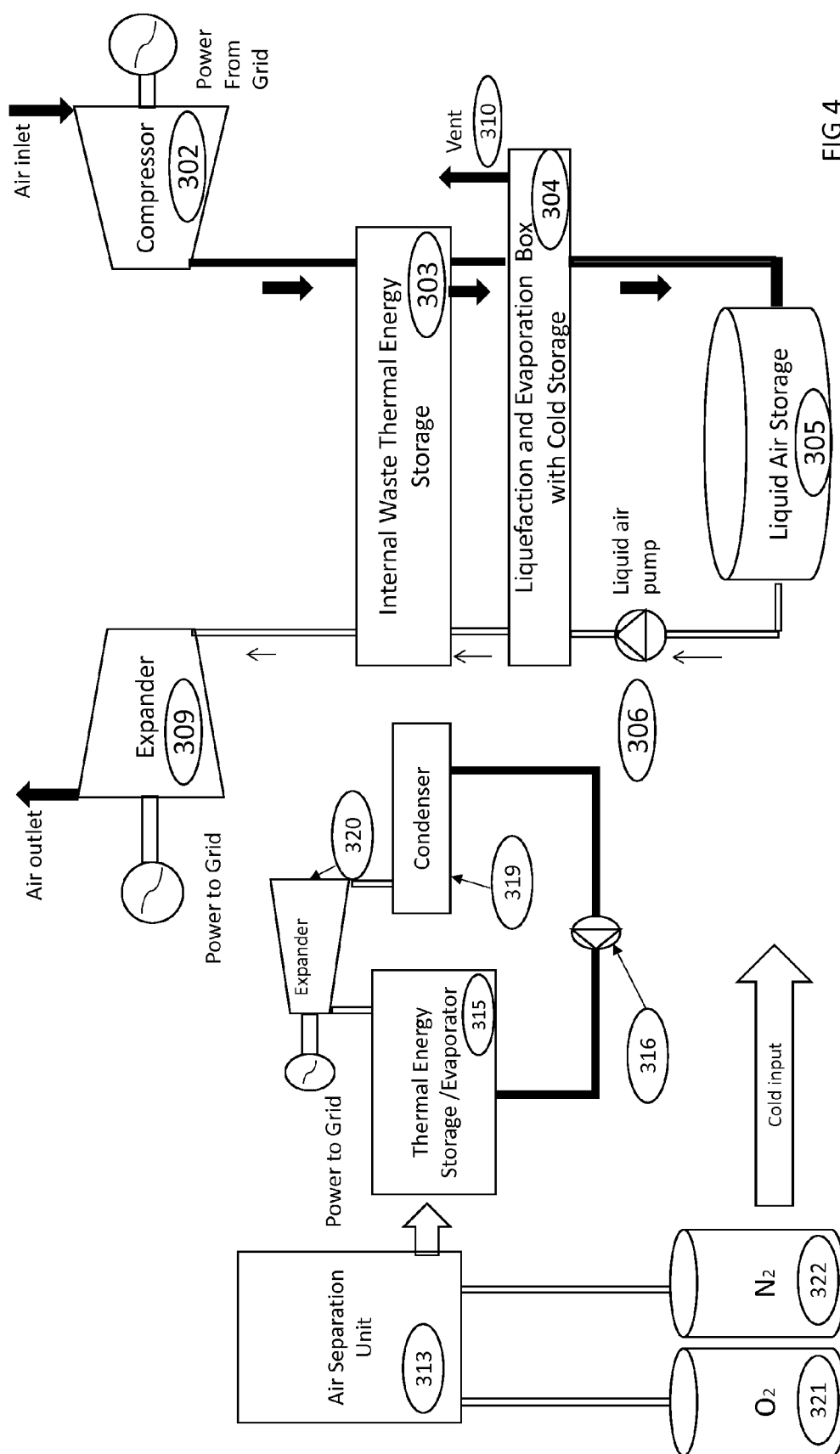


FIG 4

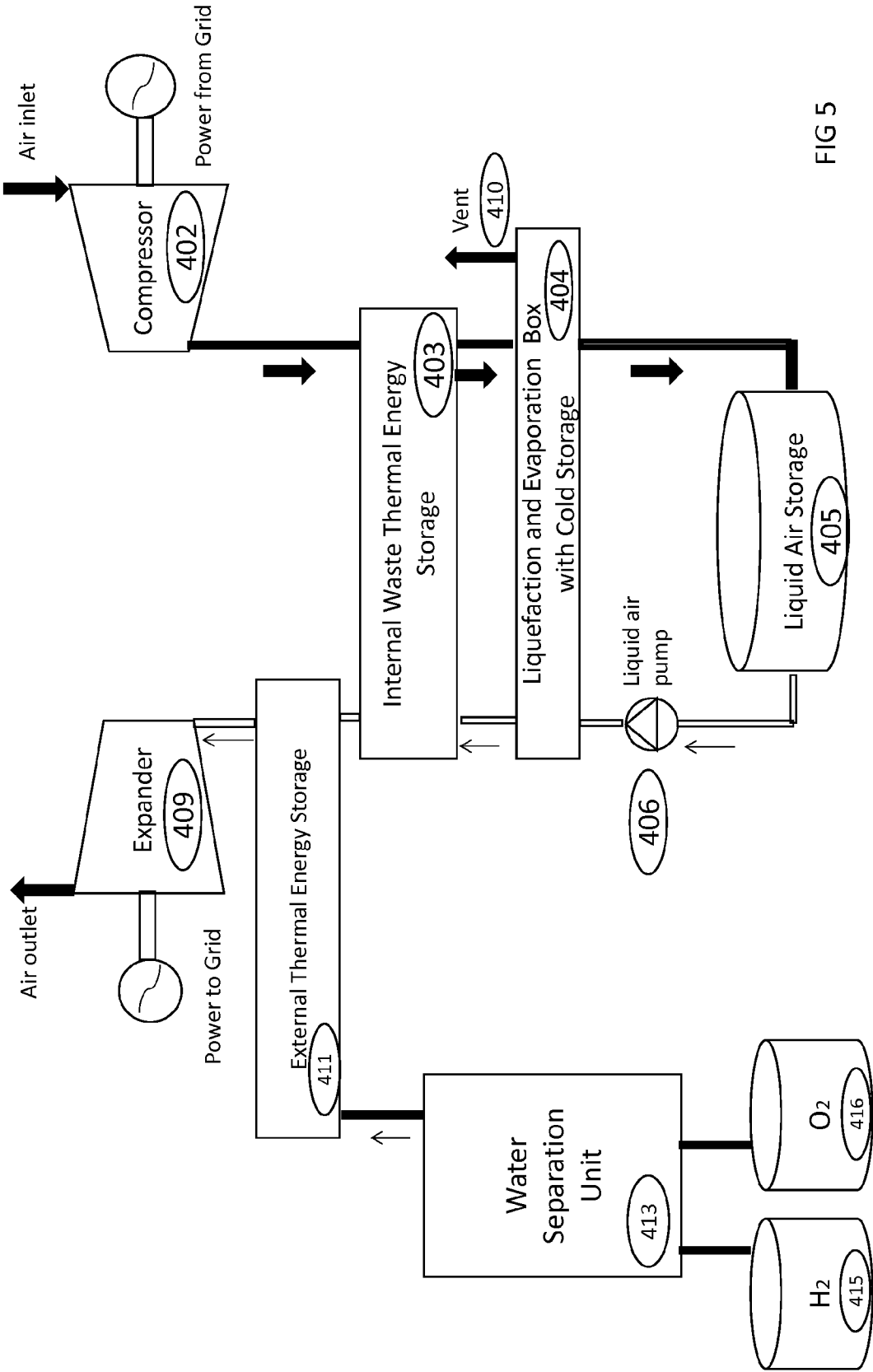


FIG 5

SYSTEMS, METHODS, AND DEVICES FOR POWER STORAGE, RECOVERY, AND BALANCING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit of U.S. Provisional Application No. 61/969,755, filed Mar. 24, 2014, and U.S. Provisional Application No. 62/061,681, filed Oct. 8, 2014, which are each hereby incorporated by reference herein in their entireties.

FIELD

[0002] This present disclosure relates generally to energy storage and generation, and, more particularly, to energy storage systems, methods, and devices for energy storage, utilization, power regulation, dispatch, and processing of multi-source energy input, and energy storage systems, methods, and devices for cogeneration with an auxiliary unit.

SUMMARY

[0003] Systems, methods, and devices for energy processing are disclosed herein. An energy processing apparatus includes an energy input unit, a bulk storage unit, an auxiliary unit, and an energy output unit. The energy input unit can include conduits and/or devices for the input of electrical and/or thermal energy sources. The bulk storage unit can include a system, conduits and/or devices for electrical and/or thermal energy storage and release. The auxiliary unit can include a system, conduits and/or devices for the production of material products. The energy output unit can contain conduits and/or devices for the output of electrical energy. The energy input unit can be connected to the bulk storage unit, auxiliary unit, and energy output unit by conduits and/or devices for the transfer of electrical and/or thermal energy. The bulk storage unit and auxiliary unit can be connected by conduits and/or devices for the transfer of material products and/or thermal energy. The energy output unit can be connected to the energy input unit and/or bulk storage unit by conduits and/or devices for the transfer of electrical energy.

[0004] Objects and advantages of embodiments of the disclosed subject matter will become apparent from the following description when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Embodiments will hereinafter be described with reference to the accompanying drawings, which have not necessarily been drawn to scale. Where applicable, some features may not be illustrated to assist in the illustration and description of underlying features. Throughout the figures, like reference numerals denote like elements. As used herein, various embodiments can mean one, some, or all embodiments.

[0006] FIG. 1 illustrates an energy processing system, according to one or more embodiments of the disclosed subject matter.

[0007] FIG. 2 illustrates a LAES apparatus with and without an external heat source, according to one or more embodiments of the disclosed subject matter.

[0008] FIG. 3 illustrates a LAES apparatus with external heat source, according to one or more embodiments of the disclosed subject matter.

[0009] FIG. 4 illustrates a LAES apparatus with air separation auxiliary unit, according to one or more embodiments of the disclosed subject matter.

[0010] FIG. 5 illustrates a LAES apparatus with water separation auxiliary unit, according to one or more embodiments of the disclosed subject matter.

DETAILED DESCRIPTION

[0011] Although technological advancements are made in the field of renewable energy with an increase annual growth, renewable sources arguably still suffer from issues such as reliability and intermittency of the renewable energy output power, which may remain key issues of their use at large scale operations. Wind, solar and hydroelectric power plants and devices may depend on the stochastic conditions of the weather and changes in insolation and precipitation. Due to these reasons (and possibly others) renewable sources cannot be reliable in a similar way to non-renewable power plants.

[0012] Arguably, power generation with non-renewable resources such as fossil or radioactive fuels may suffer from drawbacks by the changing supply and demand of power on the grid, as known by one skilled in the art. Combined cycle power plants may have a relatively high overall efficiency, but these power plants may experience low response time and efficiency loss while trying to maintain transient output power. Simple cycles like the

[0013] Brayton cycle may have a relatively low overall efficiency but these power plants may experience a better response time and lower efficiency loss in comparison to combined cycle. In addition, power plants such as coal plants or nuclear plants may also have great challenges in cycling up and down and/or turning down and starting the plant.

[0014] Arguably, the current optimum conditions for power generation are met by maintaining some generation plants such as, for example, coal, nuclear, and combined cycle, at relatively constant output power as the base load power to the grid while producing the transient power of the grid with better responding cycles.

[0015] In specific regions, which may incorporate renewable power into the matrix of the electrical grid, there may be a need and/or desire to add flexibility and/or fixable apparatuses and/or function to the grid. The need and/or desire may be attributed to the different characteristics of the generators (i.e. the non-reliable and intermittent renewable source and the non-flexible but reliable non-renewable sources). There may be a desire for apparatuses that may provide such flexibility.

[0016] In order to overcome the different challenges there may be a desire for a grid that receives its power from a combination of renewable and more conventional, nonrenewable sources. There may arise a need and/or a desire for a system, device, method, and/or apparatus that may provide the desired capabilities and may function in such a way that provides the grid with stable and reliable power when needed as needed. During the process of defining and/or choosing what system, device, method, and/or apparatus is desired, the following characteristics may play a key role: large capacity of power storage and/or production; fast response, which may allow the control, and/or level the output power and/or power on the grid, which due to changing characteristics such as intermittency, may shift rapidly; allowing multiple sources of power and/or heat to be integrated; and/or sufficient overall efficiency and cost effectiveness in order to compete other system, device, apparatus etc. available.

