



- (51) **International Patent Classification:** Not classified
- (21) **International Application Number:**
PCT/US2014/035052
- (22) **International Filing Date:**
22 April 2014 (22.04.2014)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
61/814,348 22 April 2013 (22.04.2013) US
PCT/IB2013/054094 25 May 2013 (25.05.2013) IB
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- (81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM,

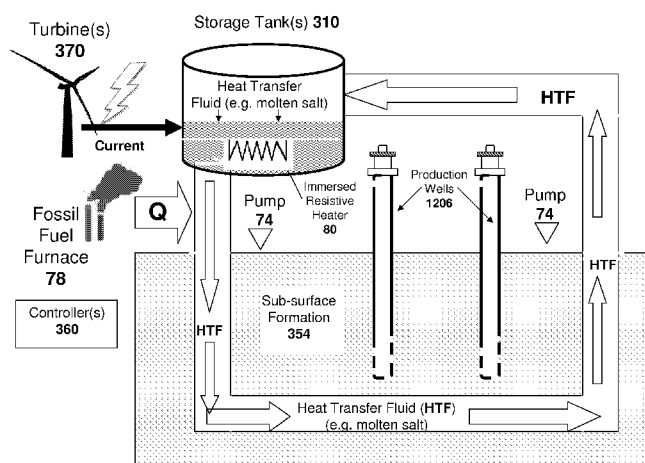
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) **Designated States** (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— without international search report and to be republished upon receipt of that report (Rule 48.2(g))

(54) **Title:** WIND-HEATED MOLTEN SALT AS A THERMAL BUFFER FOR PRODUCING OIL FROM UNCONVENTIONAL RESOURCES

**FIG. 2**

(57) **Abstract:** Embodiments of the present invention relate to heat transfer fluids (e.g. molten-salt) as a thermal buffer for heating, by thermal energy derived from wind-generated electricity, at least one of (i) a subsurface hydrocarbon-containing formation or (ii) a bed of hydrocarbon-containing rocks. During times when 5 wind is plentiful, wind electricity is used to heat the heat transfer fluid - e.g. by means of an electrically resistive heater immersed in the heat transfer fluid. At any time, thermal energy from the wind electricity may be transferred to the hydrocarbon-containing rocks or subsurface formation by the heat transfer fluid. In some embodiments, the fluid is 10 heated both by wind-generated electricity and by solar radiation. Some embodiments relate to a subsurface molten salt heater (e.g. powered by wind-generated electricity) having a non-thermally insulation portion through which molten salt flows. The heater is configured to maintain a temperature of the circulating molten salt, throughout the substantially non-thermally-insulated portion, at a temperature significantly above a 15 melt temperature of the molten salt.

WIND-HEATED MOLTEN SALT AS A THERMAL BUFFER FOR PRODUCING OIL FROM UNCONVENTIONAL RESOURCES

FIELD OF THE INVENTION

- 5 The inventions relates to methods and apparatus for heating a subsurface formation and/or a bed of rocks using electricity generated by wind.

BACKGROUND AND RELATED ART

- The world's supply of conventional crude oil is declining, and discoveries and access to new resources for are becoming more challenging. To supplement this decline and to meet the rising global demand, unconventional oils are being produced and brought to market. Sources of unconventional oils include tar sands, oil shale formations, heavy oil formations and coal formations.

- Despite the need for oil derived from unconventional sources, many policy-makers are concerned about the collateral CO₂ footprint associated with both the production of hydrocarbon fluids from unconventional sources and the exploitation of such hydrocarbon fluids.

- In order to reduce the output of greenhouse gases associated with production of oil from unconventional sources, US patent 7,104,319 discloses thermal treatment and pyrolysis of hydrocarbon-containing subsurface formations by means of solar energy and wind energy. More recently, it has been proposed in US 8,220,539 to pyrolyze kerogen by means of nuclear energy.

- One of the key issues associated with wind and solar power sources are their inherent intermittent nature. This may, for example, increase the amount of time required to produce hydrocarbon fluids from the unconventional resource, reducing their economic viability. During times when energy from the intermittent source is plentiful, it may be required to operate heaters at temperatures that exceed an optimal operating temperature thereof, in order to compensate for the lack of power at other times. Unfortunately, adopting such an approach may reduce the lifespan of the heaters, increasing project capital costs.

- 30 There is an ongoing need for methods and apparatus which facilitate the economic exploitation of renewable but intermittent energy source(s) to produce oil from unconventional resources.

SUMMARY OF EMBODIMENTS

Some embodiments of the present invention relate to a system for production of hydrocarbon fluids comprising: a. an insulated storage tank and a quantity of heat transfer fluid disposed therein, at least one electrically resistive heater(s) situated within the storage tank and immersed within the heat transfer fluid; b. a bed of hydrocarbon-containing rocks situated within an enclosure, the storage tank being located outside of the enclosure; c. a source of wind electricity configured to supply electrical power to the immersed resistive heater(s) so as to heat the heat transfer fluid within the storage tank; and d. a flow system configured to force the wind-electricity-heated heat transfer fluid received from the storage tank: (i) to flow within conduits in thermal communication with the rocks of the bed so as to heat the rocks; and (ii) to return to the storage tank for reheating.

Examples of heat-transfer fluids include molten salt, synthetic oils and supercritical fluids. Instead of, or in addition to, using wind-generated electricity to directly heat the subsurface formation by powering subsurface electrical heaters by wind-generated electricity, it is possible to indirectly heat the subsurface by means of a molten salt as a heat-transfer fluid.

At times when wind is plentiful, thermal energy derived from wind-electricity is directly transferred to the heat transfer fluid within the tank. Preferably this is accomplished forcing electrical current generated by wind through a resistive heater that is immersed within the heat transfer fluid.

When wind is less plentiful, it is possible to continue heating the formation by circulating the previously-heated heat transfer fluid within subsurface conduits. If the supply of hot molten salt is sufficient, it is possible to continuously heat the subsurface formation with minimal greenhouse gas emissions, even when wind is less plentiful.

Although the availability of energy from the intermittent energy sources fluctuates, the heat transfer fluid acts as a thermal buffer. During hours when energy is available (e.g. daylight hours when solar energy is available, or hours when ambient wind is plentiful), the intermittent energy source heats a supply of the heat transfer

fluid - for example, to temperatures of at least 300 or at least 400 or at least 500 degrees Celsius.

In some embodiments, the intermittent energy source may be augmented by one or more fossil-fuel furnaces - for example, powered by burning pyrolysis gases (e.g. methane). Nevertheless, use of the wind-electricity and/or solar radiation reduces the amount of reliance on the burning of fossil-fuels to significantly reduce carbon dioxide emissions from the in situ heat treatment process. Instead of combusting large fractions of the pyrolysis gases to provide sufficient thermal energy to produce the hydrocarbon liquids, it is possible to burn less of the pyrolysis gas, and to market the pyrolysis gas to consumers.

Preferably, the storage is thermally insulated from the ambient environment. The combination of an insulated storage tank and the inherent high heat-capacity of molten salt minimizes a temperature drop of molten salt when there is insufficient wind to maintain a molten salt temperature within the storage tank.

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Some embodiments of the present invention relate to a. an insulated storage tank and a quantity of heat transfer fluid disposed therein, at least one electrically resistive heater(s) situated within the storage tank and immersed within the heat transfer fluid; b. a bed of hydrocarbon-containing rocks situated within an enclosure, the storage tank being located outside of the enclosure; c. a source of wind electricity configured to supply electrical power to the immersed resistive heater(s) so as to heat the heat transfer fluid within the storage tank; and d. a flow system configured to force the wind-electricity-heated heat transfer fluid received from the storage tank: (i) to flow within conduits in thermal communication with the rocks of the bed so as to heat the rocks; and (ii) to return to the storage tank for reheating.

One advantage of using wind-generated electricity to indirectly heat the subsurface formation via a heat transfer fluid (i.e. as opposed to only powering subsurface electric heaters by wind electricity) is that it is relatively easy to couple wind and solar as multiple sources of intermittent power to heat the unconventional resources (i.e. a hydrocarbon subsurface formation or a bed of hydrocarbon-containing rocks) so as to produce oil therefrom. If the availability of energy from

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wind and solar sources peaks at different times, it may be possible to exploit multiple intermittent energy sources so as to reduce the overall variability.

The presently-disclosed apparatus and methods are useful for producing oil from unconventional resources in a manner that minimizes the need to burn fossil fuels. For example, there may be a reduction in the quantity of natural gas that must be combusted to heat the rocks or subsurface formation to temperatures sufficient to produce condensable hydrocarbon liquids. Instead of burning this pyrolysis-generated natural gas, it is possible to pipe this gas to consumers and to market it.

It is now disclosed a system for heating a subsurface formation comprising: a. an insulated storage tank and a quantity of heat transfer fluid disposed therein, at least one electrically resistive heater(s) situated within the storage tank and immersed within the heat transfer fluid; b. a source of wind electricity configured to supply electrical power to the immersed resistive heater(s) so as to heat the heat transfer fluid within the storage tank; and c. a flow system configured to force the wind-electricity-heated heat transfer fluid received from the storage tank: (i) to flow within subsurface conduits situated within the formation so as to heat the formation and; and (ii) to return to the storage tank for reheating.

In some embodiments, the system further comprises a fuel-burning furnace configured to further heat the heat transfer fluid as it flows from the storage tank to the subsurface conduits.

Examples of heat transfer fluids are molten salts, synthetic oils, and supercritical fluids (e.g. sulfur hexafluoride (SF₆), CO₂, methane, propane or butane).

It is now disclosed a system for production of hydrocarbon fluids comprising: a. an insulated storage tank and a quantity of heat transfer fluid disposed therein, at least one electrically resistive heater(s) situated within the storage tank and immersed within the heat transfer fluid; b. a bed of hydrocarbon-containing rocks situated within an enclosure, the storage tank being located outside of the enclosure; c. a source of wind electricity configured to supply electrical power to the immersed resistive heater(s) so as to heat the heat transfer fluid within the storage tank; and d. a flow system configured to force the wind-electricity-heated heat transfer fluid received from the storage tank: (i) to flow within conduits in thermal communication with the

rocks of the bed so as to heat the rocks; and (ii) to return to the storage tank for reheating.

In some embodiments, the conduits pass between rocks of the rock-bed.

5 In some embodiments, conduits are embedded within a wall or floor of the enclosure.

In some embodiments, the enclosure is an excavated enclosure (e.g. a pit or an impoundment).

10 In some embodiments, the system further comprises a fuel-burning furnace configured to further heat the heat transfer fluid as it flows from the storage tank to the subsurface conduits.

In some embodiments, the system further comprises a fuel-burning furnace configured to further heat the heat transfer fluid as it flows from the storage tank to the conduits in thermal communication conduits in thermal communication with the rocks of the bed.

15 In some embodiments, the system further comprises a solar furnace, and the flow system and the solar furnace are configured so that heat transfer fluid received directly or indirectly from the storage tank is (i) directly or indirectly heated by the solar furnace and (ii) forced to directly or indirectly return to the storage tank.