[0017] Renewable energy power plants with energy storage may provide means to deal with the desired characteristics, but may not provide a complete solution. A concentrated solar power plant with thermal storage may suffer from insufficient response time and a low overall efficiency. Batteries for storing energy from wind or photovoltaic solar resources may meet requirements of fast response but do so at a high price of the batteries versus what may be a more cost competitive price of large scale turbine associated system/device/apparatus such as, for example, Pumped Hydro Storage (PHS), Compressed Air Energy Storage (CAES), and Liquid Air Energy Storage (LAES). Turbine associated storage may become more cost competitive as the overall capacity of the facility increases. Further, the life cycle of such a system/device/apparatus may be much longer than that of a battery.

[0018] The present disclosure describes methods for energy processing that may achieve the needed and/or desired outcome, while maintaining cost competitiveness characteristics. These may be achieved by allowing an efficient use of multiple energy resources, energy storage, and other components and devices that operate in synergy and/or that may operate in a similar way to a cogeneration facility.

[0019] Cogeneration is the simultaneous generation of output power with production of desired products by an auxiliary unit. According to various embodiments, cogeneration may allow a more flexible use of the facility as it has multiple different production cycles that may work in synergy with each other and that may result in higher efficiency, greater usage of the facility's equipment, and higher cost effectiveness.

[0020] According to various embodiments of the disclosed subject matter, a facility is disclosed that may contain multiple components, devices, apparatuses, hardware, software, and the like. According to various embodiments, the facility may contain one or more or all of the following.

[0021] Input Interfaces: May enable information, such as (but not limited to) operator's orders, grid conditions, energy input source conditions, etc. to enter the energy processing system. According to various embodiments, the input interfaces may contain the needed apparatuses, devices, software etc. which may allow the detection and/or gathering and/or transmitting information to the facility.

[0022] System Algorithm and Control (SAAC): May decode the information received from and/or through the input interface by means such as algorithms. Decoding the information may result in the generation of information regarding the specific conditions that may be located on the electrical grid and/or co-located apparatuses and/or internal information and/or other relevant sources etc.

[0023] Smoothing and Supplementing Control (SASC): May generate control orders to be performed by the facility. Control orders may contain (but not limited to) shifting from one mode of operation to another, cycling up and down and/or switching off or on one or more apparatuses, devices etc. of the system, smoothing power, supplementing power and/or energy, passing through power etc.

[0024] High Power Control Electronics: May contain the needed electronics for shifting from one mode of operation to another.

[0025] Electrical Storage: May contain a fast responding, relatively small capacity storage unit (relative to one or more energy storage apparatuses of the facility).

[0026] Low Cost, Large Scale, Long Life Storage: May contain devices, heat flows, heat exchangers, etc. associated

with a large capacity bulk storage unit, envisioned to be one of the following: PHS, CAES, and/or LAES.

[0027] Storage Media: May be determined by the specific conditions of each site and determines the technology chosen for that particular facility.

[0028] Heat to Charge/Augment: May contain devices, heat flows, heat exchangers, etc. enabling high temperature and/or low temperature thermal energy input to enter, be stored, processed, augmented, utilized, etc. by the facility.

[0029] Output Interfaces: May contain the needed components, devices, hardware, software, etc. which may enable the facility to discharge and/or dispatch stored energy and/or products which may meet the desired outcome.

[0030] Auxiliary Unit: May contain the needed devices, apparatuses, heat flows, control systems, hardware, software, etc. that may provide additional flexibility for the facility, which may include (but not be limited to) balancing loads, increasing equipment utilization, generating energy sources, flexible capacity operation levels, generation of products for a secondary market, etc.

[0031] According to various embodiments, a facility may contain some or all of the following components. According to various embodiments, the one or more of the stated specific functions of one or more components may be absent from the components. According to various embodiments, one or more functions of one or more components may be contained or carried out by one or more different components.

[0032] According to various embodiments, the facility may receive as an input one or more sources of energy, which may include electrical energy and/or thermal energy and/or both, as will be detailed below.

[0033] According to various embodiments, the mode of operation of the facility is configured as follows: information such as operating orders, grid or energy input conditions and others are received and/or detected at the at the input interfaces unit. According to various embodiments, operating orders will be received as a means of digital communication while analyzing the grid or energy input conditions will be made by sensors and devices known to one who is skilled in the art. Decoding of the input information and evaluation of the input conditions will be made by the SAAC unit. The information regarding the evaluation of the system's input conditions will be sent to the SASC unit where a desired mode of operation of the system will be selected and relevant control orders will be sent to relevant units of the system including the high power control electronics unit. According to various embodiments, the high power control electronics unit will consist of high power switches, transformers, regulators, relay stations, electronic valves or other devices known to one who is skilled in the art.

[0034] According to various embodiments, the low cost, large scale, long life storage will consist of a large bulk capacity generated with the input of renewable energy sources, surplus or non-surplus grid electricity. The low cost, large scale, long life storage is envisioned to be one of the following:

[0035] Pumped Hydro Storage (PHS): PHS systems use electricity from the grid to pump water to an elevated ground, storing the potential energy of water and releasing it by demand to drive a hydroelectric turbine and generate electricity. PHS facilities incorporate large bulk capacity. According to various embodiments, a PHS facility could be achieved by choosing unique topographic conditions. According to various embodiments, a PHS may operate in conjunction to

another system, device, apparatus etc. in order to achieve cogeneration. Cogeneration may be achieved by utilizing heat from the system, device, apparatus etc. (assuming that heat is generated), which is operating in conjunction with the PHS. Water from the PHS may be directed to the source of heat, which may result in generation of steam, which may be directed to a steam turbine generator in order to generate electrical power, as known to one who is skilled in the art.

[0036] Compressed Air Energy Storage (CAES): CAES systems use electricity from the grid to compress air to high pressure and relatively high density, storing the compressed air in caverns and/or high pressure storage tanks and releasing it by demand to drive a gas turbine and generate electricity. According to various embodiments, CAES facilities need unique topographic conditions such as underground caverns, in order to be cost effective. According to various embodiments, CAES facilities could utilize thermal energy to enhance and gain an increase of efficiency at discharge mode by heating the air prior to entering the turbine unit or units.

[0037] LAES systems use electricity from the grid to compress and cool down air in order for it to reach a phase change to liquid. Liquid air is then stored in a cryogen tank and is released by demand to drive an expander and/or a gas turbine. LAES systems may not need a unique topographical location which may be a characteristic of both PHS and CAES and may be operational without or with very limited location restrictions. According to various embodiments, due to the thermal processes of the LAES systems incorporating cold or hot grade thermal energy that the overall efficiency of the LAES facility may increase. According to various embodiments, the use of waste heat from co-located thermal processes could increase the efficiency of the LAES. Thus it may increase the cost effectiveness of the LAES facility.

[0038] According to various embodiments, the heat to charge/augment unit will be provided with hot or cold thermal energy for use of the storage system, as stated above, in order to improve efficiency and cost effectiveness.

[0039] According to various embodiments, the output interfaces will provide electricity and/or thermal energy generated or cogenerated by the storage units, auxiliary unit or directed from the input interfaces of the facility.

[0040] According to various embodiments, the electrical storage unit may contain a fast responding storage unit such as a battery, capacitor or other storage unit, which may allow the apparatus as a whole to operate at great speed. According to various embodiments, the sizing of the electrical storage may be a function of the bulk storage unit, whereas the electrical storage should provide power or store power while the large bulk storage unit cycles up and/or down to achieve the desired operational load.

[0041] According to various embodiments, the auxiliary unit will consist of a production cycle that will work in synergy with the storage unit. The auxiliary unit is envisioned to be one of the following:

[0042] According to one embodiment of the disclosed matter the auxiliary unit may contain an air separation unit and may consist of devices, equipment etc. needed for processing air and achieving air separation. According to various embodiments, some of the devices, equipment, etc. may consist of a compressor (one or more), an expander (or turbine, one or more). According to various embodiments, a process occurring in one or more of the devices, equipment etc. may be continued with in the bulk storage unit. According to various embodiments, the bulk storage unit may be a LAES.

In such a case it may be that one or more of the LAES's compressors and/or expander may be used in order to achieve one or more needed process within the air separation process. In the event that one or more of the compressors or expanders can be utilized for both processes (i.e. energy storage and air separation) then, according to various embodiments, the device or equipment can have dual functions. According to various embodiments, the auxiliary air separation unit may work independently of the storage unit. It may be that none of the devices or equipment can have dual uses. However, in both cases, it may be that heat from the air separation unit, which may be generated during the process of air separation (during the compression of the air) may be transferred between the two systems or stored to be utilized via the bulk storage unit, such as the LAES. It further may be that cold generated via the air separation (i.e. liquid oxygen and/or liquid nitrogen) may be utilized to increase the efficiency of the LAES. The use of the air separation unit may allow for the use of the system's equipment beyond the time of operation needed for energy storage in order to achieve production of liquid air components. Thus, according to various embodiments, the overall usage of the devices or equipment etc. may grow. According to various embodiments, a portion of the produced liquid air components will be used to enhance the system's power output or to boost the system at times of ramping up from idle mode to power production mode. According to various embodiments, the use of the auxiliary air separation unit will result in an increase of efficiency of the bulk storage unit. Thus, by combining the air separation unit as an auxiliary unit the overall system, device, apparatus etc. may achieve great equipment utilization, higher efficiency, products for sale, higher flexibility of operation, and other characteristics that will be detailed, which may add value and needed and/or desired capabilities for the system, device, apparatus etc.

[0043] According to one embodiment of the disclosed matter, the auxiliary unit may contain an air separation unit. According to various embodiments, the air separation unit may generate oxygen, nitrogen (and other products). According to various embodiments, one component/product of the air may be sold while the other component may not be sold, or it may be that one component may be sold entirely while the other product may be only partly sold. This may occur due to supply and demand of both products. According to various embodiments, one product is in high demand and/or short supply, while the other component/product is at low demand and or high supply. According to various embodiments, the component/product at high demand may be sold while the remaining component/product may not be sold. For example, there may be a high demand for oxygen due to multiple applications for oxygen, and a low demand for nitrogen due to a low amount of applications for nitrogen. In addition, according to various embodiments, in a rejoin that contains multiple apparatuses of air separation, there would be a large production of nitrogen due to large quantities of nitrogen in the air verses oxygen. In such a case it may be that there is a need to effectively use the nitrogen that may be considered as a waste product (if no market is located and/or no suitable use is found). In such a case and according to the above, one or more embodiments of the nitrogen (for example) that is not sold can be effectively utilized within the LAES, as a cold input. The nitrogen may be directed to one or more areas in the LAES which may increase the efficiency of one more modes of operation such as the charge cycle and/or the dis-

charge cycle and/or both. In this way the system, apparatus, facility etc. may operate in a cogeneration mode of operation, utilizing the cold capacity of the nitrogen as a waste cold product.

[0044] According to one embodiment of the disclosed matter, the auxiliary unit may contain a water separation unit that may consist of devices for water separation such as heating devices, catalyst materials and electrodes. According to various embodiments, the auxiliary water separation unit will work independently of the storage unit but it may allow for heat transfer between the two systems. According to various embodiments, during the process of water separation there is an efficiency gain for operating at a relatively high temperature. According to various embodiments, the high temperatures may be gathered, stored and utilized during one or more operation modes of the bulk storage unit to achieve higher efficiency. For example, according to various embodiments, the bulk storage unit may be a LAES. According to various embodiments, the LAES may utilize effectively high temperature during the discharge cycle of the LAES in order to achieve higher output power from the LAES as will be detailed. The use of the water separation unit may allow for the use of one or more of the system's equipment and/or interconnect beyond the time of operation needed for energy processing and/or storage for the production of hydrogen and oxygen.

[0045] By one embodiment of the disclosed matter, a facility is detailed containing a Liquid Air Energy Storage (LAES) system with auxiliary components. According to various embodiments, the auxiliary components will enable processing air and result in the separation of air to the air components. According to various embodiments, the facility may operate in a few modes of operation such as charging, discharging, generating air components, idle, and others.

[0046] During charge mode, the LAES may draw down power from the grid to generate and store both high temperature thermal energy and low temperature thermal energy, which may be achieved by liquefying air.

[0047] During discharge mode, the LAES may generate electrical energy by pumping the liquid air throughout the LAES at a desired pressure. Evaporating and reheating the liquid air utilizes the stored high temperature thermal energy. Expanding the air through an expander generates a mechanical drive that may operate a generator and generate electrical energy that may be dispatched.

[0048] During air separation mode, the facility may process air into air components. According to various embodiments, the process of air separation may utilize specific pieces of equipment that are operating within the LAES during the charging and/or discharging cycles. According to various embodiments, the generated air components may be extracted from the energy storage facility and may be utilized, sold, or other, thus allowing the facility to draw down larger power capacity than the storage capacity of the facility. In addition, according to various embodiments, the facility may have more advantages than a standalone energy storage facility.

[0049] During idle mode, according to various embodiments, the facility may not operate any of the above modes of operation.

[0050] According to the embodiment, the facility may contain a LAES that may operate in a charging mode (cycle) and a discharging mode (cycle). During the charging cycle, ambient air may be trapped and compressed into the LAES by a compressor (one or more). The compressor may be powered

by drawing down power from the grid (or other generator), resulting in decreasing power from the grid (or other generator). The compressed air (air stream) may rise in temperature; the high temperature may be extracted from the air by direct or indirect heat exchange and may be stored for a short or long period of time within a suitable material located in a suitable tank/s or vessel/s, as known to one who is skilled in the art. The suitable tank/s or vessel/s may be referred to as a high temperature thermal energy storage unit. The air stream may be further processed in order to achieve air liquefaction. According to various embodiments, further processing of the air stream may contain purifying the air stream from undesired contaminants such as moisture, CO₂, etc. Further reduction of the air stream's temperature may be achieved by directing the air stream through one or more cold storages, by a direct or indirect heat exchanger. According to various embodiments, the air stream at the outlet of the cold storage (one or more) may be at or near the temperature in which air may undergo a phase change. The cold storages may be precooled during the discharging cycle, as will be detailed below. Expansion of the air stream may result in further reduction of the air stream's temperature alongside the reduction of the air stream's pressure. Expanding the air stream may be achieved by an expander (or other devices that may result in the same pressure reduction of the air stream). According to various embodiments, the air stream at the outlet of the expander (or other device) may undergo a phase change. According to various embodiments, only a portion of the air stream will undergo a phase change to liquid, and a second portion will remain in a gaseous form. According to various embodiments, the portion of the air stream that achieves a phase change to liquid may be the bulk of the air stream. The air stream at the outlet of the expander may be directed to a separator, separating the liquid portion from the gas portion of the processed air stream. According to various embodiments, the liquid air may be directed to and stored in a suitable liquid air tank (vessel) to be utilized during the discharging cycle. According to various embodiments, the second portion which remained in a gaseous form (byproduct stream), may be directed back through the LAES in order to further reduce the air stream's temperature during the liquefaction process. According to various embodiments, after the byproduct stream's cold temperature is effectively utilized, the byproduct stream may be vented from the LAES.

[0051] According to various embodiments, the charging cycle may result in the generation and storage of low temperature liquid air contained within the liquid air tank, alongside high temperature thermal energy contained and stored within the high temperature thermal energy storage unit.

[0052] During a second period, the LAES may operate in discharge mode. According to various embodiments, during discharge mode, a liquid air pump may pump liquid from the liquid air tank throughout the LAES at a desirable pressure. According to various embodiments, the liquid air may be directed through the cold storage unit where thermal energy may be exchanged with the liquid air and the material contained in the cold storage unit. The exchange of thermal energy may be achieved by direct or indirect methods, as known to one who is skilled in the art. According to various embodiments, the liquid air stream (reverse stream), which at this stage may have evaporated and may be in a gas form, may exchange relatively low temperature with relatively high temperature which is contained within the cold storage. According to various embodiments, the relatively low temperature of

the reversed stream may be extracted from the reverse stream and may be stored within the cold storage to be utilized during the charging cycle, as detailed above. The reversed air stream may be directed from the outlet of the cold storage to the high temperature thermal energy storage unit, and may exchange thermal energy directly or indirectly with the material located in the high temperature thermal energy storage unit. The reversed air stream at the outlet of the high temperature thermal energy storage unit now charged with high temperature at a high pressure may be directed to an air expander, which may operate a generator and generate electrical energy.

[0053] According to various embodiments, the discharging cycle may result in the storage of low temperature contained within the cold storage unit, and of relatively low temperature contained in the high temperature thermal energy storage unit. The discharging cycle may also result in the consumption of liquid air that was generated during the charging cycle, and the generation of electrical energy to be dispatched onto the grid or to any other consumer.

[0054] According to one embodiment of the disclosed matter, a facility is detailed containing a LAES with needed auxiliary equipment for processing air into air components (such as Nitrogen N₂, Oxygen O₂, and others). According to various embodiments, the auxiliary equipment may utilize one or more components and/or devices of the LAES. These devices may be compressor/s, expander/s, and/or the expander/s of the charging and/or the discharging cycle, high temperature thermal storage unit, etc. According to various embodiments, in order to separate air into air components, there is a need to first reduce the temperature of the air. According to various embodiments, the process of reducing the air's temperature may require compressing the air into high pressure and then reducing the air's temperature, which may occur during the compression process. According to various embodiments, the compressor/s of the LAES may be utilized for this process, alongside the high temperature thermal energy storage unit. According to various embodiments, during the process of splitting the air into air components, there is a need to reduce the air's pressure via an expander. According to various embodiments, one or more expanders of the LAES may be utilized during the process. According to various embodiments, additional means and devices are needed to further reduce the air's temperature, and separate the air into air components. Additional equipment and/or devices may be contained and may comprise the auxiliary equipment unit.

[0055] During the process of the air separation, according to various embodiments, the high temperature thermal energy storage unit may receive excess capacity of high temperature, this being due to the dual use of the high temperature thermal energy storage unit for both reducing the air stream's temperature during the charging cycle of the LAES and reducing the air's temperature during the process of splitting the air into air components. According to various embodiments, the high temperature thermal energy storage unit may need to be cooled down. Cooling down the high temperature thermal energy storage unit may occur by one or more method, whereas one method may be cooling down the high temperature thermal energy storage unit with water. In such a case, the water may be heated to achieve a steam. The steam may be utilized to drive a turbine to generate electrical energy, which may be dispatched onto the grid and/or utilized during one or more process of the LAES or during the separation of air into air components. According to various embodiments, the

expander within the LAES may be slightly modified, thus enabling the expander to be driven both by an air stream and by steam. According to various embodiments in which modifications are unfeasible or undesirable, a steam turbine is added to the auxiliary equipment unit.

[0056] According to one embodiment of the disclosed matter, a facility is detailed containing a LAES with an auxiliary unit, which may operate in a few modes of operation, as detailed above. According to various embodiments, during periods in which a regional grid is suffering from an excess of electrical power, the facility may charge the LAES. In the event the period of excess power exceeds the LAES's capacity, the facility may shift operations and utilize the auxiliary equipment in order to separate air into air components. According to various embodiments, the air components may then be sold in the air components market. Periods of time with excess electrical energy may be during specific times in which the power generation is very high, consumption is very low, or other reasons. One example of a period of time in which there is an imbalance of supply and demand of energy is on weekends (or other holidays). According to various embodiments, the grid operators do not desire large amounts of power to be dispatched onto the grid during these periods. In such a case the facility may store the energy in the LAES and may operate to consume power from the grid and operate in a mode that may result in air separation into air components.

[0057] According to various embodiments, such a facility may be desirable in order to stabilize (or somewhat stabilize) the supply and demand of power within a regional grid. According to various embodiments, the facility may be operating more frequently than a storage facility, due to shifting the operational mode of the facility to air separation during periods that the power capacity exceeds that of the LAES. Furthermore, according to various embodiments, the facility may sell its services and resulting air components to more than one market (i.e. the power market and air component market). Thus, the cost of the facility or the revenues for the facility may be shared by more than one participant. One or more pieces of equipment and devices of the facility may be bi-functional, being used for both the operations of the LAES for charging and/or discharging, alongside the operations of air separation. Thus, on average, these different pieces of equipment would be utilized for more hours of the day, reducing the period of time (or other matrix) for repaying the cost of the equipment.

[0058] According to one embodiment of the disclosed matter, a system/apparatus/facility etc. is revealed whereas the components of the system may contain one or more or all of the components as detailed above and may operate in one or more modes of operation, which may include (but not limited to) charging mode, discharging mode, air separation mode, power leveling mode, or may work in a combination of one or more of the disclosed modes of operation. According to various embodiments, during one period of time the electric grid may have excess power. According to various embodiments, some or all of the excess power would be utilized to charge the bulk storage system as detailed above if the bulk storage unit has not reached its full capacity. According to various embodiments, some or all of the excess power may be utilized to charge the electrical storage if the electrical storage unit has not reached its full capacity. According to various embodiments, some or all of the excess power would be utilized to drive the air separation unit. According to various embodi-

ments, the excess power from the grid may be utilized by some or all of the disclosed units simultaneously.

[0059] According to various embodiments, the air separation and storage units may have different capacities, thus enabling the system to charge one unit, some units, or all of the units simultaneously at different periods of time and at different power input of the grid. According to various embodiments, different capacities of the air separation and storage units may provide more flexibility in dealing with intermittency of input power from the grid.

[0060] The auxiliary air separation unit may be used for the cogeneration of liquid air products and high and/or low temperature thermal energy. The air separation process may include compression of air by means of a compressor/s, which may result in a rise of the air's temperature and pressure. The process may contain heat exchanger/s to lower the temperature of the air after its compression and turbine/s or expander/s to lower the air's temperature while the air expands and its pressure decreases. According to various embodiments, the high temperature air after its compression may be used as a high temperature or hot thermal energy source by the bulk storage unit. According to various embodiments, the hot thermal energy of the air separation unit may be transferred to and utilized by the bulk storage unit by means of a heat exchanger, heat storage, and necessary conduits. During expansion, the air may undergo a phase change to liquid or liquid components. The remaining air that did not undergo a phase change to liquid and remains in its gas form may be used as a low temperature or cold thermal energy source by the air separation unit or bulk storage unit. According to various embodiments, the heat and/or product transfer between the air separation unit and the bulk storage unit may achieve efficiency gain in one or both of the units. Thus, the synergy between the two units may be beneficial.

[0061] According to various embodiments, the liquid air products of nitrogen and oxygen may be stored and transferred to a designated customer, contractor, etc. by demand. According to various embodiments, by interests of supply and demand, market value, etc. the liquid air products comprising of liquid nitrogen or liquid oxygen or both would be used by the system. According to various embodiments, the system may use liquid air products by means of expansion in the LAES or CAES unit's turbine or expander device or a separate designated turbine or expander device in order to increase the bulk storage system's output power or improve the ramp up process of the system. According to various embodiments, the liquid products would be used to charge the cold thermal storage of the LAES system in order to improve the LAES system's efficiency. According to various embodiments, liquid oxygen would be used to enhance the combustion of an added fuel powered turbine unit in order to increase efficiency and decrease fuel usage.

[0062] According to various embodiments, the high temperature thermal energy of the air separation unit may be used to transfer heat and charge the hot thermal storage or heat the air stream of the LAES unit prior to entering the turbine or expander at the discharge cycle in order to improve efficiency and power output. According to various embodiments, if the air separation unit's hot thermal energy is not sufficiently high enough to be used by the bulk storage unit's discharge cycle but sufficiently high enough to generate steam, it may be used to charge a separate thermal storage or heat water at the evaporator unit of a steam generation generating cycle such as the Rankine cycle or other similar cycle. According to

various embodiments, the air separation unit's low temperature thermal energy may be used to charge the cold thermal storage of the LAES unit in order to improve efficiency.

[0063] According to various embodiments, during one period of time the electric grid may not contain sufficient power. According to various embodiments, the power needed to reach the output power requirements may come from the bulk storage unit by generating power at discharge mode if the bulk storage's capacity has not emptied. According to various embodiments, the needed power may come from the electrical storage unit if the unit's capacity has not emptied. According to various embodiments, the needed power may come from a separate steam or gas turbine related cycles. According to various embodiments, the needed energy may come from the expansion of the air separation unit's products as detailed above.

[0064] According to one embodiment of the disclosed matter, the bulk storage unit may contain a LAES that may operate in a charging mode (cycle) and a discharging mode (cycle). During the charging cycle, ambient air may be trapped and compressed into the LAES by a compressor (one or more). The compressor may be powered by drawing down power from the grid (or other generator), resulting in decreasing power to the grid (or other generator). The compressed air (air stream) may gain an increase in temperature. The high temperature may be extracted from the air by direct or indirect heat exchange, and may be stored for a short or long period of time within a suitable material located in a suitable tank/s or vessel/s, as known to one who is skilled in the art. The suitable tank/s or vessel/s may be referred to as a high temperature thermal energy storage unit. The air stream may be further processed in order to achieve air liquefaction. According to various embodiments, further processing of the air stream may contain purifying the air stream from undesired contaminations such as moisture, CO₂, etc. Further reduction of the air stream's temperature may be achieved by directing the air stream through one or more cold storages, by a direct or indirect heat exchanger. According to various embodiments, the air stream at the outlet of the cold storage (one or more) may be at or near the temperature in which air may undergo a phase change. The cold storages may be precooled during the discharging cycle, as will be detailed below. Expansion of the air stream may result in further reduction of the air stream's temperature alongside the reduction of the air stream's pressure. Expanding the air stream may be achieved by an expander (or other devices that may result in the same pressure reduction of the air stream). According to various embodiments, the air stream at the outlet of the expander (or other device) may undergo a phase change. According to various embodiments, during the expansion of the air stream via the expander power may be generated, which may be utilized in a range of methods, which may increase the LAES system's efficiency. According to various embodiments, only a portion of the air stream will undergo a phase change to liquid, and a second portion will remain in a gaseous form. According to various embodiments, the portion of the air stream that achieves a phase change to liquid may be the bulk portion of the air stream. The air stream at the outlet of the expander may be directed to a separator, separating the liquid portion from the gas portion of the processed air stream. According to various embodiments, the liquid air may be directed to and stored in a suitable liquid air tank (vessel) to be utilized during the discharging cycle. According to various embodiments, the second portion, which remained in a gas-

eous form (byproduct stream), may be directed back through the LAES in order to further reduce the air stream's temperature during the liquefaction process. According to various embodiments, after the byproduct stream's cold temperature is effectively utilized, the byproduct stream may be vented from the LAES.