20 It is now disclosed a solar-wind integrated system for heating hydrocarbon-containing matter, the system comprising: a. a flow system configured to force a heat transfer fluid to flow through subsurface conduits that are (i) located within and in thermal communication with a hydrocarbon-containing subsurface formation or (ii) in thermal communication with a bed of hydrocarbon-containing rocks situated within an enclosure; b. a solar furnace configured to configured re-direct concentrated solar
25 radiation onto the heat-transfer fluid or onto an auxiliary fluid in thermal communication therewith so that at least some energy of the solar radiation is transferred to the subsurface or to the hydrocarbon-containing rocks by the heated, flowing heat-transfer fluid; and c. a wind-electricity heating apparatus configured to resistively heat the heat-transfer fluid by wind energy so that at least some wind
30 energy is transferred to the subsurface by the heated, flowing heat-transfer fluid.

In some embodiments, the wind-electricity heating apparatus comprises (i) an electrically-conductive element(s) in thermal communication with the heat transfer fluid; and (ii) a source of wind-electricity configured such that electrical current received therefrom is forced through the electrically-conductive element and
5 converted into thermal energy which is transferred to the heat transfer fluid.

In some embodiments, the solar furnace includes a solar receiver located or a near the top of a centralized tower through which the heat transfer fluid or the auxiliary fluid flows and a plurality of heliostats focused upon the centralized tower.

In some embodiments, the solar thermal heating system includes at least one
10 of a solar parabolic trough and a solar parabolic dish.

In some embodiments, the source of wind electricity includes one or more wind turbine(s).

In some embodiments, the flow system includes one or more pump(s).

A method of allocating wind electricity to an integrated wind-solar thermal
15 apparatus for heating a subsurface formation, the method comprising:

It is now disclosed a method comprising: a. heating a heat transfer fluid by solar thermal means; b. convectively heating a subsurface formation by circulating solar-thermal heated heat transfer fluid in a closed-loop through the formation; and c. resistively heating, by locally-generated wind electricity, an electrically conductive
20 material(s) in thermal communication with the subsurface formation and/or with the heat transfer fluid so as to heat the subsurface formation.

In some embodiments, the method further comprises: c. monitoring respective power-level indicators of local generation of wind electricity and of the solar-thermal-heating of the heat transfer fluid; and d. responsive to the monitoring, allocating a
25 first portion of locally-available wind electricity to the resistive heating of the electrically conductive material and a second portion of the locally-available wind electricity for remote power transmission.

It is now disclosed an integrated wind-solar thermal system for heating a subsurface formation, the system comprising: a. a solar thermal apparatus
30 operative to heat a heat transfer fluid; b. a heat transfer fluid circulation apparatus configured to force the solar-thermal-apparatus-heater heat transfer fluid to flow

through a closed loop embedded in the subsurface formation; c. a source of locally generated wind electricity operative to resistively heat an electrically conductive element(s) so as to supply thermal energy to the subsurface formation directly and/or indirectly via the flowing heat transfer fluid; d. a controller operative to allocate at least a first portion of the locally generated wind electricity to the resistive heating and to remotely transmit a second portion of the locally generated wind electricity, the controller being further operative to: i. monitor respective power-level indicators of local generation of wind electricity and of the solar-thermal-heating of the heat transfer fluid; ii. responsive to the monitoring, modifying relative fractions of the locally-generated wind electricity that are allocated to the resistive heating and to the remote transmission.

It is now disclosed an apparatus for heating a subsurface formation, the apparatus comprising: a. a subsurface molten salt heater including a substantially non-thermally-insulated portion within the subsurface formation through which molten salt flows so as to heat the subsurface formation primarily by convective heat transfer; b. a molten salt circulation system configured to supply molten salt to and to receive returning molten salt from the subsurface molten heater so as to form a closed flow loop; and c. an electrical power source configured to electrically-resistively heat an electrically conductive element(s) arranged within the subsurface molten salt heater to indirectly heat the circulating molten salt, the electrical power source and the electrically conductive element being configured to maintain a temperature of the circulating molten salt, throughout the substantially non-thermally-insulated portion, at a temperature significantly above a melt temperature of the circulating molten salt.

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maintain a temperature of the circulating molten salt, throughout a majority of the substantially non-thermally-insulated portion, within a substantially constant set-point temperature range having a lower bound that is significantly above a melt temperature of the circulating molten salt.

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10 to receive returning molten salt from the subsurface molten heater so as to form a closed flow loop; and c. an alternating current electrical power source configured to electrically-resistively heat an electrically conductive element(s) arranged within the subsurface molten salt heater to indirectly heat the circulating molten salt; the electrical power source and the electrically conductive element being configured to
15 maintain a temperature of the circulating molten salt, throughout a majority of the substantially non-thermally-insulated portion, within a substantially constant set-point temperature range having a lower bound that is significantly above a melt temperature of the circulating molten salt.

 It is now disclosed an apparatus for heating a subsurface formation, the
20 apparatus comprising: a. a subsurface molten salt heater configured to heat the subsurface formation primarily by convective heat transfer from molten salt circulating therein to the subsurface formation, b. a molten salt circulation system configured to supply molten salt to and to receive returning molten salt from the subsurface molten heater so as to form a closed flow loop; and c. an electrical power
25 source configured to electrically-resistively heat an electrically conductive element(s) arranged within the subsurface molten salt heater to indirectly heat the circulating molten salt, the apparatus being configured such that: i. the circulation system provides a sufficient molten salt flow rate so that, in the hypothetical absence of the resistive heating, a temperature difference between molten salt at upstream and
30 downstream subsurface heater locations due to the convective heat transfer from the circulating molten salt to the formation is significant; ii. the electrical power source and the electrically conductive element are configured to deliver sufficient thermal

energy to the circulating molten salt so as to maintain the upstream, downstream and a majority of intervening locations at substantially the same set-point temperature.

In some embodiments, i. the system is configured to heat the subsurface formation such that first and second thermal energy fractions are respectively
5 delivered to the subsurface formation from the circulating molten salt by enthalpy of the supplied molten salt entering the subsurface molten salt heater and by the resistive heating of the molten salt within the subsurface heater; and ii. each of the first and second fractions exceeds 0.1.

In some embodiments, the substantially constant set-point temperature
10 exceeds the melt temperature by at least 150 degrees Celsius.

In some embodiments, the apparatus is configured such that: i. an amount of thermal energy convectively transferred to the subsurface formation by circulating molten salt *en route* from an upstream location to a downstream location equals at least 20% of the liquid-phase enthalpy of the molten salt at the upstream location; ii.
15 the electrical power source and the electrically conductive are operative to maintain the molten salt for a majority of locations between the upstream and downstream location, substantially at the set-point temperature.

In some embodiments, the subsurface heater is an L-shaped heater, a U-shaped heater, a horizontally-oriented heater, a vertically-oriented heater and/or a slant-oriented heater.
20

In some embodiments, the electrically conductive element includes a ferromagnetic material having a Curie temperature substantially equal to the set-point temperature and/or significantly exceeding the molten salt melt temperature.

In some embodiments, the subsurface heater has a conduit-in-conduit
25 structure defining nested inner and outer flow regions such that: i. in the inner flow region, molten salt longitudinally flows in a first direction; ii. in the annular-shaped outer region, molten salt longitudinally flows in the opposite direction.

In some embodiments, the subsurface molten salt heater is configured to heat at least a portion of the subsurface formation by at least 100 degrees Celsius above
30 ambient temperatures

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A depicts a schematic view of an embodiment of a portion of the in situ heat treatment system for treating the hydrocarbon-containing formation.

- 5 FIGS. 1B-1D illustrated a bed of rocks within an excavated enclosure that is heated sufficiently to produce hydrocarbon fluids.

FIG. 1E illustrated an impoundment.

FIGS. 2 and 10A-10B illustrate systems for heating a subsurface formation using wind-generated electricity.

- 10 FIG. 3, 6A-6B, 7-8 and 11 illustrate integrated solar and wind-powered systems for heating a subsurface formation.

FIG. 4 illustrates a graph of the hourly average power of wind and solar irradiance for many regions of Mongolia.

- 15 FIGS. 5A-5B respectively illustrate trough-based and tower-based solar thermal systems.

FIGS. 12 is a flow-chart of methods for heating an unconventional resource.

- FIG. 13 depicts a schematic representation of an embodiment of a heater (e.g. an L-shaped heater) including heating a substantially non-thermally-insulated portion where circulating molten salt heats the subsurface formation primarily by heat convection.
- 20

FIGS. 14A-14C depicts cross sections, or portions thereof, of a heater within the subsurface formation.

FIG. 15 is a flow-chart of a routine for maintaining circulating molten salt at a set-point temperature that significantly exceeds the molten-salt freeze temperature.

- 25 FIG. 16 illustrates an embodiment whereby wind electricity is used to heat molten salt circulating within the subsurface formation.

FIG. 17 illustrates actual and hypothetical temperature profiles of molten salt circulating in a substantially non-thermally-insulated heater section within the subsurface formation according to one non-limiting example.

DETAILED DESCRIPTION OF EMBODIMENTS

Apparatus and methods for thermally heating a hydrocarbon-containing subsurface formation and/or a bed of hydrocarbon-containing rocks by one or more
5 intermittent energy sources are now disclosed. In some embodiments, the formation or rocks are sufficiently heated so as to pyrolyze kerogen and/or mobilize bitumen. Hydrocarbon fluids from pyrolysis, and/or mobilized hydrocarbon fluids may be recovered via production wells or production conduits. Examples of hydrocarbon-bearing formations include oil shale formations, coal formations, heavy oil formations
10 and tar sands formations. For the case of the bed of rocks, the rocks may be pieces of oil shale, pieces of coal, tar sands or any combination thereof, in a pit or impoundment.

FIG. 1A depicts a schematic view of an embodiment of a portion of the in situ heat treatment system for treating the hydrocarbon-containing formation. The in situ heat treatment system may include barrier wells **1200**. Barrier wells are used to form a
15 barrier around a treatment area. The barrier inhibits fluid flow into and/or out of the treatment area. Barrier wells include, but are not limited to, dewatering wells, vacuum wells, capture wells, injection wells, grout wells, freeze wells, or combinations thereof. In some embodiments, barrier wells **1200** are dewatering wells. Dewatering wells may remove liquid water and/or inhibit liquid water from entering a portion of the
20 formation to be heated, or to the formation being heated. In the embodiment depicted in FIG. 1A, the barrier wells **1200** are shown extending only along one side of heater sources **1202**, but the barrier wells typically encircle all heat sources **1202** used, or to be used, to heat a treatment area of the formation.

25 Heat sources **1202** are placed in at least a portion of the formation. Heat sources **1202** may include heaters such as insulated conductors, conductor-in-conduit heaters, surface burners, flameless distributed combustors, and/or natural distributed combustors. Heat sources **1202** may also include other types of heaters. Heat sources **1202** provide heat to at least a portion of the formation to heat hydrocarbons in the
30 formation. Energy may be supplied to heat sources **1202** through supply lines **1204**. Supply lines **1204** may be structurally different depending on the type of heat source or heat sources used to heat the formation. Supply lines **1204** for heat sources may

transmit electricity for electric heaters, may transport fuel for combustors, or may transport heat exchange fluid that is circulated through pipes in the formation.

When the formation is heated, the heat input into the formation may cause expansion of the formation and geomechanical motion. The heat sources may be turned on before, at the same time, or during a dewatering process. Computer simulations may model formation response to heating. The computer simulations may be used to develop a pattern and time sequence for activating heat sources in the formation so that geomechanical motion of the formation does not adversely affect the functionality of heat sources, production wells, and other equipment in the formation.

Heating the formation may cause an increase in permeability and/or porosity of the formation. Increases in permeability and/or porosity may result from a reduction of mass in the formation due to vaporization and removal of water, removal of hydrocarbons, and/or creation of fractures. Fluid may flow more easily in the heated portion of the formation because of the increased permeability and/or porosity of the formation. Fluid in the heated portion of the formation may move a considerable distances through the formation because of the increased permeability and/or porosity. The considerable distance may be over 1000 m depending on various factors, such as permeability of the formation, properties of the fluid, temperature of the formation, and pressure gradient allowing movement of the fluid. The ability of fluid to travel considerable distance in the formation allows production wells **1206** to be spaced relatively far apart in the formation.

Production wells **1206** are used to remove formation fluid from the formation. In some embodiments, production well **1206** includes a heat source. The heat source in the production well may heat one or more portions of the formation at or near the production well. In some in situ heat treatment process embodiments, the amount of heat supplied to the formation from the production well per meter of the production well is less than the amount of heat applied to the formation from a heat source that heats the formation per meter of the heat source. Heat applied to the formation from the production well may increase formation permeability adjacent to the production

well by vaporizing and removing liquid phase fluid adjacent to the production well and/or by increasing the permeability of the formation adjacent to the production well by formation of macro and/or micro fractures.

- 5 More than one heat source may be positioned in the production well. A heat source in a lower portion of the production well may be turned off when superposition of heat from adjacent heat sources heats the formation sufficiently to counteract benefits provided by heating the formation with the production well. In some embodiments, the heat source in an upper portion of the production well may remain
10 on after the heat source in the lower portion of the production well is deactivated. The heat source in the upper portion of the well may inhibit condensation and reflux of formation fluid.

- In some embodiments, the heat source in production well **1206** allows for vapor
15 phase removal of formation fluids from the formation. Providing heating at or through the production well may: (1) inhibit condensation and/or refluxing of production fluid when such production fluid is moving in the production well proximate the overburden, (2) increase heat input into the formation, (3) increase production rate from the production well as compared to a production well without a heat source, (4)
20 inhibit condensation of high carbon number compounds (C₆ hydrocarbons and above) in the production well, and/or (5) increase formation permeability at or proximate the production well.

- Subsurface pressure in the formation may correspond to the fluid pressure
25 generated in the formation. As temperatures in the heated portion of the formation increase, the pressure in the heated portion may increase as a result of thermal expansion of in situ fluids, increased fluid generation and vaporization of water. Controlling rate of fluid removal from the formation may allow for control of pressure in the formation. Pressure in the formation may be determined at a number of
30 different locations, such as near or at production wells, near or at heat sources, or at monitor wells.

In some hydrocarbon-containing formations, production of hydrocarbons from the formation is inhibited until at least some hydrocarbons in the formation have been mobilized and/or pyrolyzed. Formation fluid may be produced from the formation when the formation fluid is of a selected quality. In some embodiments, the selected
5 quality includes an API gravity of at least about 20⁰, 30⁰, or 40⁰. Inhibiting production until at least some hydrocarbons are mobilized and/or pyrolyzed may increase conversion of heavy hydrocarbons to light hydrocarbons. Inhibiting initial production may minimize the production of heavy hydrocarbons from the formation. Production of substantial amounts of heavy hydrocarbons may require expensive equipment
10 and/or reduce the life of production equipment.

In some hydrocarbon-containing formations, hydrocarbons in the formation may be heated to mobilization and/or pyrolysis temperatures before substantial permeability has been generated in the heated portion of the formation. An initial lack
15 of permeability may inhibit the transport of generated fluids to production wells **1206**. During initial heating, fluid pressure in the formation may increase proximate heat sources **1202**. The increased fluid pressure may be released, monitored, altered, and/or controlled through one or more heat sources **1202**. For example, selected heat sources **1202** or separate pressure relief wells may include pressure relief valves that
20 allow for removal of some fluid from the formation.

In some embodiments, pressure generated by expansion of mobilized fluids, pyrolysis fluids or other fluids generated in the formation may be allowed to increase although an open path to production wells **1206** or any other pressure sink may not
25 yet exist in the formation. The fluid pressure may be allowed to increase towards a lithostatic pressure. Fractures in the hydrocarbon-containing formation may form when the fluid approaches the lithostatic pressure. For example, fractures may form from heat sources **1202** to production wells **1206** in the heated portion of the formation. The generation of fractures in the heated portion may relieve some of the
30 pressure in the heated portion. Pressure in the formation may have to be maintained below a selected pressure to inhibit unwanted production, fracturing of the overburden or underburden, and/or coking of hydrocarbons in the formation.

After mobilization and/or pyrolysis temperatures are reached and production from the formation is allowed, pressure in the formation may be varied to alter and/or control a composition of formation fluid produced, to control a percentage of condensable fluid as compared to non-condensable fluid in the formation fluid, and/or to control an API gravity of formation fluid being produced. For example, decreasing pressure may result in production of a larger condensable fluid component. The condensable fluid component may contain a larger percentage of olefins.

10 In some in situ heat treatment process embodiments, pressure in the formation may be maintained high enough to promote production of formation fluid with an API gravity of greater than 20⁰. Maintaining increased pressure may reduce or eliminate the need to compress formation fluids at the surface to transport the fluids in collection conduits to treatment facilities.

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Maintaining increased pressure in a heated portion of the formation may surprisingly allow for production of large quantities of hydrocarbons of increased quality and of relatively low molecular weight. Pressure may be maintained so that formation fluid produced has a minimal amount of compounds above a selected carbon number. The selected carbon number may be at most 25, at most 20, at most 12, or at most 8. Some high carbon number compounds may be entrained in vapor in the formation and may be removed from the formation with the vapor. Maintaining increased pressure in the formation may inhibit entrainment of high carbon number compounds and/or multi-ring hydrocarbon compounds in the vapor. High carbon number compounds and/or multi-ring hydrocarbon compounds may remain in a liquid phase in the formation for significant time periods. The significant time periods may provide sufficient time for the compounds to pyrolyze to form lower carbon number compounds.

30 Generation of relatively low molecular weight hydrocarbons is believed to be due, in part, to autogenous generation and hydrogenation in a portion of the hydrocarbon-containing formation. For example, maintaining an increased pressure

may force hydrogen generated during pyrolysis into the liquid phase within the formation. Heating the portion to a temperature in a pyrolysis temperature range may pyrolyze hydrocarbons in the formation to generate liquid phase pyrolyzation fluids. The generated liquid phase pyrolyzation fluids components may include double bonds and/or radicals. Hydrogenation may reduce double bonds of the generated pyrolyzation fluids, thereby reducing a potential for polymerization or formation of long chain compounds from the generated pyrolyzation fluids. In addition, hydrogenation may also neutralize radicals in the generated pyrolyzation fluids. Hydrogenation in the liquid phase may inhibit the generated pyrolyzation fluids from reacting with each other and/or with other compounds in the formation.

Formation fluid produced from production wells **1206** may be transported through collection piping **1208** to treatment facilities **1210**. Formation fluids may also be produced from heat sources **1202**. For example, fluid may be produced from heat sources **1202** to control pressure in the formation adjacent to the heat sources. Fluid produced from heat sources **1202** may be transported through tubing or piping to collection piping **1208** or the produced fluid may be transported through tubing or piping directly to treatment facilities **1210**. Treatment facilities **1210** may include separation units, reaction units, upgrading units, fuel cells, turbines, storage vessels, and/or other systems and units for processing produced formation fluids. The treatment facilities may form transportation fuel from at least a portion of the hydrocarbons produced from the formation. In some embodiments, the transportation fuel may be jet fuel, such as JP-8.

Formation fluid may be hot when produced from the formation through the production wells. Hot formation fluid may be produced during solution mining processes and/or during in situ heat treatment processes. In some embodiments, electricity may be generated using the heat of the fluid produced from the formation. Also, heat recovered from the formation after the in situ process may be used to generate electricity. The generated electricity may be used to supply power to the in situ heat treatment process. For example, the electricity may be used to power heaters, or to power a refrigeration system for forming or maintaining a low temperature

barrier. Electricity may be generated using a Kalina cycle, Rankine cycle or other thermodynamic cycle. In some embodiments, the working fluid for the cycle used to generate electricity is aqua ammonia.

FIGS. 1B-1D relate to the situation where a bed of rocks within an excavated enclosure is heated - e.g. sufficiently to produce hydrocarbon fluids. In the example of FIG. 1B, at least a significant portion, or at least a majority, or at least a significant majority, or substantially an entirety of the enclosed volume of the enclosure is filled by the bed of rocks. A plurality of elongated heaters are deployed within the pit. Thermal energy is transferred from the heaters to the bed of rocks and heats the rocks. For example, the hydrocarbon-containing rocks may be sufficiently heated to pyrolyze kerogen and/or bitumen thereof so as to yield formation fluids that are recovered via the production conduits. The formation fluids may include water or condensable hydrocarbon liquids or hydrocarbon gases. The transfer of heat within the bed of rocks may be substantially by thermal conduction, although some convective and radiative heat transfer also occurs.

In the example of FIG. 1B, the heaters are vertical heaters; in the example of FIG. 1C the heaters are horizontal heaters. FIGS 1A-1C are side views of a pit -- FIG. 1D is a top view of the pit.

FIG. 1E is a view of an impoundment. In some embodiments, walls of a container or an impoundment receives structure support from earth or soil -- for example, a presence of earth or soil may obviate the need for thick supporting walls, thereby saving capital costs. The earth or soil may provide horizontal support to a wall of the impoundment or of a container.

The enclosure may be lined with one or more of: (i) an impermeable liner (ii) a thermally insulating liner (iii) clay and (iv) a ceramic liner. For example, the pit may be constructed below grade level using earth-moving equipment. The pit may be lined with clay, such as bentonite, to render the walls and bottom substantially impermeable to liquids and vapors.

This is not a requirement. Alternatively, instead of lining the pit (e.g. with clay and/or ceramics), it may be desirable to choose a location where the surface geology is a naturally-occurring clay so that lining the pit is unnecessary.

In some embodiments, the vertical heaters are conduit-in-conduit heaters which is one example of an advection-based heater. In one example of a vertical conduit-in-conduit heater, (i) a hot heat transfer fluid flows downwards into the bed of rocks through an inner or core portion of the heater and (ii) exits the bed of rocks by
5 flowing upwards through an outer annular-shaped portion of the heater. In another example of a conduit-in-conduit heater, (i) a hot heat transfer fluid flows downwards into the bed of rocks through an outer annular-shaped portion of the heater and (ii) exits the bed of rocks by flowing upwards through an inner or core portion of the heater. The heat transfer fluid may be a gas, such as carbon dioxide, nitrogen, flue gas,
10 superheated steam, natural gas, mixtures thereof and/or others; or the heat transfer fluid may be a liquid, such as a high temperature oil like Dow Therm A, or a molten salt, such as a nitrate eutectic such as HiTec Solar Salt (60:40 Na:K NO₃), or binary or tertiary mixtures of carbonate molten salts, or binary or tertiary mixtures of chloride molten salts, or others. The temperature of the heat transfer fluid may need
15 to be in the range of about 400 to 700 °C to pyrolyze the hydrocarbon material in the enclosure.