[0065] According to various embodiments, the charging cycle may result in the generation and storage of low temperature liquid air contained within the liquid air tank, alongside high temperature thermal energy contained and stored within the high temperature thermal energy storage unit. And that the cold storage may be at a temperature in the range between the liquid air temperature and the high temperature thermal energy storage unit.

[0066] During a second period, the LAES may operate in discharge mode. According to various embodiments, during discharge mode, a liquid air pump may pump liquid air from the liquid air tank throughout the LAES at a desirable pressure. According to various embodiments, the liquid air may be directed through the cold storage unit where thermal energy may be exchanged with the liquid air and the material contained in the cold storage unit. The exchange of thermal energy may be achieved by direct or indirect methods, as known to one who is skilled in the art. According to various embodiments, the liquid air stream (reverse stream), which at this stage may have evaporated and may be in a gas form, may exchange relatively low temperature with relatively high temperature, which is contained within the cold storage. According to various embodiments, the relatively low temperature of the reversed stream may be extracted from the reverse stream and may be stored within the cold storage to be utilized during the charging cycle, as detailed above. The reversed air stream may be directed from the outlet of the cold storage to the high temperature thermal energy storage unit, and may exchange thermal energy directly or indirectly with the material located in the high temperature thermal energy storage unit. The reversed air stream at the outlet of the high temperature thermal energy storage unit now charged with high temperature at a high pressure may be directed to an air expander, which may operate a generator and generate electrical energy.

[0067] According to various embodiments, the discharging cycle may result in the storage of low temperature contained within the cold storage unit, and of relatively low temperature contained in the high temperature thermal energy storage unit. The discharging cycle may also result in the consumption of liquid air that was generated during the charging cycle, and the generation of electrical energy to be dispatched onto the grid or to any other consumer.

[0068] According to various embodiments, a LAES may operate in conjunction to one or more facilities that may generate heat. According to various embodiments, the generated heat may be gathered, stored any may be effectively utilized by the LAES in order to achieve a higher efficiency, as stated above. According to various embodiments, gathering and storing the generated heat may be achieved by a direct or indirect heat exchanger, which may be connected to the heat generating source by suitable conduits. According to various embodiments, the heat may be stored as high temperature thermal energy in a suitable material contained within a suitable vessel. According to various embodiments, the vessel containing the heat input from an external source may be referred to as an external heat storage.

[0069] According to various embodiments, in the event that the thermal energy contained in the external heat source is of

substantial higher temperature to the thermal energy temperature contained within the thermal energy storage associated with the LAES (as detailed above), it may be utilized during the discharge cycle. According to various embodiments, the high temperature contained in the external heat storage may be utilized to charge the reversed stream with higher temperatures (higher than if not utilized) prior to expanding through the expander, thus achieving a greater production of the expander, as known to one who is skilled in the art.

[0070] According to various embodiments, in the event that an external heat source is available and a LAES is configured to utilize the generated heat as detailed above, then additional devices and conduits may be added. According to various embodiments, the LAES would operate in a similar way to that which has been detailed above during the charging cycle. During the discharge cycle liquid air may be pumped from the liquid air tank, through the cold storage and then through the high temperature thermal energy storage (associated with the LAES), all as detailed above. However, at the outlet of the high temperature thermal energy storage (associated with the LAES) and prior to entering the expander, the air stream may be directed to the external heat storage. According to various embodiments, the air stream will be charged with high temperature thermal energy that has been stored in the external heat storage. According to various embodiments, the air stream at the outlet of the external heat storage may be directed to an expander, which may generate mechanical work that may drive a generator and generate electrical energy that may be placed on the electrical grid or be used by another consumer. According to various embodiments, if the generator of the heat source is operating and thus generating heat during the period that the LAES is operating in a discharge cycle, then the reversed stream at the outlet of the cold storage will be directed to the heat source (or associated heat storage) with bypassing the high temperature thermal energy storage (associated with the LAES). According to various embodiments, the LAES may alternatively be configured as detailed above but without the high temperature thermal energy storage (associated with the LAES). In such embodiments, during the charging cycle, the air stream would be cooled down not by passing through the direct or indirect heat exchanger of the high temperature thermal energy storage (associated with the LAES), but by other methods such as air cooling, etc. known to one who is skilled in the art.

[0071] According to various embodiments, the bulk storage unit may be required to operate in a specific set mode of operations and duration whereas the system will be operational to store and generate energy for a fixed amount of hours during the day according to specification of the operator or customer. As an example, the system will be specified to draw down power and store it for a duration of six hours, and will be specified to operate in the discharge cycle for the duration of six hours of discharge mode (the typical working conditions may not be a symmetric or equal amount of charge/discharge time), in this example, the system's equipment will be unused for 12 hours a day. In the event that the equipment utilized during the charge cycle and the discharge cycle are separate pieces of equipment, then the number of hours that the equipment will remain ideal will grow to 18 hours each day. According to various embodiments, with the use of an auxiliary unit, the system's equipment may be used for more hours during the day. Thus, the utilization of the equipment may grow. This may be achieved due to the synergy between

the auxiliary unit and the bulk storage unit, as detailed below, and in addition may result in an increase of the bulk storage unit's efficiency.

[0072] According to various embodiments, the system is configured to operate in an asymmetrical mode of operation in regards to the charging and discharging cycle. In such embodiments, the charging cycle would be characterized by rapidly shifting changes between modes of operation (e.g., from one mode to another mode of operation) and/or rapidly shifting between load sizes from one period to another, where the shifting from one mode or period to another can occur rapidly and frequently. In such embodiments, the discharge cycle is configured to dispatch a specified output of power at or near a constant rate. Such embodiments may be applicable where the power input comes from sources of renewable energy such as wind or solar, which provide the input power from a number of different sources directed to the same location. Due to the intermittency of the power input, the power input may vary substantially at different periods of time. In addition, each one of the renewable sources may have a specific capacity factor (CF) associated with the specific generator and the specific location, as known to one skilled in the art. For example, a specific location or a system that is receiving power from multiple generators (as an example) which may contain one 300 MW capacity solar input and 4 different 300 MW capacity wind input (that may be located at the same or at different locations and are connected by one or more power line to the same location) may generate together a total of minimum 0 MW power at one period of time and a maximum of 1500 MW power at another period of time, whereas at every point of time the total generation will be at some point on the scale. According to various embodiments, frequency of the input power as a function of time or the probabilistic distribution of the input power may be fitted to a bell curve where the bell curve may not be represented by an ideal Gaussian function but rather a modified approximation. For example, the mean of expectation may not be at the center of the power axis and the distribution at the end points of the power axis may not have a value of zero or a small number close to zero. According to various embodiments, the probabilistic function of the power output may vary between different locations and types of renewable power inputs as known to one who is skilled in the art.

[0073] According to various embodiments, an embodiment of the disclosed matter may operate by generating a fixed power output determined relatively by the mean of expectation. According to various embodiments, the design of the working range in regard to the input power of the system will exclude input power regions of a relatively small percentage. According to various embodiments, the system's equipment and power transmission lines will be restricted to work at a range of power inputs determined from the bell curve and other specific requirements. According to various embodiments, the proposed system may utilize a higher range of working power inputs by directing surplus energy to the auxiliary unit and/or a backup gas turbine, according to one embodiment of the disclosed matter. According to various embodiments, by generating a fixed output power, a lower transmission line's capacity may be needed relative to the transmission lines of the input sources or the required output transmission lines that would be used without the proposed system. According to various embodiments, the use of the auxiliary unit in the disclosed matter will improve the storage unit's efficiency and the entire system's cost effectiveness.

[0074] According to various embodiments, in specific regions there may be multiple renewable power generators. According to various embodiments, the renewable generators are located in the region and/or located outside of the region but are interconnected through the grid, which may carry the generated power to the region. According to various embodiments, the different renewable power generators may have different capacity factors (CF) associated to each one. As one who is skilled in the art will know, different renewable facilities may have power output at different periods of time. In addition, the same facility may have different power output levels during different periods of the day and/or the year. According to various embodiments, a variety of conditions may affect the power output of each facility. The conditions may include (but are not limited to) specific technology, weather conditions, geographical conditions, facility maintenance etc. According to various embodiments, if a multitude of renewable power sources from different locations are directed to a single location, then the power in the location may be vital and intermittent. According to various embodiments, at one period of time there may be a large amount of power while at a second period of time they may have a small amount of power. According to various embodiments, the maximum amount of power in the location may receive may be calculated as the sum of all of the generators that are being directed to the location. And the minimum power that the location may receive is during a period of time when none of the generators are generating any power, or in other words zero. According to various embodiments, at any given moment the actual amount of power that is received in the location will be in the area of the maximum and the minimum amount of power.

[0075] According to various embodiments, the expected power that is received and/or will be received in the location is calculated. The calculation may result in a bell curve average or an average resembling a bell curve. Whereas in a relative small percentage of time the received power is at or near the minimum power levels, at a majority of the time the received power is at some point between the minimum and maximum, and at a small percentage of the time the received power is at or near the maximum amount of power that may be received in the area.

[0076] According to various embodiments, in the specific location there may be a desire and/or need to receive renewable power that may be utilized to power the specific location. According to various embodiments, in the specific location there may be a desire or need to receive renewable power, and direct the power from the location to a different location. According to various embodiments, in both cases (i.e. utilization at the location and/or directing the power to a different location) there may be a need and/or desire that the power that is utilized or directed be at a specified capacity. In such embodiments, there may be a need and/or desire to level the power received to match the specific desired capacity that is to be utilized and/or dispatched. There may be a few reasons for the desire to level the power capacity, which may include (but not limited to) contractual obligations, needed capacity for utilization, electrical grid limitations etc. According to various embodiments, in a specific location that is trying to achieve the leveled power utilization and/or dispatch, there may be a need and/or desire for a system, device, apparatus, method, and/or the like that may function to level the input power to the desired output or utilized power. According to various embodiments, the desired utilized and/or dispatch

power may be smaller than the maximum level of power (in the event that the desired output is equal to the maximum input, there may be a need and/or desire for backup power). According to various embodiments, a storage system, device, apparatus, method, or the like that may draw down power at a period of power excess and dispatch power during periods of power deficiency, may be capable of achieving the desired outcome. As stated above, it may be advantageous for a system, device, apparatus, method, and/or the like to have the characteristics such as, for example, low cost, high efficiency, and/or high flexibility. According to various embodiments, a storage system, device, apparatus, method, and/or the like meeting these characteristics may increase the likelihood of being chosen and implemented.

[0077] According to various embodiments, in addition to leveling the output utilization and/or dispatch power at and/or from the location (or system, device, apparatus etc. located in the location), a need and/or desire may exist that the output power from the location be characterized as having a stable power output.

[0078] According to one embodiment of the disclosed matter, a system, device, apparatus etc. is disclosed containing some or all of the components as detailed above. According to various embodiments, due to the fluctuating nature of the input power, the system, device, apparatus etc. may receive information regarding the power conditions that may be entering the location. According to various embodiments, the information received may undergo a decoding process that may be achieved via the use of specific algorithms and other methods in order to enable the system, device, apparatus etc. to generate control orders for the system, device, apparatus etc. to allow the system, device, apparatus etc. to meet the desired outcome. According to various embodiments, the system, device, apparatus etc. may be configured to operate in a few modes of operation including (but not limited to): charging storage, discharging storage, passing through power, operating auxiliary unit, shutting down auxiliary unit, augmenting power from auxiliary unit, leveling output power, operating backup etc. According to various embodiments, due to shifting conditions of the input power to the location, the system, device, apparatus etc. may shift from one mode of operation to the other in order to achieve the desired outcome.