Throughout the text of the present disclosure and in FIGS. 2-17, various embodiments relating to the use of wind electricity and/or solar radiation to heat a heat transfer fluid. The heat transfer fluid is forced to flow within conduits that pass
20 through subsurface conduits. Although explicitly illustrated, it is now disclosed that for any embodiment described with respect to heating the subsurface, the wind-heated and/or solar-heated heat transfer fluid, in alternate embodiments, could also flow through conduits in thermal communication with the bed of rocks - e.g. passing through the bed of rocks.

FIG. 2 is a block diagram of a system for heating a subsurface formation **354** using wind-generated electricity. A tank of heat transfer fluid (e.g. a liquid or subcritical fluid) is maintained with thermally-insulated storage tank(s) **310**. Within the tank are one or resistive heaters that are immersed within the fluid. The resistive heaters are powered by wind-electricity supplied by turbine(s) **370**. One or more
30 pump(s) **74** are used to force the heat-transfer fluid to flow through subsurface conduits so as to heat the subsurface. When sufficient thermal energy is transferred to the subsurface **354**, hydrocarbon fluids produced from the hydrocarbon-containing

subsurface (e.g. pyrolysis formations fluids or mobilized hydrocarbon fluids) may recovered via production well(s) **1206**.

In some embodiments, it may be desirable to further heat the heat transfer fluid in a fossil fuel furnace **78** after the heat transfer fluid exits the storage tank **310** *en route* to the subsurface conduits. For example, it may be desired for the heat transfer fluid to enter the subsurface conduit at a temperature of around 500 degree Celsius. Instead of maintaining the heat transfer fluid within the storage tanks at 500 degrees Celsius, it may be desirable to maintain the heat transfer fluid at a lower temperature (e.g. around 400 degrees Celsius) to minimize heat-losses from the reservoir within tanks(s) **310** to the environment - e.g. when there is a decrease in the availability of wind-generated electricity.

Although some fossil fuel (e.g. pyrolysis gases such as hydrogen gas or natural gas) may be combusted in fossil fuel furnace **76**, the system of FIG. 2 may allow for reduction or elimination of carbon dioxide emissions from the in situ heat treatment process.

In some embodiments, furnace **76** may be used when wind and/or solar are not available.

FIG. 3 is a block diagram of an integrated solar and wind-powered system **300A** for heating a subsurface formation **354** – for example, a hydrocarbon-bearing formation such as oil shale, tar sands, coals, bitumen-containing carbonates, gilsonite, or heavy oil - containing diatomite. In one non-limiting example, the subsurface formation **354** is heated by a heat transfer fluid (e.g. molten salt, synthetic oil or molten metal) which flows within the subsurface (e.g. within subsurface conduit assembly **360**) so that thermal energy is transferred from the flowing hot heat transfer fluid to the subsurface formation.

One salient feature of integrated system **300A** of FIG. 3 is that multiple sources of ‘intermittent energy’ are employed. In the particular example of FIG. 2, concentrated-solar (CS) apparatus **320** is configured for the heating of heat transfer fluid (e.g. flowing heat transfer fluid) by concentrated insolation/solar radiation. In addition, wind-generated electrical current (e.g. electrical current having a power level that is temporally correlated to an ambient wind intensity and/or direction) is supplied to resistive heater(s) **330** in thermal communication with the heat transfer

fluid. In addition, some portion of pyrolysis gases from the in situ process may be utilized to augment the intermittent energy sources. As illustrated in FIG. 3, integrated system **300A** includes wind-to-electricity conversion apparatus (e.g. wind turbine(s) **370**) for converting kinetic energy of wind into electrical current which is supplied to
5 resistive heater(s) **330**.

In different embodiments, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of the thermal energy of system **300A** and/or of the thermal energy required to heat the subsurface formation to produce hydrocarbon fluids (e.g. to heat subsurface formation to a pyrolysis temperature) is supplied by the combination of
10 wind and solar energy. In some embodiments, first and second fractions of the thermal energy required to heat the subsurface formation to produce hydrocarbon fluids from the subsurface formation are supplied respectively by solar radiation and by wind-generated electricity, and both the first and second fractions have values between 0.2 and 0.8. In this sense, it may be said that both solar energy and wind
15 energy play 'significant roles' in producing the hydrocarbon fluids.

Wind and solar energy are so-called 'intermittent' energy sources. Because local wind intensity and/or direction may fluctuate in time, the power level of resistive heating element **330(s)**, and the rate at which heat transfer fluid is heated by wind energy, may fluctuate in a manner that is temporally correlated with wind intensity
20 and/or direction. Solar radiation is intermittent as well – solar radiation/insolation is variable both predictably (diurnal variation) and unpredictably, due to cloud cover, dust, or other reasons.

Not wishing to be bound by any theory, it is noted that the integrated system **300A** of FIG. 3 may rely on multiple intermittent energy sources each of which has a relatively low CO₂ footprint. Because of the high heat capacity and low thermal conductivity of the hydrocarbon bearing formation, intermittency with timescales
25 smaller than 1 day may not have any substantial impact on the heating of the formation. In this case, wind power and solar heat may be used to augment each other in cases of intermittency of one of the sources.

30 If the intermittency between the two sources is uncorrelated, use of both wind and solar may increase the power reliability of the whole system. FIG. 4 illustrates a graph of the hourly average power of wind and solar irradiance for many regions of

Mongolia. In some embodiments, during the day, solar power may be used as the main heating source and wind power may be used for auxiliary electricity needs or to augment the heating.

5 During the evening when there is no solar power, wind power may be used for flow assurance in the molten salt piping system. This may be accomplished by using electricity to heat trace the surface piping, direct resistive heating of the molten salt surface and subsurface piping, providing electricity to the pumps to maintain circulation, heating of electric heaters immersed in the molten salt tanks or
10 combinations of each. During the evening when there is no solar power, wind power may be used to augment the heating of the subsurface by direct electric resistive heating of the molten salt subsurface piping or by providing electricity to electric heaters embedded in the molten salt tanks. To maintain a constant power load to the heaters, the effective land area for the wind farm may be 4 to 5 times larger than the
15 effective land area for the solar farm.

Reference is made, once again, to FIG. 3. System **300A** of FIG. 3 also includes heat transfer fluid storage apparatus **310** – for example, one or more storage vessels or tanks. In one non-limiting example, resistive heater(s) **330** are immersed in heat transfer fluid within vessel(s) **310**. Although storage apparatus **310** is illustrated in
20 FIG. 2 as being located above the surface, this is not a limitation.

In some embodiments, hot heat transfer fluid is sent from storage apparatus **310** into subsurface formation, so as to heat the subsurface formation. After circulating within subsurface formation, the heat transfer fluid may return to storage apparatus **310**. Within subsurface formation **354**, hot heat transfer fluid may flow through a
25 subsurface conduit assembly **360** (e.g. embedded within a wellbore), or directly through a wellbore within the formation. One example of a subsurface conduit assembly **360** is closed-loop piping. Heat transfer fluid may flow at any depth within the subsurface formation, for example, at least 50 meters or at least 100 meters or at least 150 meters or at least 250 meters beneath the surface. In different embodiments,
30 this flow may be sustained over a period of time (e.g. weeks, months or years) – for example, to produce hydrocarbon fluids from the subsurface hydrocarbon-bearing formation.

As a consequence of this transfer of thermal energy from the heat transfer fluid, the temperature of the storage fluid may decrease – in FIG. 3, the temperature decreases from $T_{\text{PRE-FORM}}$ to $T_{\text{POST-FORM}}$ ('FORM' is an abbreviation for 'formation').

As noted above, concentrated-solar (CS) apparatus **320** may be configured to
5 heat heat-transfer fluid by concentrated insolation/solar radiation. In some embodiments, solar radiation is concentrated on a 'target(s)' that is thermally coupled to the heat transfer fluid. In one example, heat transfer fluid flows through a conduit located at a focus point of an elongated parabolic mirror of a solar trough (see FIG. 5A). In another non-limiting example (see FIG. 5B), a plurality of heliostats may be
10 focused upon a target at or near the top of one or more solar towers. For example, heat transfer fluid may flow through a pipe located at or near the top of the solar tower, and solar radiation concentrated by the heliostats may heat up on 'target object' (e.g. a pipe or a panel within which pipe(s) are located) in thermal contact with flowing heat transfer fluid. In another example, a Fresnel solar concentrator (NOT SHOWN) may
15 be used.

In the non-limiting example of FIG. 3, a temperature of the storage fluid increases from a first temperature $T_{\text{BEFORE-CS}}$ (i.e. a temperature before being heated by concentrated solar (CS) radiation) to a second temperature $T_{\text{AFTER-CS}}$ within concentrated-solar (CS) apparatus **320**.

20 In the non-limiting example of FIG. 3, (i) heat transfer fluid flows from storage apparatus **310** into subsurface heater/fluid conduit assembly **360** without passing through CS apparatus **320 en route**; and (ii) heat transfer fluid which exits CS apparatus **320** is first sent back to storage apparatus **310** rather than being sent first to subsurface heater/fluid conduit assembly **360**. This is not a limitation. In other
25 examples, heat transfer fluid which exits CS apparatus **320** may be force through subsurface heater/fluid conduit assembly **360** before returning to storage apparatus **310**.

FIGS. 6A-6B are schematic flow charts illustrating how electricity from wind turbines may be used in combination with solar powered molten salt heating system.
30 In both examples, electricity generated by wind power may be used to supply the electrical needs of field equipment and/or resistive heating of the hydrocarbon bearing

formation. In the example of FIG. 6A, wind electricity maybe used for startup/flow assurance and/or to supply auxiliary electrical demand.

FIG. 6B is a block diagram of an integrated solar and wind-powered system **300B** for heating subsurface formation **354**. In contrast to the system **300A** of FIG. 3, in the system **300B** of FIG. 6B wind-generated electricity is supplied to subsurface resistive heaters **332** configured to deliver thermal energy to heat transfer fluid (e.g. molten salt) flowing within the subsurface formation. In some embodiments, this may be useful for at least partly counteracting the heat losses suffered by the heat transfer fluid (i.e. to the subsurface formation) as it circulates within the subsurface. In one non-limiting example, this may be useful for maintaining a substantially constant temperature along a length of a heater – e.g. a conduit-in-conduit heater – within which the heater transfer fluid flows.

In the system **300C** of FIG. 8, a first portion of the wind-generated electricity is supplied to surface or near-surface **330** resistive heaters, while a second portion of the wind-generated electricity is supplied to subsurface **332** resistive heaters.

FIG. 9 is a flow chart of a heating method which may be carried out, for example, in system **300C** of FIG. 8. In step **S101**, surface or near-surface resistive heaters (for example, FIGS. 10A-10B) ‘immersed’ heaters **330** or any other resistive heater) are supplied with wind electricity so as to heat the heat transfer fluid (e.g. within a storage tank). This heat transfer fluid may be circulated, in step **S105**, within the subsurface formation. In step **S109**, wind electricity is supplied to subsurface resistive heaters **332** so as to deliver thermal energy to circulating heat transfer fluid.

In some embodiments, the fraction of thermal energy provided by the surface or near-surface resistive heaters may exceed that supplied by the subsurface resistive heaters.

Not wishing to be bound by theory, one advantage of the system of FIGS. 2-3 is that there is no need to supply frequency and amplitude regulated alternating current electricity – the frequency and/or amplitude may fluctuate and/or be unregulated.