[0079] According to various embodiments, if the input power is lower or equal to the desired output power, then the system will direct the input power to the outlet of the system, device, apparatus etc. In the event that the input power is lower than the desired output capacity, the system, device, apparatus etc. may augment the input power by dispatching power from the different storage units of the system, device, apparatus etc. in such a way to achieve the desired output. According to various embodiments, there is a need and/or desire to have the output power be stable. In such an event, according to various embodiments, the system, device, apparatus etc. may stabilize the input power prior or during the process of directing the input power to the outlet. Stabilizing the input power may be achieved by operating the needed storage units in the needed operation mode. According to various embodiments, if the input power is shifting rapidly (i.e. the capacity level is increasing and decreasing many times) in such a case it may be that the system, device, apparatus etc. will balance the power by operating a fast responding electrical storage unit (which may be a battery or capacitor). According to various embodiments, the electrical storage unit may shift rapidly from an operation mode of

charging to discharging and/or to standby, in such a way that allows the output power at the outlet to be at a steady (or near steady) level.

[0080] In the event that the input power capacity is lower than the desired output capacity, according to various embodiments, the system, device, apparatus etc. may dispatch power from one or more storage units to match the needed and/or desired output power.

[0081] In the event that the input power exceeds the desired output capacity, the system may direct a portion of the power to the power outlet of the system. And a second portion may be directed to be utilized within the system. According to various embodiments, the portion of power directed from the input to the power outlet may be equal to the needed and/or desired output capacity. According to various embodiments, the system, device, apparatus etc. may stabilize the power of the input power prior or during the process of directing the power to the outlet (as detailed above). According to various embodiments, the remaining portion (second portion) of the input power may be utilized effectively in the system, device, apparatus etc. According to various embodiments, the system, device, apparatus etc. may store the second portion in the one or more storage units. According to various embodiments, the second portion may be stored in the electrical storage and/or in the larger bulk storage unit. As detailed above the large bulk storage unit may be a PHES, CAES and/or LAES. According to various embodiments, the second portion may be stored in one or more methods (in regard to the different storage units and/or storage technology). According to various embodiments, the stored power and/or energy may be utilized during a period of power deficiency.

[0082] In the event the second portion is larger than the charging capacity of the storage unit, according to various embodiments, the system, device, apparatus etc. may operate an auxiliary unit. In such a case it may be that the input capacity may be divided and directed to a few different destinations. A first portion equal to the desired output of the system, device, apparatus etc. may be directed to the power outlet of the system, device, apparatus etc. and the power may be leveled. A second portion may be stored in one or more storage units. A third portion may be directed to an auxiliary unit. As stated above, the auxiliary unit may be an air separation unit and/or a water separation unit.

[0083] According to various embodiments, the input capacity exceeds the desired output capacity. According to various embodiments, the input power may be divided into at least two portions. The first portion may be directed to the output outlet of the system, device, apparatus etc. as stated above, and the second portion may be directed to operate the auxiliary unit. There may be a variety of reasons to direct the second portion to the auxiliary unit, which may include (but not limited to): the second portion is of a capacity that is ideal for the auxiliary unit and not ideal for the storage; the storage unit is at full charge; the value for auxiliary products are higher than that of power (or energy storage), etc.

[0084] As stated above, according to various embodiments, the different components of the system, device, apparatus etc. may operate with a large amount of synergy one with the other. According to various embodiments, the input power that is received in the location may be lower than the output power desired and/or needed at the outlet of the system, device, apparatus etc. As stated above, according to various embodiments, the system, device, apparatus etc. may dispatch power in order to achieve the needed and/or output

power capacity. However, it may be that during a specific period of time the energy storage may be exhausted i.e. the amount of power stored in the storage unit is lower than the amount of power needed to augment the power at the outlet of the system, device, apparatus etc. In such a case, according to various embodiments, energy may be added to the system, device, apparatus etc., which may be directed from the auxiliary unit. According to various embodiments, added energy may be in one or more forms in regard to the specific configuration of the system, device, apparatus etc.

[0085] According to various embodiments, the auxiliary unit is an air separation unit and the bulk storage unit is a LAES, and energy may be added as a high temperature thermal energy input, which may increase the efficiency of the system, device, apparatus etc., thus achieving higher power output. In the event that the collected heat from the air separation unit is not sufficient to add major efficiency gain to the LAES, then, according to various embodiments, water can be passed through the collected heat and expand through one or more expanders of the LAES or through an expander external to the LAES in order to achieve the needed power output. According to various embodiments, energy may be added in the form of increasing the cold capacity of the LAES. In such an event liquid nitrogen (N₂) and/or liquid oxygen (O₂) may be added to the LAES. According to various embodiments, the additional N₂ and/or O₂ may be utilized in order to generate power, thus enabling the system, device, apparatus etc. to meet its needed and/or desired output level. According to various embodiments, the system, device, apparatus etc. may be backed up by some other method such as burning gas, which may ensure that the system, device, apparatus etc. will dispatch the needed and/or desired capacity at any time.

[0086] According to one embodiment of the disclosed matter, a system, apparatus, facility etc. is revealed whereas the components of the system may contain one or more or all of the components as detailed above and may operate in one or more modes of operation, which may include (but not limited to) charging mode, discharging mode, air separation mode, power leveling mode, or may work in a combination of one or more of the modes of operation. According to various embodiments, during one period of time the system, apparatus, facility etc. may operate in a charge mode (i.e. drawing down power from the electrical grid or other generator/s). According to various embodiments, some or all of the power drawn down would be utilized to charge the bulk storage system, as detailed above. According to various embodiments, some or all of the power drawn down would be utilized to charge the electrical storage. According to various embodiments, some or all of the power drawn down would be utilized to drive the air separation unit. According to various embodiments, the power drawn down from the grid may be utilized by one or more and/or all of the disclosed units simultaneously.

[0087] According to various embodiments, the auxiliary unit may be an air separation unit. According to various embodiments, the air separation and storage units may be configured to have different capacities. Thus it may enable the system to charge one unit, some, or all of the units simultaneously at different periods of time and by different power inputs of the grid. According to various embodiments, different capacities of the air separation and storage units may provide additional flexibility operations.

[0088] The auxiliary air separation unit may be used for the cogeneration of liquid air products. According to various

embodiments, during the generation process of the liquid air and/or liquid air components, high and/or low temperature thermal energy will be generated. The air separation process may include a stage of compression of air, which may be achieved by means of a compressor/s. Compressing the air may result in a rise of the compressed air's (air stream's) temperature and pressure. According to various embodiments, the air stream may need to be cooled down. According to various embodiments, the air stream may be directed to a direct and/or non-direct heat exchanger. According to various embodiments, high temperature thermal energy may be extracted from the air stream, thus achieving a reduction in the temperature of the air stream. According to various embodiments, the high temperature thermal energy extracted from the air stream by means of the direct or non-direct heat exchangers may be gathered and stored in a suitable material located in a suitable tank or vessel, as known to one who is skilled in the art. According to various embodiments, the high temperature extracted from air stream after its compression may be used as a high temperature or hot thermal energy source by the bulk storage unit as detailed above. According to various embodiments, the hot thermal energy of the air separation unit may be transferred to and utilized by the bulk storage unit by means of heat exchanger, heat stores and necessary conduits. According to various embodiments, the air stream would be further processed in order to achieve air liquefaction and/or air separation. Further processing the air may include expansion of the air stream which may result in a reduction in the air stream's pressure and further reduction in the air stream's temperature. Expansion of the air stream may be achieved by directing the air stream through an expander, turbine, throttle valve, etc. During the expansion the air stream may undergo a phase change to liquid or liquid components. According to various embodiments, the whole air stream may undergo a phase change. According to various embodiments, a portion of the air stream may undergo a phase change and a second portion may remain in a gasses form (byproduct stream). In the event that a byproduct stream is generated and the bulk energy storage unit is a LAES, the byproduct stream may be effectively utilized within on or more components of the LAES during one or more modes of operation of the LAES in order to achieve increase the efficiency of LAES. According to various embodiments, the portion of the air stream that was liquefied and/or separated to air components may be stored in one or more suitable tanks or vessels as known to one who is skilled in the art. According to various embodiments, the heat and/or products transfer between the air separation unit and the bulk storage unit may achieve efficiency gain in one or both of the units thus the synergy between the two units may be beneficial.

[0089] According to various embodiments, the liquid air products of nitrogen and oxygen may be stored and/or sold and/or transferred to a designated customer, contractor, etc. According to various embodiments, by interests of supply and demand, market value, etc. the liquid air products comprising of liquid nitrogen or liquid oxygen or both would be used by the system. According to various embodiments, the system may use liquid air products by means of expansion in the LAES unit's turbine or expander device or a separate designated turbine or expander device in order to increase the bulk storage system's output power, improve LAES efficiency or improve the ramp up process of the system. According to various embodiments, the liquid products would be used in one or more methods within the LAES system in order

to improve the LAES system's efficiency. According to various embodiments, liquid oxygen would be used to enhance the combustion of an added fuel powered turbine unit in order to increase efficiency and decrease fuel usage. According to various embodiments, the high temperature thermal energy of the air separation unit may be used to transfer heat and charge the hot thermal storage or heat the air stream of the LAES unit prior to entering the turbine or expander at the discharge cycle in order to improve efficiency and/or power output, as detailed above. According to various embodiments, if the air separation unit's hot thermal energy is not high enough to be used by the bulk storage unit's discharge cycle but high enough to generate steam, then it may be used to charge and separate thermal storage or heat water at the evaporator unit of a steam generation cycle such as the Rankine cycle or other similar cycles.

[0090] According to various embodiments, during a second period of time the system, apparatus, facility etc. may be configured to operate at a discharge mode of operation. According to various embodiments, the power needed to reach the output power requirements may be achieved by discharging the bulk storage unit by generating power during the discharge mode, as detailed above. According to various embodiments, the needed power may be achieved by discharging the electrical storage unit. According to various embodiments, the needed power may come from a separate steam or gas turbine power generating cycle as detailed below. According to various embodiments, the needed energy may come from the expansion of the air separation unit's products, as detailed above.

[0091] According to various embodiments, the system may have an additional power generation unit. The purpose of the disclosed unit is to provide backup output power in the event that the system's input power sources, storage and power generation units have insufficient capacity to provide the required output power and/or in the event that the customer/s may require a larger capacity of power. The disclosed unit may use combustible fuels such as natural gas, coal, etc. According to various embodiments, the backup output power unit may use the LAES unit's expander to generate the required output. According to various embodiments, the backup output power unit may use separate expander for its power generating operation. According to various embodiments, the backup output power unit may exchange heat with the hot thermal storage of the LAES and/or an external thermal storage unit, which may be associated to the LAES unit in order to increase its efficiency.

[0092] According to various embodiments, the interconnected LAES and air separation units may use shared components such as a compressor and/or expander or expander units. According to various embodiments, the compressor unit may have the valves and conduits at its inlet and outlet needed for making the compressor unit functional for both the LAES and air separation units. However, separate compressor units can be used for the LAES and air separation units. According to various embodiments, an expander unit may have the valves and conduits at its inlet and outlet needed for making the compressor unit functional for both the LAES and air separation units. Alternatively, according to various embodiments, a separate expander unit is used for the LAES and air separation unit. According to various embodiments, the LAES expander device will be used by the steam generation cycle such as the Rankine cycle or other similar cycles;

and the expander may include further modifications in order to operate with both air gas and water steam fluids.

[0093] According to one embodiment of the disclosed matter, a system similar to the system of the previous embodiment is revealed with the exception of a CAES bulk storage unit. In the charge mode of operation, air from the environment is compressed by a compressor or compressor units. According to various embodiments, the air may gain a rise in temperature and pressure after its compression. According to various embodiments, the air after the compression may be diverted to a heat exchanger or thermal storage to transfer hot thermal energy, and the air's temperature may decrease. The air may be stored in a cavern, pressure vessel or other high pressure storage media as known to one skilled in the art. At the discharge mode of operation, compressed air may be diverted to a thermal storage or heat exchanger in order to gain an increase in temperature that may increase the output power. The air is then expanded by the expander or expander units in order to generate power.

[0094] The CAES unit may work in conjunction with an auxiliary air separation unit. According to various embodiments, hot thermal energy of the air separation unit may come from the compression of air at the air separation unit. According to various embodiments, the CAES unit may use hot thermal energy from the air separation unit to heat the air at the discharge mode of operation prior to its entrance to the expander. The air may receive an increase in temperature, which may result in an increase of power and efficiency. According to various embodiments, both the CAES bulk storage and air separation units may have shared equipment such as compressor and/or expander, as detailed in the previous embodiment.