FIG. 11 illustrates a system whereby a first fraction of locally-generated wind electricity is used to heat the formation **354** and a second fraction is transmitted to a remote location via transmission lines. In various embodiments, the first and second

fraction may fluctuate in time in accordance with a number of factors, including but not limited to a local wind speed (i.e. at higher wind speeds a greater fraction is transmitted), local cloud cover (i.e. on a cloudy days a lesser fraction is transmitted and a greater fraction is used to heat the subsurface formation, a remote demand for
5 electricity (i.e. on days of greater demand less wind electricity is used to resistively-heat the subsurface formation).

FIG. 12 relates to a routine for operating a system where the heat transfer fluid is heated both by wind electricity and by solar radiation. In the example of FIG. 12, excess electricity may be exported to the electric grid.

10 Reference is now made to FIGS. 13-17.

In some embodiments, it is possible to perform an initial start-up using wind electricity - for example, before pyrolysis gases are available for combustion. At a later stage, once pyrolysis gases are available, electricity from wind-turbines (i.e. that were formerly used to heat the subsurface) may be sold to the grid.

15 Embodiments of the present invention relate to self-regulating molten-salt heating apparatus operative to heat a subsurface formation primarily by convective heat transfer from molten salt circulating within the subsurface formation in a closed flow loop. The apparatus includes an electrical power source (i.e. any power source including but not limited to 'renewal energy sources' such as wind sources)
20 configured to deliver electrical current to a subsurface electrically conductive element(s) (for example, a wall of a conduit through which molten salt flows) in thermal communication with the molten salt. Thermal energy generated by electric resistive heating of the subsurface electrically conductive element(s) may be transferred to the circulating molten salt. In this way, it may be said that the electrical
25 power source 'indirectly' heats the circulating molten salt.

The Currie heater may be supplied by wind electricity or electricity from any other sources. In some embodiments, the Currie heater is a downhole Currie heater.

In some embodiments (see FIGS. 13-17) to provide a 'self-regulating' system so as to maintain a molten salt temperature that is 'significantly above' the molten-salt-freezing temperature. Towards this end, sufficient electrical current may need to
30 be supplied for counteracting heat losses, to the subsurface formation, suffered by the flowing molten salt.

In some embodiments, when the temperature of the circulating molten salt significantly exceeds a molten salt melt temperature, sufficient electrical current is delivered to the electrically conductive element so that the rate at which thermal energy is transferred to the circulating molten salt from the resistively-heated electrically conductive element(s) substantially balances the rate of heat transfer (i.e. primarily due to heat convection) from the circulating molten salt to the subsurface formation.

In this manner, it is possible to configure a subsurface heater such that instead of observing a significant temperature decrease along the length of the heater, the molten salt temperature may remain both significantly above the molten salt melt temperature as well as substantially constant along the heater length.

In some embodiments, the electrically conductive element(s) are made of a ferromagnetic material.

FIG. 13 depicts a schematic representation of an embodiment of a heater (e.g. an L-shaped heater) including heating a substantially non-thermally-insulated portion where circulating molten salt heats the subsurface formation primarily by heat convection.

FIGS. 14A-14C depicts cross sections, or portions thereof, of a heater (e.g. the heater of FIG. 13) within the subsurface formation.

FIG. 15 is a flow-chart of a routine for maintaining circulating molten salt at a set-point temperature that significantly exceeds the molten-salt freeze temperature.

FIG. 16 illustrates an embodiment whereby wind electricity is used to heat molten salt circulating within the subsurface formation.

FIG. 17 illustrates actual and hypothetical temperature profiles of molten salt circulating in a substantially non-thermally-insulated heater section within the subsurface formation according to one non-limiting example.

The present invention has been described using detailed descriptions of embodiments thereof that are provided by way of example and are not intended to limit the scope of the invention. The described embodiments comprise different features, not all of which are required in all embodiments of the invention. Some embodiments of the present invention utilize only some of the features or possible

combinations of the features. Variations of embodiments of the present invention that are described and embodiments of the present invention comprising different combinations of features noted in the described embodiments will occur to persons of the art.

WHAT IS CLAIMED IS:

1. A system for heating a subsurface formation comprising:
 - a. an insulated storage tank and a quantity of heat transfer fluid disposed therein, at least one electrically resistive heater(s) situated within the storage tank and immersed within the heat transfer fluid;
 - b. a source of wind electricity configured to supply electrical power to the immersed resistive heater(s) so as to heat the heat transfer fluid within the storage tank; and
 - c. a flow system configured to force the wind-electricity-heated heat transfer fluid received from the storage tank: (i) to flow within subsurface conduits situated within the formation so as to heat the formation and; and (ii) to return to the storage tank for reheating.
2. The system of claim 1, further comprising a fuel-burning furnace configured to further heat the heat transfer fluid as it flows from the storage tank to the subsurface conduits.
3. The system of any of claims 1-2 wherein the heat transfer fluid is molten salt.
4. The system of any of claims 1-2 wherein the heat transfer fluid is synthetic oil.
5. The system of any of claims 1-2 wherein the heat transfer fluid is a supercritical fluid.
6. A system for production of hydrocarbon fluids comprising:
 - a. an insulated storage tank and a quantity of heat transfer fluid disposed therein, at least one electrically resistive heater(s) situated within the storage tank and immersed within the heat transfer fluid;

b. a bed of hydrocarbon-containing rocks situated within an enclosure, the storage tank being located outside of the enclosure;

c. a source of wind electricity configured to supply electrical power to the immersed resistive heater(s) so as to heat the heat transfer fluid within the storage tank; and

d. a flow system configured to force the wind-electricity-heated heat transfer fluid received from the storage tank: (i) to flow within conduits in thermal communication with the rocks of the bed so as to heat the rocks; and (ii) to return to the storage tank for reheating.

7. The system of claim 6 wherein the conduits pass through rocks of the rock-bed.

8. The system of any of claims 6-7 wherein the conduits are embedded within a wall or floor of the enclosure.

9. The system of any of claims 6-8 wherein the enclosure is an excavated enclosure.

10. The system of claim 9 the excavated enclosure is a pit or an impoundment.

11. The system of any of claims 6-10, further comprising a fuel-burning furnace configured to further heat the heat transfer fluid as it flows from the storage tank to the subsurface conduits.

12. The system of any of claims 6-11 wherein the heat transfer fluid is molten salt.

13. The system of any of claims 6-11 wherein the heat transfer fluid is synthetic oil.

14. The system of any of claims 6-11 wherein the heat transfer fluid is a supercritical fluid.

5

15. The system of any of claims 5-14, further comprising a fuel-burning furnace configured to further heat the heat transfer fluid as it flows from the storage tank to the conduits in thermal communication with the rocks of the bed.

10

16. The system of any previous claim further comprising a solar furnace, the flow system and the solar furnace being configured so that heat transfer fluid received directly or indirectly from the storage tank is (i) directly or indirectly heated by the solar furnace and (ii) forced to directly or indirectly return to the storage tank.

15

17. A solar-wind integrated system for heating hydrocarbon-containing matter, the system comprising:

20 a. a flow system configured to force a heat transfer fluid to flow through subsurface conduits that are (i) located within and in thermal communication with a hydrocarbon-containing subsurface formation or (ii) in thermal communication with a bed of hydrocarbon-containing rocks situated within an enclosure;

25 b. a solar furnace configured to re-direct concentrated solar radiation onto the heat-transfer fluid or onto an auxiliary fluid in thermal communication therewith so that at least some energy of the solar radiation is transferred to the subsurface or to the hydrocarbon-containing rocks by the heated, flowing heat-transfer fluid; and

30 c. a wind-electricity heating apparatus configured to resistively heat the heat-transfer fluid by wind energy so that at least some energy of wind energy is transferred to the subsurface by the heated, flowing heat-transfer fluid

18. The system of claim 17 wherein the wind-electricity heating apparatus comprises (i) an electrically-conductive element(s) in thermal communication with the heat transfer fluid; and (ii) a source of wind-electricity configured such that electrical
5 current received therefrom is forced through the electrically-conductive element and converted into thermal energy which is transferred to the heat transfer fluid.

19. The system of any of claims 17-18 wherein the heat transfer fluid is molten salt.

10 20. The system of any of claims 17-18 wherein the heat transfer fluid is synthetic oil.

21. The system of any of claims 17-18 wherein the heat transfer fluid is a supercritical fluid.

22. The system of any of claims 16-21 wherein the solar furnace includes a solar
15 receiver located or a near the top of a centralized tower through which the heat transfer fluid or the auxiliary fluid flows and a plurality of heliostats aimed at the centralized tower.

23. The system of any of claims 16-21 wherein the solar thermal heating system
20 includes at least one of a solar parabolic trough and a solar parabolic dish.

24. The system of any preceding claim wherein the source of wind electricity includes one or more wind turbine(s).

25 25. The system of any previous claim wherein the flow system includes one or more pump(s).

26. Use of the system of any of preceding claim to produce hydrocarbon fluids by pyrolyzing kerogen or bitumen or by mobilizing bitumen.

27. A method of allocating wind electricity to an integrated wind-solar thermal apparatus for heating a subsurface formation, the method comprising:

- 5 a. heating a heat transfer fluid by solar thermal means;
- b. convectively heating a subsurface formation by circulating solar-thermal heated heat transfer fluid in a closed-loop through the formation; and
- c. resistively heating, by locally-generated wind electricity, an electrically
10 conductive material(s) in thermal communication with the subsurface formation and/or with the heat transfer fluid so as to heat the subsurface formation.

28. The method of claim 27 further comprising:

- c. monitoring respective power-level indicators of local generation of wind
15 electricity and of the solar-thermal-heating of the heat transfer fluid; and
- d. responsive to the monitoring, allocating a first portion of locally-available wind electricity to the resistive heating of the electrically conductive material and a second portion of the locally-available wind electricity for remote power transmission.

20

29. An integrated wind-solar thermal system for heating a subsurface formation, the system comprising:

- a. a solar thermal apparatus operative to heat a heat transfer fluid;
- b. a heat transfer fluid circulation apparatus configured to force the solar-
25 thermal-apparatus-heater heat transfer fluid to flow through a closed loop embedded in the subsurface formation;
- c. a source of locally generated wind electricity operative to resistively heat an electrically conductive element(s) so as to supply thermal energy to the

subsurface formation directly and/or indirectly via the flowing heat transfer fluid;

5 d. a controller operative to allocate at least a first portion of the locally generated wind electricity to the resistive heating and to remotely transmit a second portion of the locally generated wind electricity, the controller being further operative to:

- i. monitor respective power-level indicators of local generation of wind electricity and of the solar-thermal-heating of the heat transfer fluid;
- 10 ii. responsive to the monitoring, modifying relative fractions of the locally-generated wind electricity that are allocated to the resistive heating and to the remote transmission.

30. An apparatus for heating a subsurface formation, the apparatus comprising:

15 a. a subsurface molten salt heater including a substantially non-thermally-insulated portion within the subsurface formation through which molten salt flows so as to heat the subsurface formation primarily by convective heat transfer,

20 b. a molten salt circulation system configured to supply molten salt to and to receive returning molten salt from the subsurface molten heater so as to form a closed flow loop; and

c. an electrical power source configured to electrically-resistively heat an electrically conductive element(s) arranged within the subsurface molten salt heater to indirectly heat the circulating molten salt,

25 the electrical power source and the electrically conductive element being configured to maintain a temperature of the circulating molten salt, throughout the substantially non-thermally-insulated portion, at a temperature significantly above a melt temperature of the circulating molten salt.