[0095] According to one embodiment of the disclosed matter, a system similar to the system of the previous embodiment is revealed, with the exception of a PHS bulk storage unit. In the charge mode of operation, water may be pumped to a high elevation reservoir by a pump or pump units in order to convert energy from the grid to potential energy of the water. At the discharge mode of operation, the water from the elevated reservoir is allowed to flow to a ground of a lower elevation in order to transfer the water's potential energy to kinetic energy. The resulting water flow may enter a turbine or turbine units in order to generate electricity. According to various embodiments, water from the PHS unit and hot thermal energy from the air separation unit may be used to drive a separate steam power generating cycle.

[0096] According to one embodiment of the disclosed matter, a system similar to the system of the previous embodiments is revealed with the exception that the auxiliary unit may be a water separation unit, and may not be an air separation unit. The water separation unit may be used for the generation of water products. According to various embodiments, during the process of water separation it may be desirable to heat the water to a high temperature, which may result in a high efficacy of the water separation process. During the generation process of the water components, separation of high temperature thermal energy may be generated and used by the water separation unit. The water separation unit may comprise of heat generating devices for the heating of water to high temperature steam, preferably at the temperatures above 100 degrees centigrade and below 850 degrees centigrade. The water separation unit may contain high temperature electrolysis cells comprising of anode, cathode and a solid or liquid electrolyte, diaphragm, or membrane. The

water separation unit may receive power from the grid in order to pass a current between the anode and cathode of high temperature electrolysis cells, which may result in separation of water into the components of hydrogen and oxygen. According to various embodiments, a catalytic substance may be added to the system in order to reduce the input energy for water splitting, thus increasing the efficiency of the water splitting process. According to various embodiments, the water separation unit may contain heat exchangers, heat storage, cooling devices and the conduits needed for the operation of transferring and storing the water products from the high temperature electrolysis cells. According to various embodiments, high temperature thermal energy may be obtained from the high temperature water products of hydrogen and oxygen.

[0097] According to various embodiments, high temperature thermal energy from the water separation unit may be used to transfer heat and charge thermal stores of the bulk storage unit in a manner similar to the embodiments detailed above. According to various embodiments, water products of hydrogen and oxygen may be sold, transferred, stored or used by the system in any manner similar to the detailed above embodiments. According to various embodiments, the water products of hydrogen and/or oxygen may be combusted by the system in order to generate power or boost the performance of the bulk storage system in a manner similar to the detailed above embodiments.

[0098] A specific region that may have a significant amount of power generated from renewable sources may suffer power issues that may be associated to the characteristics of the different generators. Some of these issues may be associated with the capacity factors (CF) of the different renewable generators. According to various embodiments, the CFs of the different generators that generate power within the specific region may fluctuate dramatically. The shift in the generated power may result in an inefficiency of the grid utilization. Inefficient use of the grid may be a result of the limit of the power that the grid may handle. According to various embodiments, a grid may have an upper limit to the power capacity it may transmit. In such a case it may be that the generators that are dispatching power to that grid may not surpass the power that the grid may contain. In such an event, during periods that the renewable generators are generating and dispatching power at or near full load there may be excess power. In order to ensure that the grid will not receive excess power, according to various embodiments, the grid operators may not accept power from all or some of the generators, and/or may accept only a portion of generated power from all or some of the renewable generators. According to various embodiments, difficulties of such nature will arise in new renewable power generators that seek to build a facility in the specific region. One who is skilled in the art would know that a renewable power generator may not generate and dispatch power at full load constantly. According to various embodiments, a renewable power generator may generate at full load for a limited period of time during the day, week and year, in respect to the CF of each generator.

[0099] As detailed above, according to various embodiments, in a specific region during one period of time the renewable generators may generate at or near full load, thus there may be a relatively large amount of capacity dispatched from the renewable generators on the grid. And during a second period of time the renewable power generators may not dispatch power at or near full load power. Thus, during

this period of time the amount of power that the grid receives from the renewable generators may be insufficient and/or low.

[0100] According to one embodiment of the disclosed matter, a system is disclosed containing some or all of the components as detailed above. According to various embodiments, the system may enable a more efficient use of the grid in a specific region in which a portion of the power is generated via renewable generators. According to various embodiments, during a first period of time in which the generators are generating at or near full load and the electrical grid may be receiving large power capacity from the renewable generators, the system may draw down excess power to be either stored as energy and/or utilized to power the auxiliary unit of the system. According to various embodiments, during a second period of time in which the renewable power generators are not generating power at or near full load, which may result in a desire to add additional power to the grid, it may be that the system will dispatch power and place it on the grid. Thus, the system may enable a larger utilization of the grid, i.e. enabling the power generated by the renewables to be transmitted on the grid for a long period of time. According to various embodiments, the system may enable the incorporation of additional renewable capacity to enter, be handled, be placed etc. on the grid in the specific location. Additional renewable capacity may be achieved by directing renewable power from other location to the specific location, and/or the construction of new renewable facilities.

[0101] According to various embodiments, the additional capacity that may be constructed and/or directed at or to the specific location may be a function of the CF of the different generators. According to various embodiments, a reverse relationship may exist between the CF and the added capacity. According to various embodiments, the lower the CF is, the higher the added capacity is.

[0102] According to one embodiment of the disclosed matter a system is disclosed containing some or all of the components as detailed above. According to various embodiments, the system may contain some or none of its energy sources as renewable energy sources as detailed above. According to various embodiments, adding more renewable energy resources may not require a change in the system's output power capacity and/or output transmission lines capacity. According to various embodiments, the added energy may be utilized to increase the capacity factor of the system's storage units as detailed above. According to various embodiments, the added energy may be used by the auxiliary unit in order to produce air or water products as detailed above.

[0103] According to various embodiments, the system with or without the use of renewable energy sources may be used to generate base load power at a constant or near constant power output and dispatch it to the grid. According to various embodiments, the system may achieve the goal of base load power production with the use of multiple renewable energy sources. According to various embodiments, the renewable energy sources may have a larger capacity than the capacity of the desired output power.

[0104] According to various embodiments, the system will receive input power and may dispatch output power in such a way that the output power may be similar or different from the input power that has been received. The different power at the output's outlet may differ in capacity and/or stability (i.e. regulation of the output stream to meet the needs of the desired stream such as a non-intermittent stream). According

to various embodiments, the change in the capacity may be a reduction or an addition to the capacity received at the inlet of the input power of the system. According to various embodiments, the change of the power from the inlet of the input power of the system may be a reduction of intermittency/stabilization/waveform conversion (ac to dc or dc to ac) or other modifications or changes as required. According to various embodiments, the change in capacity and/or stability may be achieved by configuring the system to operate one of the components such as the electrical storage/the bulk storage/the auxiliary unit as stated above.

[0105] FIG. 1 illustrates an energy processing system, according to one or more embodiments of the disclosed subject matter. FIG. 1 may contain multiple components as detailed above. According to various embodiments, the system may receive an electrical input from one or more source such as the electrical grid, wind power, PV etc. 18. According to various embodiments, one component of the system may be an input interface 3 component. According to various embodiments, the input interface 3 may receive information regarding a variety of fields from multiple sources. Information received may be power conditions on the grid, operators or customers' orders, weather reports, etc. According to various embodiments, the input interface 3 may receive the information from variety of sources such as, sensors, detection devices, communication from operators etc. According to various embodiments, the information received in the input interface 3 may undergo a processing phase which that result in operation orders and/or configurations for the system. According to various embodiments, processing the received information may include multiple stages whereas one of the stages may be evaluating and decoding the received information via a set of algorithms. According to various embodiments, the needed algorithms and other programs of such nature may be stored or associated with System Algorithms and Control 6 (SAAC). According to various embodiments, the desired output of the system may be achieved by configuring the system in specific modes of operation such as supplement, pass through power, smoothing input to output etc. According to various embodiments, the algorithm, code, programs etc. needed for such operation may be located in or associated with Smoothing and Supplementing Control 4 (SASC). According to various embodiments, in accordance to the control orders the system may need to shift from one mode of operation to a different mode of operation. According to various embodiments, the High Power Control Electronics 5 may contain the needed devices, control, equipment etc. to achieve the desired shift in operation mode.

[0106] According to various embodiments, the system may have multiple storage units. One of the storage units may be an electrical storage unit 9. According to various embodiments, the electrical storage unit 9 may response rapidly. According to various embodiments, a second storage unit may be a low cost, large scale, long life storage 8 (bulk storage unit). According to various embodiments, the bulk storage unit may be a storage system that utilizes and/or is associated with a turbine technology. According to various embodiments, the bulk storage unit 8 may contain the equipment, devices, heat or other flow rates, hardware, software etc. of a storage system including PHS, CAES and LAES as detailed above.

[0107] According to various embodiments, the system may receive thermal energy from one or more thermal energy sources. According to various embodiments, the needed

equipment and/or devices such as heat exchangers, conduits, valves etc. may be located in or associated with heat to charge/augment unit 7.

[0108] According to various embodiments, the system may contain an output interfaces unit 10 which may enable the system to meet the desired output from the system. According to various embodiments, output interfaces may include the needed equipment, devices, code, controls etc. to meet the needed requirements.

[0109] As stated above the system may receive, store, utilize etc. high temperature thermal energy from one or more heat inputs 11 such as a heat input from facilities such as a gas plant, coal plant, nuclear plant, solar plant or others.

[0110] The bulk storage unit 8 may differ from one system to another with respect to different conditions, which may include topography, land size, available transmission lines customers' requirements etc. According to various embodiments, the storage media may change in respect to the selected bulk storage unit 8. According to various embodiments, the storage medium 12 may be compressed air, water, or liquid air.

[0111] A system may contain an auxiliary unit 13. According to various embodiments, the auxiliary unit may contain the needed equipment, devices, control units, control software etc. According to various embodiments, the auxiliary unit 13 may operate in synergy with and/or as a cogeneration facility to the bulk storage unit 8. According to various embodiments, the auxiliary unit 13 may be one of an air sedation unit and/or a water separation unit. In the event the auxiliary unit 13 is an air separation unit, according to various embodiments, some or all of the air components generated may be sold as air components 14 in the air components market. According to various embodiments, some or all of the air components and/or a portion or all of one or more components may be utilized, through an auxiliary heat output 15, as a cold input to the bulk storage unit 8. According to various embodiments, heat that is generated as a byproduct during the process of air separation may be utilized effectively as a cold input, through the auxiliary heat output 15, within the bulk storage unit 8.

[0112] FIG. 2 illustrates a LAES apparatus with and without an external heat source, according to one or more embodiments of the disclosed subject matter. FIG. 2 depicts a LAES whereas the LAES may operate in at least two modes of operation: a charging cycle and a discharging cycle. During the charging cycle, power may be drawn down from the grid (or any other generator) and may power a motor 56 that may drive a compressor (one or more) 52. The compressor/s may trap ambient air and compress the air in and through the LAES. According to various embodiments, during the compression process, the air may rise in both temperature and pressure. The compressed air (air stream) at the outlet of the compressor/s 52 may be directed to an Internal Waste Thermal Energy Storage 53, where it may undergo a direct or indirect heat exchange with materials that are located within suitable tanks (vessels) of Internal Waste Thermal Energy Storage 53, as known to one who is skilled in the art. According to various embodiments, the air stream may be further processed in order to achieve air liquefaction. Further processing of the air may be achieved by directing the air stream through one or more Deep Cooling 50 storage units. According to various embodiments, the air stream's temperature may be further reduced by directly or indirectly exchanging thermal energy with a material located within suitable tank/s

(vessel/s) located in more Deep Cooling 50 storage units. The materials located within the more Deep Cooling 50 storage units may have been charged with cold temperature during the discharge cycle of the LAES, as will be detailed below. The air stream at the outlet of more Deep Cooling 50 storage units may be directed to Deep Cooling and Expansion Stage (Liquefaction Stage) 54, according to various embodiments, the air stream's temperature and pressure will be decreased in Deep Cooling and Expansion Stage (Liquefaction Stage) 54, achieved by directing the air stream through an air expander (one or more). According to various embodiments, the air stream at the outlet of the Deep Cooling and Expansion Stage (Liquefaction Stage) 54 may undergo a phase change. According to various embodiments, a portion of the air stream may be liquid while a second portion may remain in a gaseous form. The air stream may be directed to a separator 51 which may separate the portion of the liquid air from the portion of the air stream that has remained a gas. Liquid air may be stored in Liquid Air Storage 55 in one or more tank (vessel). The portion of the air stream that remained in a gaseous form (byproduct) may be directed back through the LAES in order to achieve further reduction of the air stream's temperature that is being cycled through the LAES. The byproduct stream may be vented out of the LAES 60 once its cold capacity has been fully (or nearly fully) utilized in the process of the reduction of the air stream's temperature. At the end of the charging cycle, liquid air may have been generated and stored within the Liquid Air Storage 55. High temperature thermal energy that has been extracted from the air stream at the outlet of the compressor/s 52 may be stored within a suitable material within the Internal Waste Thermal Energy Storage 53. And the materials within Deep Cooling 50 storage units may be charged with temperatures that are at or near the temperature of the air stream at the outlet of Internal Waste Thermal Energy Storage 53.

[0113] During a second period the LAES may operate in discharge mode, whereas a Liquid Air Pump 56 may pump liquid air from the Liquid Air Storage 55 through the LAES. The pumped liquid air (reverse stream) may be pumped to the desired pressure, and may be directed through the Deep Cooling 50 storage units. The reversed stream may exchange thermal energy with the material that is stored within the Deep Cooling 50 storage units, thus charging the materials of the Deep Cooling 50 storage units with cold temperature to be utilized during the charging cycle. The reversed air stream (gas at this stage) may be directed to the Internal Waste Thermal Energy Storage 53, and may be charged with high temperature thermal energy. During the exchange of thermal energy, the reverse stream is charged with high temperature, and the temperature of the material stored within Internal Waste Thermal Energy Storage 53 is reduced to temperatures that are close to the reversed air stream's temperature at the outlet of the Deep Cooling 50 storage units. The air stream at the outlet of the Internal Waste Thermal Energy Storage 53 is directed to expand through an air expander 59 that may power a generator 57 that may generate electrical energy to the grid (or other consumer). In the event that there is an available external heat source (i.e. external of the heat generated from the LAES operation) then the external heat can be stored in High Temperature External Thermal Storage Unit 61 and may be utilized during the discharge cycle, in order to increase the temperature of the reversed air stream prior to entering the Expander 59.

[0114] According to one embodiment of the disclosed matter, Facility 1 may contain Auxiliary Unit 13 shown in FIG. 1. According to various embodiments, the facility 1 may be configured to operate at some period to generate air components. According to various embodiments, in order to achieve air components production there is a need to process the air. According to various embodiments, one air processing stage is to compress air to a high pressure and reduce the air's temperature. By one embodiment, this stage may be achieved via the motor 56, compressor/s 52 and Internal Waste Thermal Energy Storage 53 (all depicted in FIG. 1). The now high pressure and low temperature air stream may be processed within the auxiliary function and equipment unit 16 shown in FIG. 1. Further processing the air stream may contain further reduction of the air's temperature, which may be achieved by one or more methods known to one who is skilled in the art. According to various embodiments, further processing of the air stream may require expansion of the air stream, according to various embodiments, expansion of the air may be achieved by utilization of the expander (one or more) located in the deep cooling and expansion stage (liquefaction stage) 54 (expander not shown in FIG. 2), and/or the air expander (one or more) 59. According to various embodiments, Internal Waste Thermal Energy Storage 53 may receive an excess of high temperature thermal energy due to the extraction of high temperature thermal energy from two processes (i.e. liquefaction of air in the LAES and separation of air into components). There may be a need to cool down the Internal Waste Thermal Energy Storage 53. This may be achieved by a number of methods, as known to one who is skilled in the art. By one embodiment, cooling down Internal Waste Thermal Energy Storage 53 is achieved by passing water through Internal Waste Thermal Energy Storage 53, achieving a reduction in temperature. During this period, the water may be transformed into steam. According to various embodiments, the steam may be directed to one or more of the expanders within the LAES. In such a case there may be a need to slightly modify the expander/s, and/or to process the waste by doping, pressurizing, or other methods in order to achieve power generation from the expander (combined with a generator). According to various embodiments, modifying or processing the water is not desirable. In such a case a steam turbine may be added to Facility 1. Such a turbine will be located within and associated with auxiliary function and equipment unit 16 shown in FIG. 1. The generated electricity, from either the expander needed to expand the air stream and/or the expander and/or steam turbine driven by the steam, may be consumed by the auxiliary function and equipment unit 16 shown in FIG. 1 in order to achieve air separation. According to various embodiments, the generated electricity will be consumed by compressor/s 52 (motor 56), or other needed equipment for the process. Alternatively, according to various embodiments, the power will be dispatched to the grid or other consumer. According to various embodiments, the final product of the air separation (i.e. air components) may be sold or utilized within Facility 1. The process of charging/discharging the LAES and the process of the air separation may occur at different periods of time and or at the same period of time.

[0115] FIG. 3 illustrates a LAES apparatus with external heat source, according to one or more embodiments of the disclosed subject matter. In the charge mode of operation, as detailed above in FIG. 2, air from the environment is directed to a compressor 202 powered by electricity from the grid. The

air stream may gain an increase in pressure and temperature. The compressed air may exchange heat with the internal waste thermal energy storage unit **203** and may gain a decrease in temperature. The air may further be cooled by exchanging heat with the liquefaction and evaporation box with cold storage unit **204**. According to various embodiments, bulk portion of the air stream may undergo a phase change to liquid and will be stored in the liquid air storage **205** while the remainder cool gas stream may circulate in the system in order to improve heat transfer and thermal efficiency of the system. The remaining gas stream may be exhausted from the system through a vent **210**. At the discharge mode of operation, as detailed above in FIG. 2, liquid air from the storage unit **205** is pumped by a liquid air pump **206**. The air exchanges heat with the liquefaction and evaporation box with cold storage **204** and internal waste thermal energy storage **203** units. The air may gain an increase in temperature and may gain an increase in pressure by undergoing a phase change to gas. The air may be further heated by the external thermal energy storage unit **211**, which receives the thermal energy from an external heat source **213**. Further the air may expand through the expander **209** in order to generate power to be dispatched to the grid.

[0116] FIG. 4 illustrates a LAES apparatus with air separation auxiliary unit, according to one or more embodiments of the disclosed subject matter. In the charge mode of operation, as detailed above in FIG. 2, air from the environment is directed to a compressor **302** that may be powered by electricity from the grid. The air stream may gain an increase in pressure and temperature. The compressed air may exchange heat with the internal waste thermal energy storage unit **303** and gain a decrease in temperature. The air is further cooled by exchanging heat with the liquefaction and evaporation box with cold storage unit **304**. According to various embodiments, the bulk portion of the air stream may undergo a phase change to liquid and be stored in the liquid air storage unit **305**, while the remainder of the cool gas stream may circulate throughout the system in order to improve heat transfer and thermal efficiency of the system. The remaining gas stream may be exhausted from the system through a vent **310**. In the discharge mode of operation, as detailed above in FIG. 2, liquid air from the storage unit **305** is pumped by a liquid air pump **306**. The air may exchange heat with the liquefaction and evaporation box with cold storage **304** and internal waste thermal energy storage **303** units. Further the air may expand through the expander **309** in order to generate power to be dispatched to the grid. Thermal energy from the air separation unit **313** may be utilized by the LAES unit as detailed above in FIG. 3. According to various embodiments, thermal energy directed from the air separation unit does not have a high enough temperature to be utilized by the LAES unit but may have a high enough temperature to generate steam, in which case it may be utilized by a steam generating power cycle as detailed above. The air separation unit **313** may allow the system to cogenerate cryogen products such as liquid nitrogen **322** and oxygen **321** for further use and cold thermal energy. According to various embodiments, the products and thermal energy may be further used by the LAES facility. In various circumstances the thermal energy from the air separation unit **313** may be used to power a steam cycle such as the Rankine cycle or other similar cycles. Water is pumped by a water pump **316** from a water storage tank **317**. The water may exchange heat with the air separation unit and may evaporate to steam through the thermal energy storage/evaporator

unit **315**, which may receive heat from the air separation unit **313**. Further the steam may expand and cool down in the expander **320** in order to generate power to the grid. The air may be further cooled in the condenser unit **319** prior to entering the water tank unit **319**.

[0117] FIG. 5 illustrates a LAES apparatus with water separation auxiliary unit, according to one or more embodiments of the disclosed subject matter. In the charge mode of operation, as detailed above in FIG. 2, air from the environment is directed to a compressor **402** that may be powered by electricity from the grid. The air stream may gain an increase in pressure and temperature. The compressed air may exchange heat with the internal waste thermal energy storage unit **403** and may gain a decrease in temperature. The air may be further cooled by exchanging heat with the liquefaction and evaporation box with cold storage unit **404**, according to various embodiments, bulk portion of the air stream may undergo a phase change to liquid and be stored in the liquid air storage unit **405** while the remainder cool gas stream may circulate in the system in order to improve heat transfer and thermal efficiency of the system, the remaining gas stream may be exhausted from the system through a vent **410**. At the discharge mode of operation, as detailed above in FIG. 2, liquid air from the storage unit **405** is pumped by a liquid air pump **406**. The air may exchange heat with the liquefaction and evaporation box with cold storage **404** and internal waste thermal energy storage **403** units. The air may gain an increase in temperature and may gain an increase in pressure by undergoing a phase change to gas. The air may be further heated by the external thermal energy storage unit **411**, which receives the thermal energy from the water separation unit **413**. The air may expand through the expander **409** in order to generate power to the grid. The water separation unit **413** may allow the system to cogenerate hydrogen **415** and oxygen **416** for further use.

[0118] In one or more first embodiments, an energy processing apparatus comprises an energy input unit, a bulk storage unit, an auxiliary unit, and an energy output unit. The energy input unit contains conduits and devices for the input of electrical and/or thermal energy sources. The bulk storage unit contains a system, conduits and devices for electrical and/or thermal energy storage and release. The auxiliary unit contains a system, conduits and devices for the production of material products. The energy output unit contains conduits and devices for the output of electrical energy. The energy input unit is connected to the bulk storage unit, auxiliary unit and energy output unit by conduits and devices for the transfer of electrical and/or thermal energy. The bulk storage unit and auxiliary unit are connected by conduits and devices for the transfer of material products and/or thermal energy. The energy output unit is connected to the energy input unit and bulk storage unit by conduits and devices for the transfer of electrical energy.

[0119] In the first embodiments or any other of the disclosed embodiments, the auxiliary unit can comprise a system and devices for the production of liquid air components.

[0120] In the first embodiments or any other of the disclosed embodiments, the auxiliary unit can be an air separation unit.

[0121] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system and thermal energy from the compression of air from the air separation unit can be transferred to a hot thermal storage of the LAES system.

[0122] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system and thermal energy from the compression of air from the air separation unit can be transferred to a steam power generating cycle.

[0123] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system and liquid air products from the air separation unit can be expanded in the LAES system's discharge cycle.

[0124] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system and cold gas byproduct from the liquefaction process at the air separation unit may be used to transfer thermal energy to the LAES cold thermal storage.

[0125] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system and liquid air products from the air separation unit can be transferred to be utilized within the LAES.

[0126] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a CAES system and thermal energy from the compression of air from the air separation unit can be transferred to a hot thermal storage of the CAES system.

[0127] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a CAES system and liquid air products from the air separation unit can be expanded in the CAES system.

[0128] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a CAES system and thermal energy from the compression of air from the air separation unit can be transferred to a steam power generating cycle.

[0129] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a PHS system and thermal energy from the compression of air from the air separation unit can be transferred to a steam power generating cycle.

[0130] In the first embodiments or any other of the disclosed embodiments, the auxiliary unit can comprise a system and devices for water components production.

[0131] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system and thermal energy from the products of the water separation unit can be transferred to a hot thermal storage of the LAES system.

[0132] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system and thermal energy from the products of the water separation unit can be transferred to a steam power generating cycle.

[0133] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system and water products from the water separation unit can be combusted in the LAES system's discharge cycle.

[0134] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a CAES system and thermal energy from the products of the water separation unit can be transferred to a hot thermal storage of the CAES system.

[0135] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit is a CAES system and water products from the water separation unit can be combusted in the CAES system's discharge cycle.

[0136] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be a PHS system and thermal energy from the products of the water separation unit can be transferred to a steam power generating cycle.

[0137] In the first embodiments or any other of the disclosed embodiments, the system can further comprise an electrical storage unit.

[0138] In the first embodiments or any other of the disclosed embodiments, the auxiliary unit can be one of air and/or water separation.

[0139] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can be one of PHS, CAES and/or LAES.

[0140] In the first embodiments or any other of the disclosed embodiments, the bulk storage unit can operate in conjunction to said electrical storage unit.

[0141] In the first embodiments or any other of the disclosed embodiments, the apparatus input power can be one of high frequency and/or low frequency.

[0142] In the first embodiments or any other of the disclosed embodiments, the output power can differ from the input power by the use of one, some or all of the system's units including: the electrical storage unit, bulk storage unit, auxiliary unit, fuel combustion unit.

[0143] In the first embodiments or any other of the disclosed embodiments, the output power's magnitude can be less than, equal to or more than the input power's.

[0144] In the first embodiments or any other of the disclosed embodiments, the output power's waveform type can differ from the input power by the power stability or instability, frequency, different ac or dc waveform type.