31. An apparatus for heating a subsurface formation, the apparatus comprising:

- a. a subsurface molten salt heater including a substantially non-thermally-insulated portion within the subsurface formation through which molten salt flows so as to heat the subsurface formation primarily by convective heat transfer;
- 5 b. a molten salt circulation system configured to supply molten salt to and to receive returning molten salt from the subsurface molten heater so as to form a closed flow loop; and
- c. an alternating current electrical power source configured to electrically-resistively heat an electrically conductive element(s) arranged within the
- 10 subsurface molten salt heater to indirectly heat the circulating molten salt;
- the electrical power source and the electrically conductive element being configured to maintain a temperature of the circulating molten salt, throughout a majority of the substantially non-thermally-insulated portion, within a substantially constant set-point temperature range having a lower bound that is
- 15 significantly above a melt temperature of the circulating molten salt.
32. An apparatus for heating a subsurface formation, the apparatus comprising:
- a. a subsurface molten salt heater including a substantially non-thermally-insulated portion within the subsurface formation through which molten salt
- 20 flows so as to heat the subsurface formation primarily by convective heat transfer,
- b. a molten salt circulation system configured to supply molten salt to and to receive returning molten salt from the subsurface molten heater so as to form a closed flow loop; and
- c. an alternating current electrical power source configured to electrically-resistively heat an electrically conductive element(s) arranged within the
- 25 subsurface molten salt heater to indirectly heat the circulating molten salt;
- the electrical power source and the electrically conductive element being configured to maintain a temperature of the circulating molten salt, throughout a majority of the substantially non-thermally-insulated portion, within a
- 30 substantially constant set-point temperature range having a lower bound that is significantly above a melt temperature of the circulating molten salt.

33. An apparatus for heating a subsurface formation, the apparatus comprising:

- a. a subsurface molten salt heater configured to heat the subsurface formation primarily by convective heat transfer from molten salt circulating therein to the subsurface formation,
- 5 b. a molten salt circulation system configured to supply molten salt to and to receive returning molten salt from the subsurface molten heater so as to form a closed flow loop; and
- c. an electrical power source configured to electrically-resistively heat an electrically conductive element(s) arranged within the subsurface molten salt heater to indirectly heat the circulating molten salt,
- 10 the apparatus being configured such that:
 - i. the circulation system provides a sufficient molten salt flow rate so that, in the absence of the resistive heating, a temperature difference between molten salt at upstream and downstream subsurface heater locations due to the convective heat transfer from the circulating molten salt to the formation is significant;
 - 15 ii. the electrical power source and the electrically conductive element are configured to deliver sufficient thermal energy to the circulating molten salt so as to maintain the upstream, downstream and a majority of intervening locations at substantially the same set-point temperature.
- 20

34. The apparatus of any of claims 30-33 wherein:

- i. the apparatus is configured to heat the subsurface formation such that first and second thermal energy fractions are respectively delivered to the subsurface formation from the circulating molten salt by enthalpy of the supplied molten salt entering the subsurface molten salt heater and by the resistive heating of the molten salt within the subsurface heater; and
- 25 ii. each of the first and second fractions exceeds 0.1.

35. The apparatus of any of claims 30-33 wherein the substantially constant set-point temperature exceeds the melt temperature by at least 150 degrees Celsius.

36. The apparatus of any of claims 30-35 wherein the system is configured such that:

- i. an amount of thermal energy convectively transferred to the subsurface formation by circulating molten salt *en route* from an upstream location to a downstream location equals at least 20% of the liquid-phase enthalpy of the molten salt at the upstream location;
- ii. the electrical power source and the electrically conductive elements are operative to maintain the molten salt for a majority of locations between the upstream and downstream location, substantially at the set-point temperature.

37. The apparatus of any of claims 30-36 wherein the subsurface heater is an L-shaped heater, a U-shaped heater, a horizontally-oriented heater, a vertically-oriented heater and/or a slant-oriented heater.

38. The apparatus of any of claims 30-36 wherein the electrically conductive element includes a ferromagnetic material having a Curie temperature substantially equal to the set-point temperature and/or significantly exceeding the molten salt melt temperature.

39. The apparatus of any of claims 30-38 wherein the subsurface heater has a conduit-in-conduit structure defining nested inner and outer flow regions such that:

- i. in the inner flow region, molten salt longitudinally flows in a first direction;
- ii. in the annular-shaped outer region, molten salt longitudinally flows in the opposite direction.

40. The apparatus of any of claims 30-39 wherein the subsurface molten salt heater is configured to heat at least a portion of the subsurface formation by at least 100 degrees Celsius.

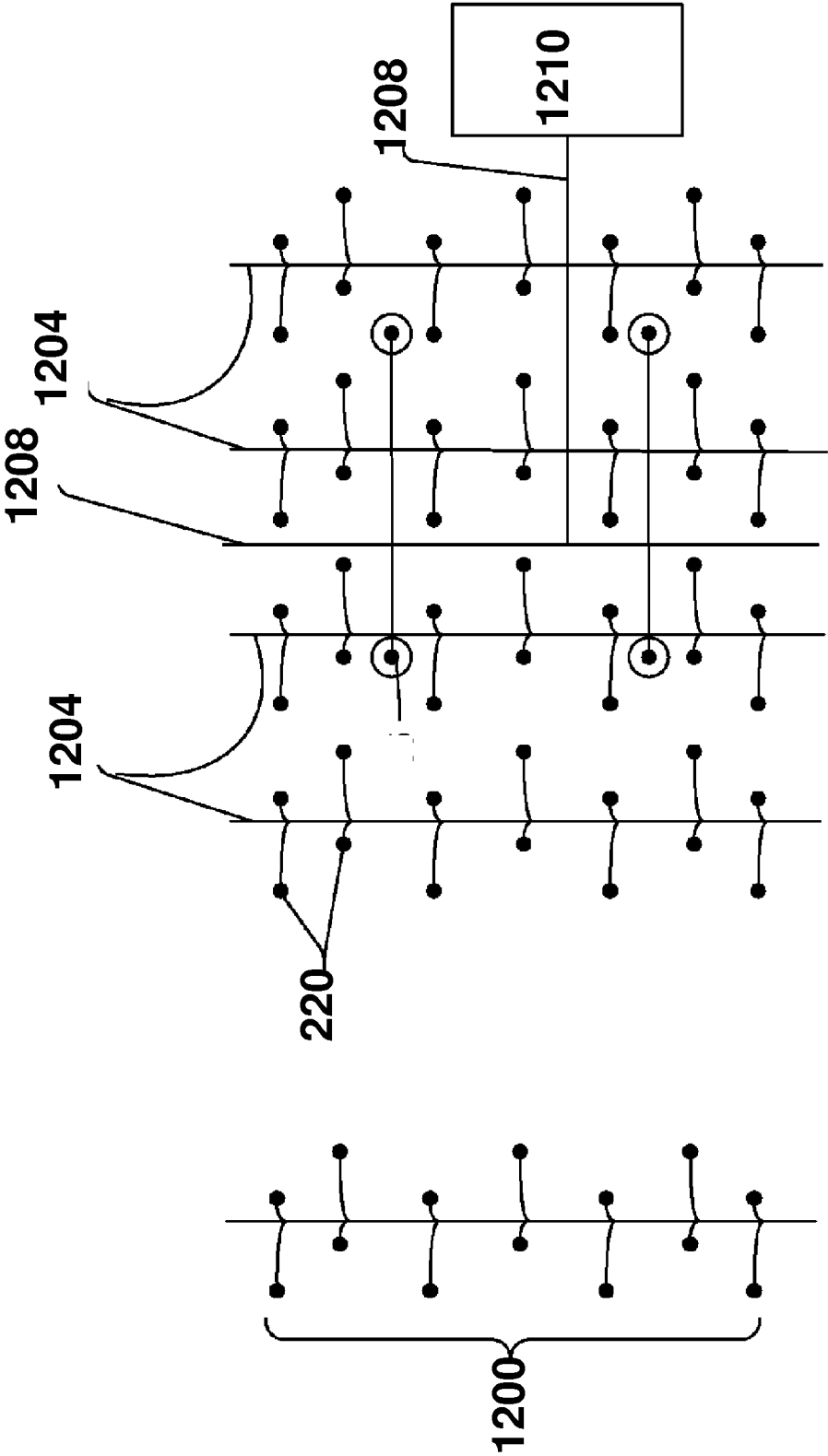
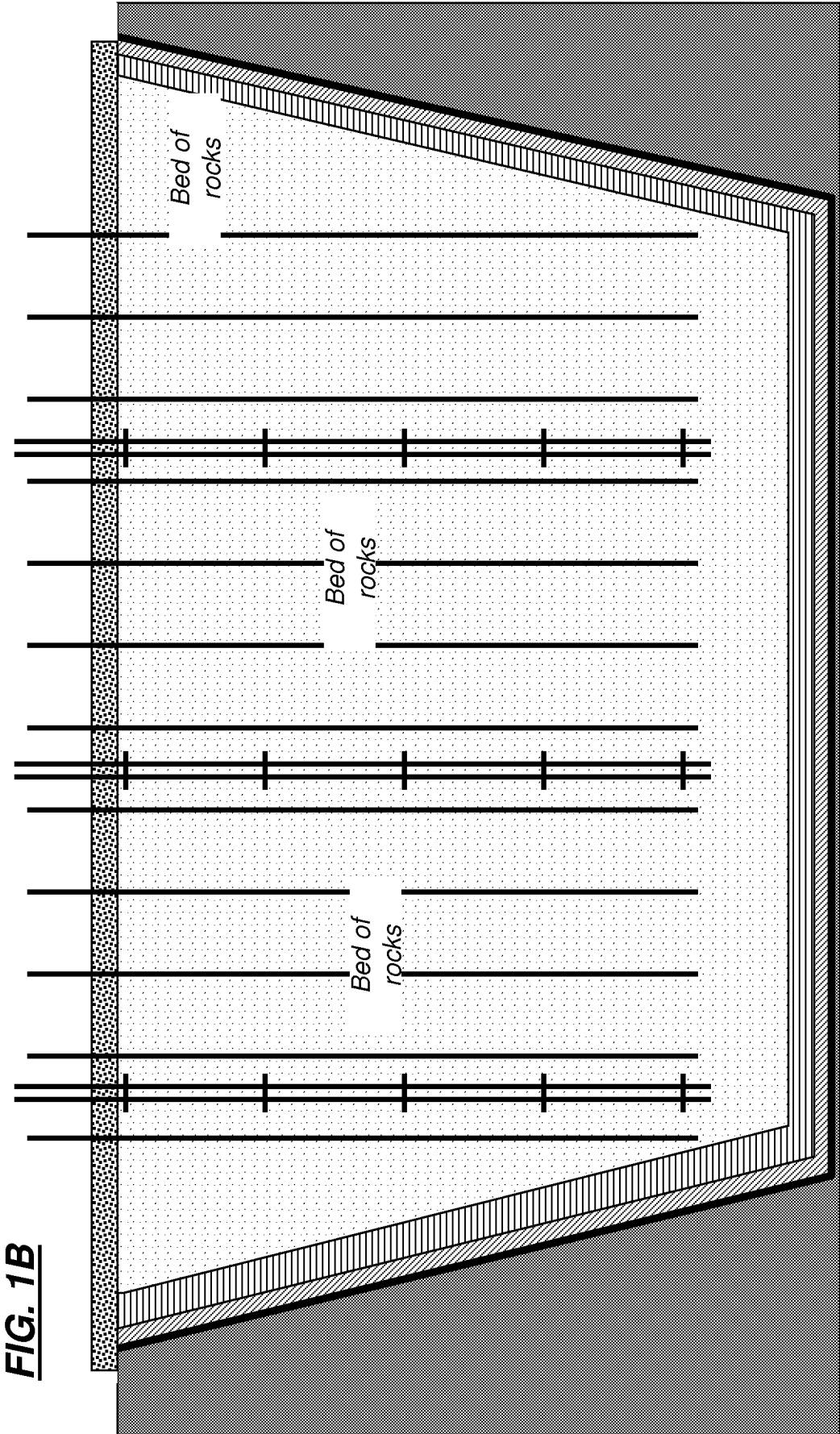