[0145] In the first embodiments or any other of the disclosed embodiments, the system can further comprise a fuel combustion unit.

[0146] In the first embodiments or any other of the disclosed embodiments, the bulk energy storage unit and the auxiliary unit can share at least one device and/or component consisting of: a shared compressor; a shared expander; a shared High temperature thermal energy storage unit; and/or a shared Low temperature thermal energy storage unit.

[0147] In the first embodiments or any other of the disclosed embodiments, the at least one shared device and/or component can be shared in at least one period of time including simultaneously and/or separately.

[0148] In one or more second embodiments, an energy processing apparatus comprises an energy input unit, a bulk storage unit, an auxiliary unit; and an energy output unit. The energy input unit comprises conduits and devices for the input of electrical and/or thermal energy sources. The bulk storage unit comprises a system, conduits, and devices for electrical and/or thermal energy storage and release. The auxiliary unit comprises a system, conduits, and devices for the production of material products. The energy output unit comprises conduits and devices for the output of electrical energy. The energy input unit is connected to the bulk storage unit, the auxiliary unit, and the energy output unit by conduits and devices for the transfer of electrical and/or thermal energy. The bulk storage unit and auxiliary unit are connected by conduits and devices for the transfer of material products and/or thermal energy. The energy output unit is connected to the energy input unit and bulk storage unit by conduits and devices for the transfer of electrical energy.

[0149] In the second embodiments or any other of the disclosed embodiments, the auxiliary unit comprises a system and devices for the production of liquid air components.

[0150] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system, and thermal energy from the compression of air from the auxiliary unit can be transferred to a hot thermal storage of the LAES system.

[0151] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system, and thermal energy from compression of air from the auxiliary unit can be transferred to a steam power generating cycle.

[0152] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system, and liquid air products from the auxiliary unit can be expanded during a discharge cycle of the LAES system.

[0153] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system, and a cold gas byproduct from a liquefaction process of the auxiliary unit can be thermal energy that can be transferred to a LAES cold thermal storage.

[0154] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system, and liquid air products from the auxiliary unit can be transferred to be utilized within the LAES system.

[0155] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a CAES system, and thermal energy from the compression of air from the air separation unit can be transferred to a hot thermal storage of the CAES system.

[0156] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a CAES system, and liquid air products from the air separation unit can be expanded in the CAES system.

[0157] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a CAES system, and thermal energy from the compression of air from the air separation unit can be transferred to a steam power generating cycle.

[0158] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a PHS system, and thermal energy from the compression of air from the air separation unit can be transferred to a steam power generating cycle.

[0159] In the second embodiments or any other of the disclosed embodiments, the auxiliary unit can comprise a system and devices for water components production.

[0160] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system, and thermal energy from products of the water separation unit can be transferred to a hot thermal storage of the LAES system.

[0161] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system, and thermal energy from the products of the water separation unit can be transferred to a steam power generating cycle.

[0162] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a LAES system, and water products from the water separation unit can be combusted during a discharge cycle of the LAES system.

[0163] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a CAES

system, and thermal energy from products of the water separation unit can be transferred to a hot thermal storage of the CAES system.

[0164] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a CAES system, and water products from the water separation unit can be combusted during a discharge cycle of the CAES system.

[0165] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be a PHS system, and thermal energy from products of the water separation unit can be transferred to a steam power generating cycle.

[0166] In the second embodiments or any other of the disclosed embodiments, the system can further comprise an electrical storage unit.

[0167] In the second embodiments or any other of the disclosed embodiments, the auxiliary unit can be one of an air separation unit or a water separation unit.

[0168] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can be one of a PHS system, a CAES system, or a LAES system.

[0169] In the second embodiments or any other of the disclosed embodiments, the bulk storage unit can operate in conjunction with the electrical storage unit.

[0170] In the second embodiments or any other of the disclosed embodiments, input power of the apparatus can be one of high frequency or low frequency.

[0171] In the second embodiments or any other of the disclosed embodiments, output power can differ from input power based on a use of one, some or all of the system's units including: the electrical storage unit, the bulk storage unit, the auxiliary unit, and the fuel combustion unit.

[0172] In the second embodiments or any other of the disclosed embodiments, the output power's magnitude can be less than, equal to, or more than the input power's magnitude.

[0173] In the second embodiments or any other of the disclosed embodiments, the output power's waveform type can differ from the input power by the power stability or instability, frequency, different ac or dc waveform type.

[0174] In the second embodiments or any other of the disclosed embodiments, the system can further comprise a fuel combustion unit.

[0175] In the second embodiments or any other of the disclosed embodiments, the bulk energy storage unit and the auxiliary unit can share at least one shared component of: a shared compressor; a shared expander; a shared high temperature thermal energy storage unit; and/or a shared low temperature thermal energy storage unit.

[0176] In the second embodiments or any other of the disclosed embodiments, the at least one shared component can be shared during at least one period of time including simultaneously and/or separately.

[0177] In the second embodiments or any other of the disclosed embodiments, the at least one shared component can be shared simultaneously during at least one period of time including.

[0178] In the second embodiments or any other of the disclosed embodiments, the at least one shared component can be shared separately during at least one period of time.

[0179] It will be appreciated that the modules, processes, systems, and sections described above can be implemented in hardware, hardware programmed by software, software instruction stored on a non-transitory computer readable medium or a combination of the above. For example, a

method for power storage, recovery, and balancing can be implemented, for example, using a processor configured to execute a sequence of programmed instructions stored on a non-transitory computer readable medium. For example, the processor can include, but not be limited to, a personal computer or workstation or other such computing system that includes a processor, microprocessor, microcontroller device, or is comprised of control logic including integrated circuits such as, for example, an Application Specific Integrated Circuit (ASIC). The instructions can be compiled from source code instructions provided in accordance with a programming language such as Java, C++, C#.net or the like. The instructions can also comprise code and data objects provided in accordance with, for example, the Visual Basic™ language, LabVIEW, or another structured or object-oriented programming language. The sequence of programmed instructions and data associated therewith can be stored in a non-transitory computer-readable medium such as a computer memory or storage device which may be any suitable memory apparatus, such as, but not limited to read-only memory (ROM), programmable read-only memory (PROM), electrically erasable programmable read-only memory (EEPROM), random-access memory (RAM), flash memory, disk drive and the like.

[0180] Furthermore, the modules, processes, systems, and sections can be implemented as a single processor or as a distributed processor. Further, it should be appreciated that the steps mentioned above may be performed on a single or distributed processor (single and/or multi-core). Also, the processes, modules, and sub-modules described in the various figures of and for embodiments above may be distributed across multiple computers or systems or may be co-located in a single processor or system. Exemplary structural embodiment alternatives suitable for implementing the modules, sections, systems, means, or processes described herein are provided below.

[0181] The modules, processors or systems described above can be implemented as a programmed general purpose computer, an electronic device programmed with microcode, a hard-wired analog logic circuit, software stored on a computer-readable medium or signal, an optical computing device, a networked system of electronic and/or optical devices, a special purpose computing device, an integrated circuit device, a semiconductor chip, and a software module or object stored on a computer-readable medium or signal, for example.

[0182] Embodiments of the method and system (or their sub-components or modules), may be implemented on a general-purpose computer, a special-purpose computer, a programmed microprocessor or microcontroller and peripheral integrated circuit element, an ASIC or other integrated circuit, a digital signal processor, a hardwired electronic or logic circuit such as a discrete element circuit, a programmed logic circuit such as a programmable logic device (PLD), programmable logic array (PLA), field-programmable gate array (FPGA), programmable array logic (PAL) device, or the like. In general, any process capable of implementing the functions or steps described herein can be used to implement embodiments of the method, system, or a computer program product (software program stored on a non-transitory computer readable medium).

[0183] Furthermore, embodiments of the disclosed method, system, and computer program product may be readily implemented, fully or partially, in software using, for

example, object or object-oriented software development environments that provide portable source code that can be used on a variety of computer platforms. Alternatively, embodiments of the disclosed method, system, and computer program product can be implemented partially or fully in hardware using, for example, standard logic circuits or a very-large-scale integration (VLSI) design. Other hardware or software can be used to implement embodiments depending on the speed and/or efficiency requirements of the systems, the particular function, and/or particular software or hardware system, microprocessor, or microcomputer being utilized. Embodiments of the method, system, and computer program product can be implemented in hardware and/or software using any known or later developed systems or structures, devices and/or software by those of ordinary skill in the applicable art from the function description provided herein and with a general basic knowledge of energy processing and storage and/or computer programming arts.

[0184] Moreover, embodiments of the disclosed method, system, and computer program product can be implemented in software executed on a programmed general purpose computer, a special purpose computer, a microprocessor, or the like.

[0185] It is, thus, apparent that there is provided, in accordance with the present disclosure, systems, methods, and devices for power storage, recovery, and balancing. Many alternatives, modifications, and variations are enabled by the present disclosure. Features of the disclosed embodiments can be combined, rearranged, omitted, etc., within the scope of the invention to produce additional embodiments. Furthermore, certain features may sometimes be used to advantage without a corresponding use of other features. Accordingly, Applicants intend to embrace all such alternatives, modifications, equivalents, and variations that are within the spirit and scope of the present invention.

1-29. (canceled)

30. An energy processing apparatus comprising:

an energy input unit to receive input energy from an electrical and/or a thermal energy source;

a bulk storage unit to store and release electrical and/or thermal energy;

an auxiliary unit to produce one or more material products; and

an energy output unit to output electrical energy,

wherein the energy input unit is connected to the bulk storage unit, the auxiliary unit, and the energy output unit to transfer electrical and/or thermal energy,

wherein the bulk storage unit and auxiliary unit are connected to transfer the material products and/or thermal energy, and

wherein the energy output unit is connected to the energy input unit and bulk storage unit to transfer electrical energy.

31. The apparatus of claim 30, wherein the auxiliary unit is configured to produce one or more liquid air components.

32. The apparatus of claim 31,

wherein the bulk storage unit is a LAES or CAES system, and

wherein thermal energy from compression of air by the auxiliary unit is transferrable to a hot thermal storage of the LAES/CAES system and/or is transferrable to a steam power generating cycle.

33. (canceled)

- 34.** The apparatus of claim **31**, wherein the bulk storage unit is a LAES or CAES system, and wherein the liquid air products produced by the auxiliary unit are expandable during a discharge cycle of the LAES/CAES system and/or are transferrable to the LAES/CAES system.
- 35.** The apparatus of claim **31**, wherein the bulk storage unit is a LAES system, and wherein a cold gas byproduct from a liquefaction process of the auxiliary unit is transferrable to a LAES cold thermal storage.
- 36-40.** (canceled)
- 41.** The apparatus of claim **30**, wherein the auxiliary unit is configured to produce one or more water components.
- 42.** The apparatus of claim **41**, wherein the auxiliary unit is a water separation unit, and wherein thermal energy from products produced by the water separation unit is transferrable to a hot thermal storage of the bulk storage unit.
- 43.** The apparatus of claim **41**, wherein the auxiliary unit is a water separation unit, and wherein thermal energy from the products produced by the water separation unit is transferrable to a steam power generating cycle.
- 44.** The apparatus of claim **41**, wherein the auxiliary unit is a water separation unit, and wherein water products produced by the water separation unit are combustible during a discharge cycle of the bulk storage unit.
- 45-48.** (canceled)
- 49.** The apparatus of claim **30**, wherein the auxiliary unit is an air separation unit or a water separation unit.
- 50.** The apparatus of claim **49**, wherein the bulk storage unit is a PHS system, a CAES system, or a LAES system.
- 51.** The apparatus of claim **50**, further comprising an electrical storage unit, wherein the bulk storage unit is operable in conjunction with the electrical storage unit.
- 52.** The apparatus of claim **50**, wherein input power of the apparatus is high frequency or low frequency.
- 53.** The apparatus of claim **50**, wherein output power differs from input power based on a use of one or more of the system's units including: the electrical storage unit, the bulk storage unit, and the auxiliary unit.
- 54.** The apparatus of claim **53**, wherein the output power's magnitude can be less than, equal to, or more than the input power's magnitude.
- 55.** The apparatus of claim **53**, wherein the output power's waveform type is different than that of the input power.
- 56.** (canceled)
- 57.** The apparatus of claim **30**, wherein the bulk energy storage unit and the auxiliary unit share at least one shared component of:
- a shared compressor;
 - a shared expander;
 - a shared high temperature thermal energy storage unit; and/or a shared low temperature thermal energy storage unit.
- 58.** The apparatus of claim **57**, wherein the at least one shared component is shared during at least one period of time including simultaneously and/or separately.
- 59.** The apparatus of claim **58**, wherein the at least one shared component is shared simultaneously during at least one period of time.
- 60.** The apparatus of claim **58**, wherein the at least one shared component is shared separately during at least one period of time.

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