FIG. 1A

Pit including vertical heaters and porous media (e.g. hydrocarbon-containing) porous media

— = heater (e.g. highly elongated heater)
= production conduit (e.g. perforated)

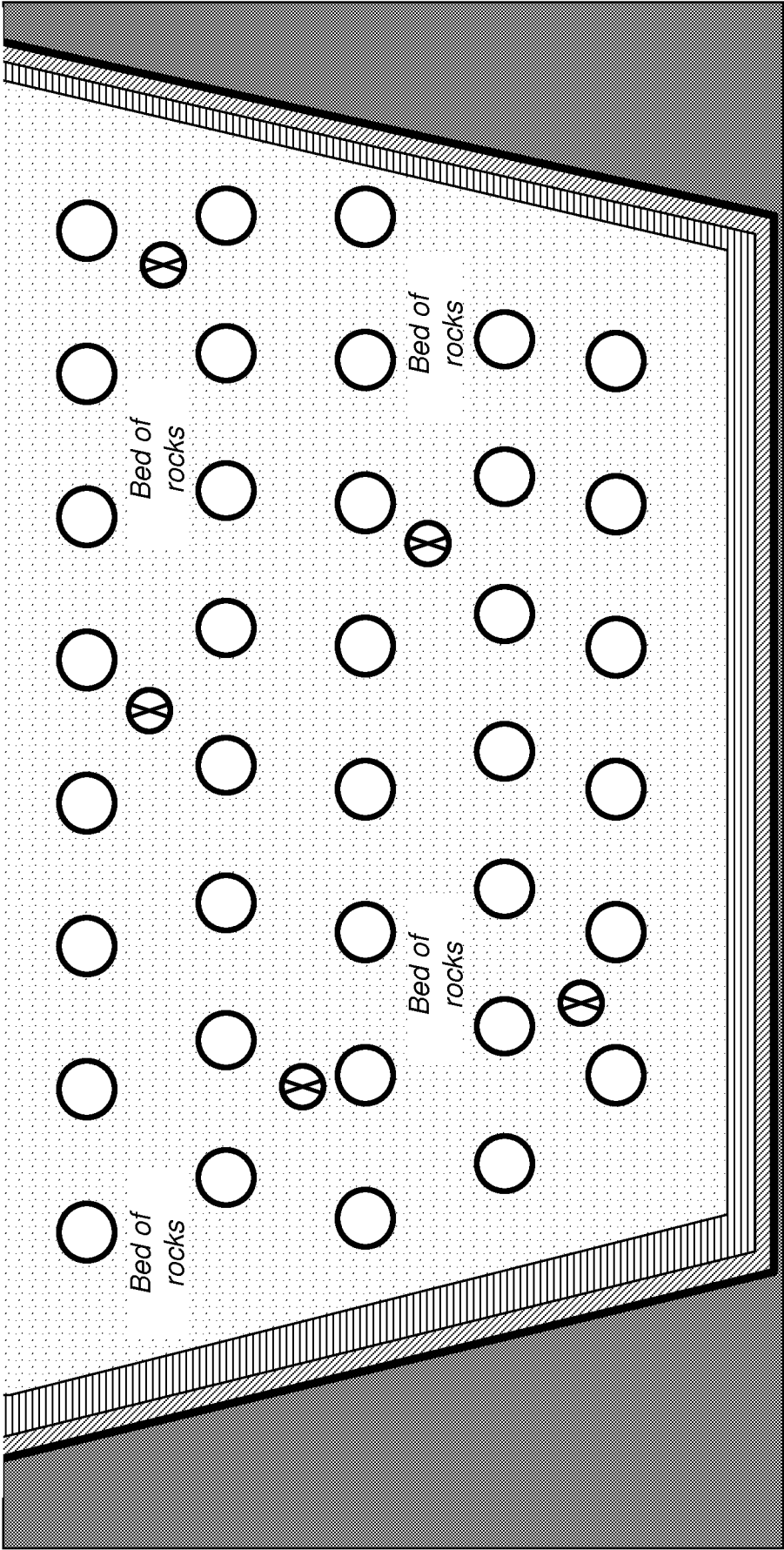
SIDE VIEW



Pit including horizontal heaters and porous media (e.g. hydrocarbon-containing) porous media [SIDE VIEW]

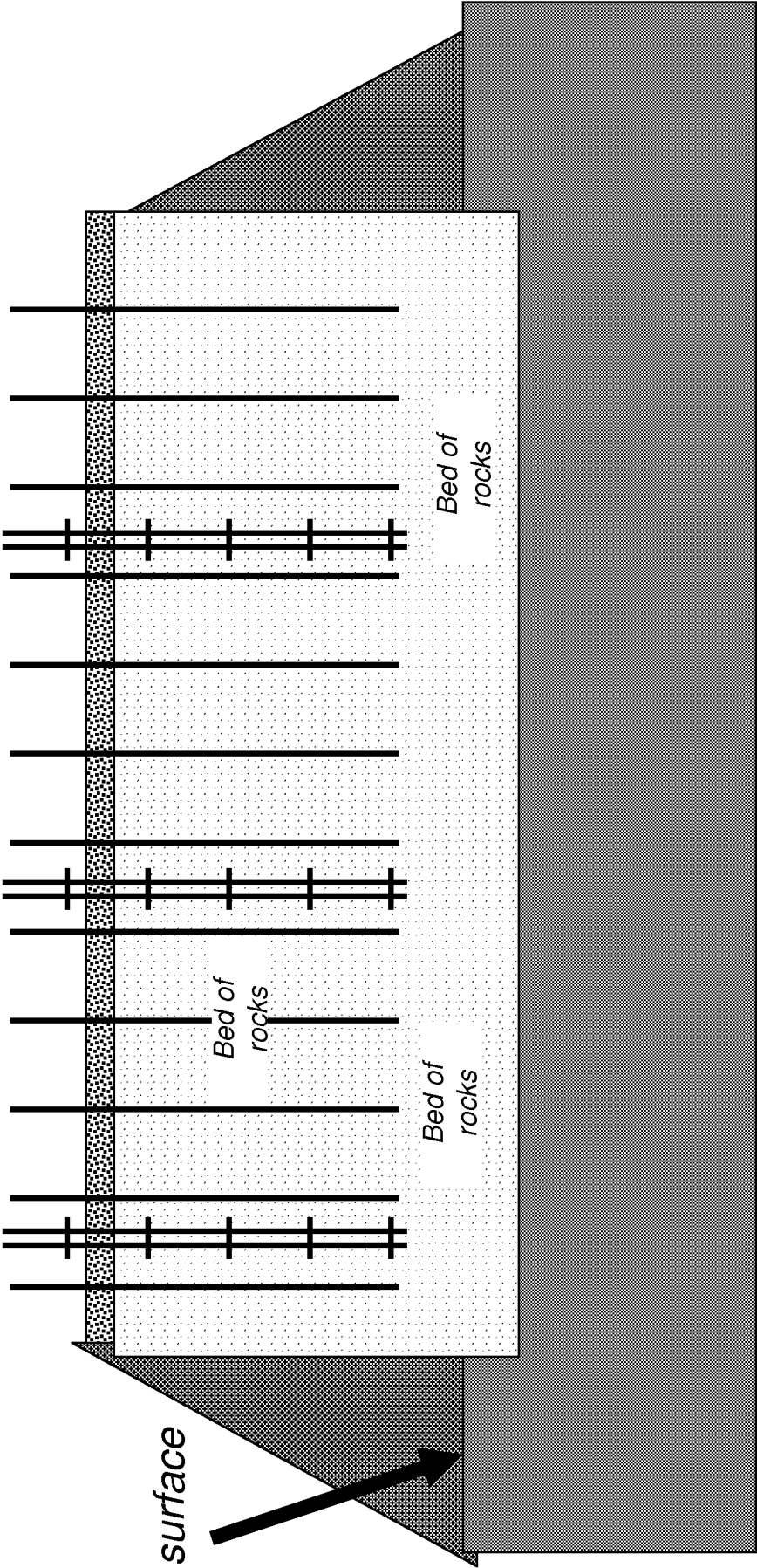
○ = heater (e.g. highly elongated heater) **FIG. 1C** **SIDE VIEW**

⊗ = production conduit (e.g. perforated)

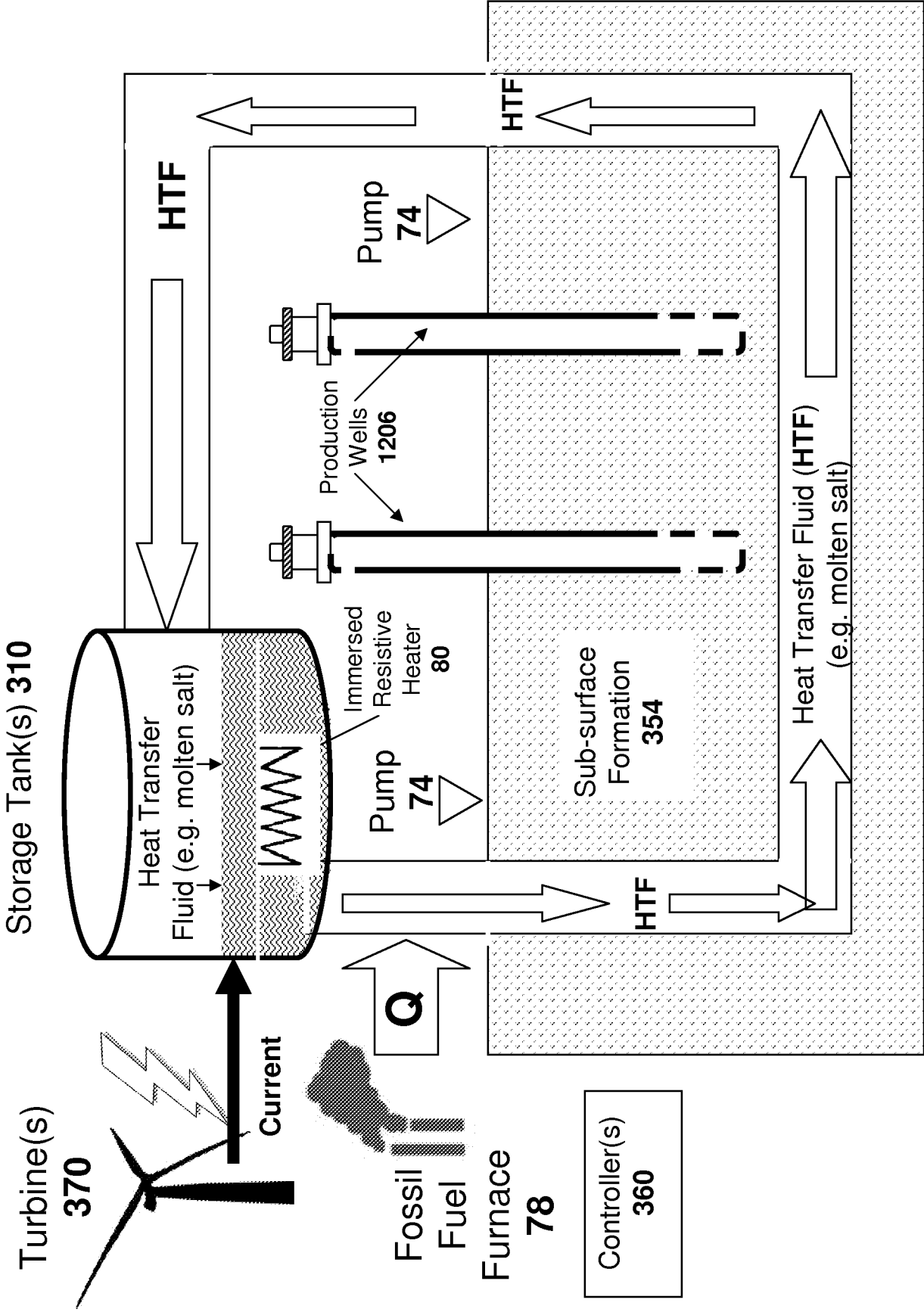


Impoundment

FIG. 1D



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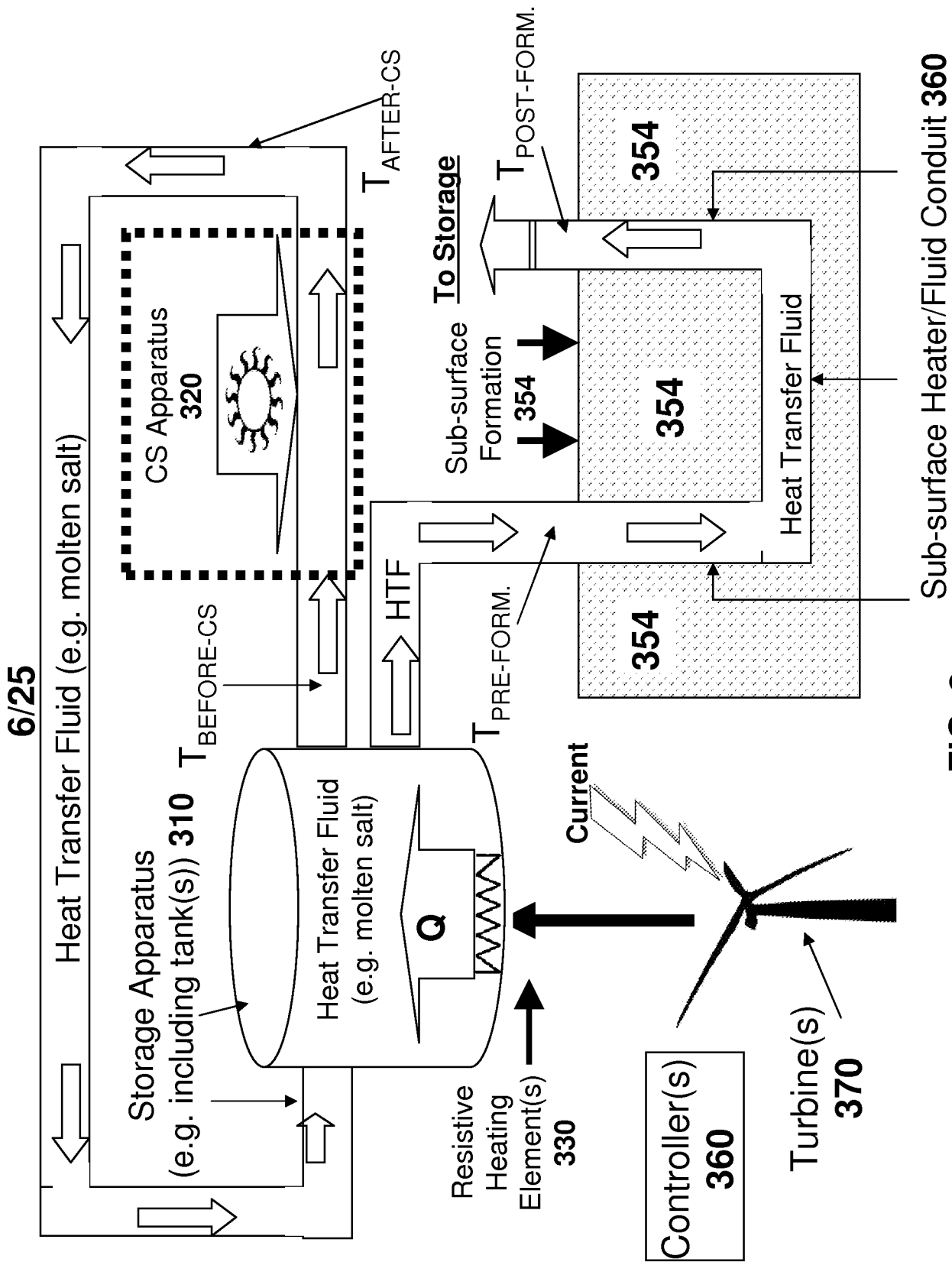


FIG. 3

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Hourly Wind/Solar Power

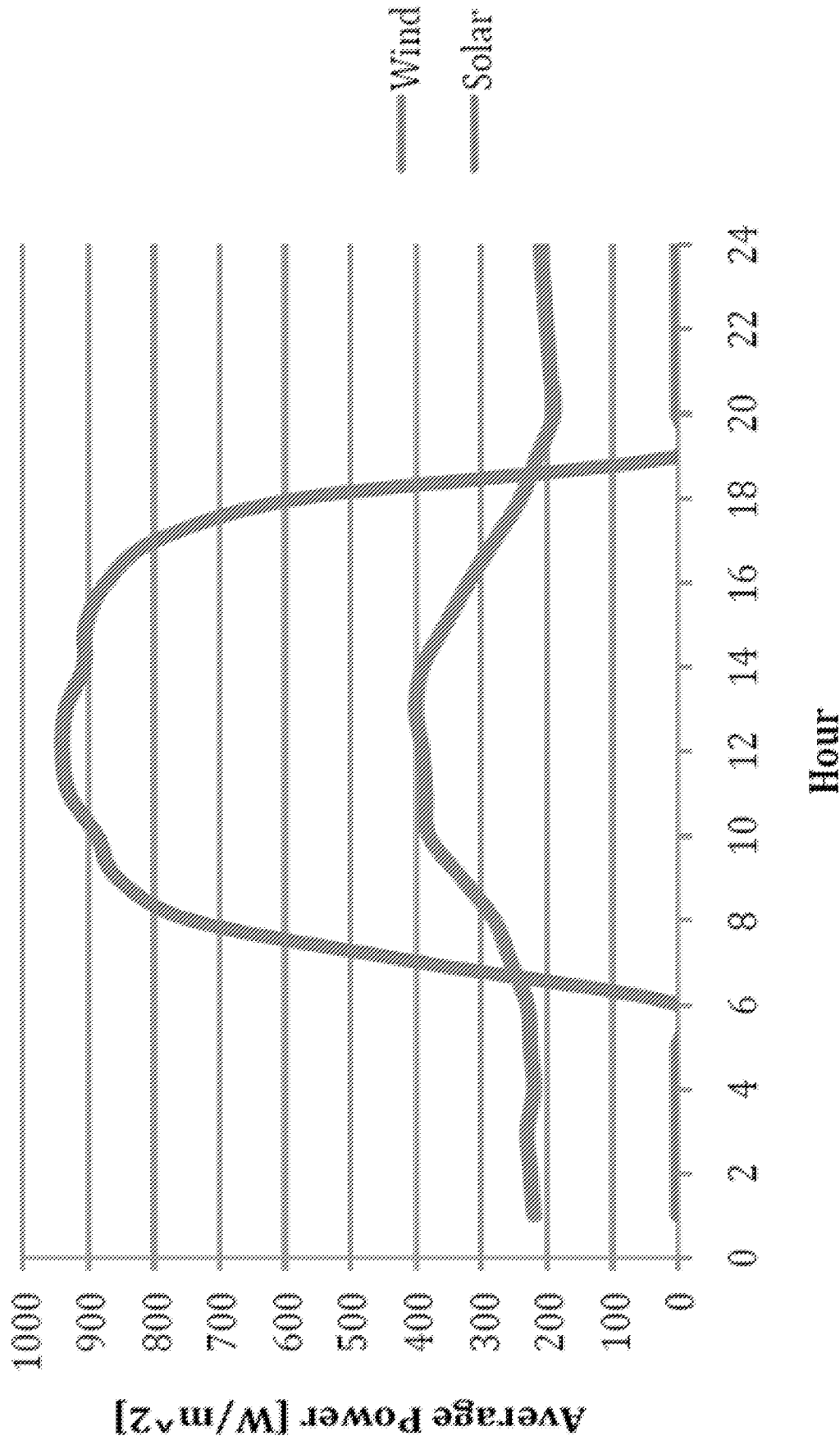


FIG. 4

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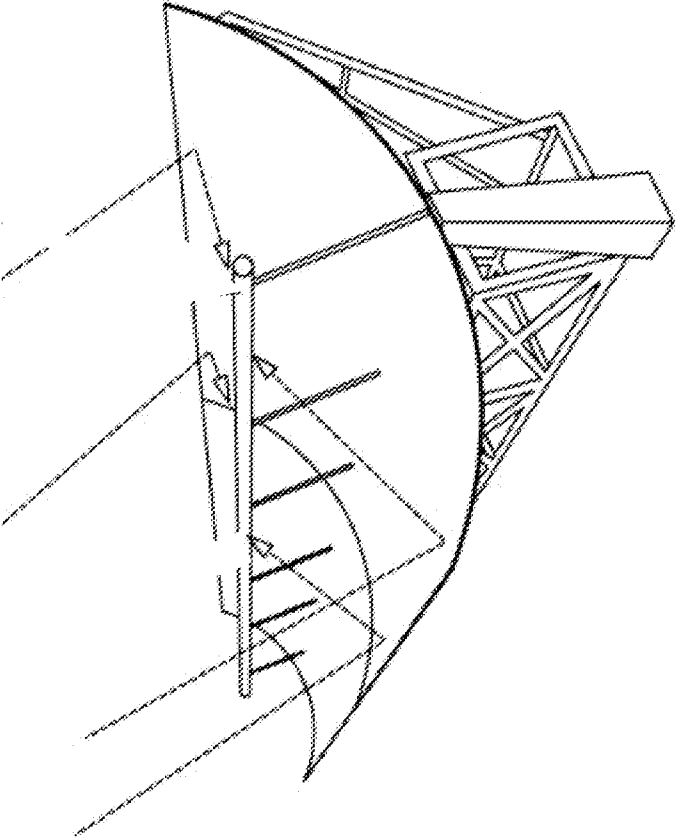


FIG. 5A

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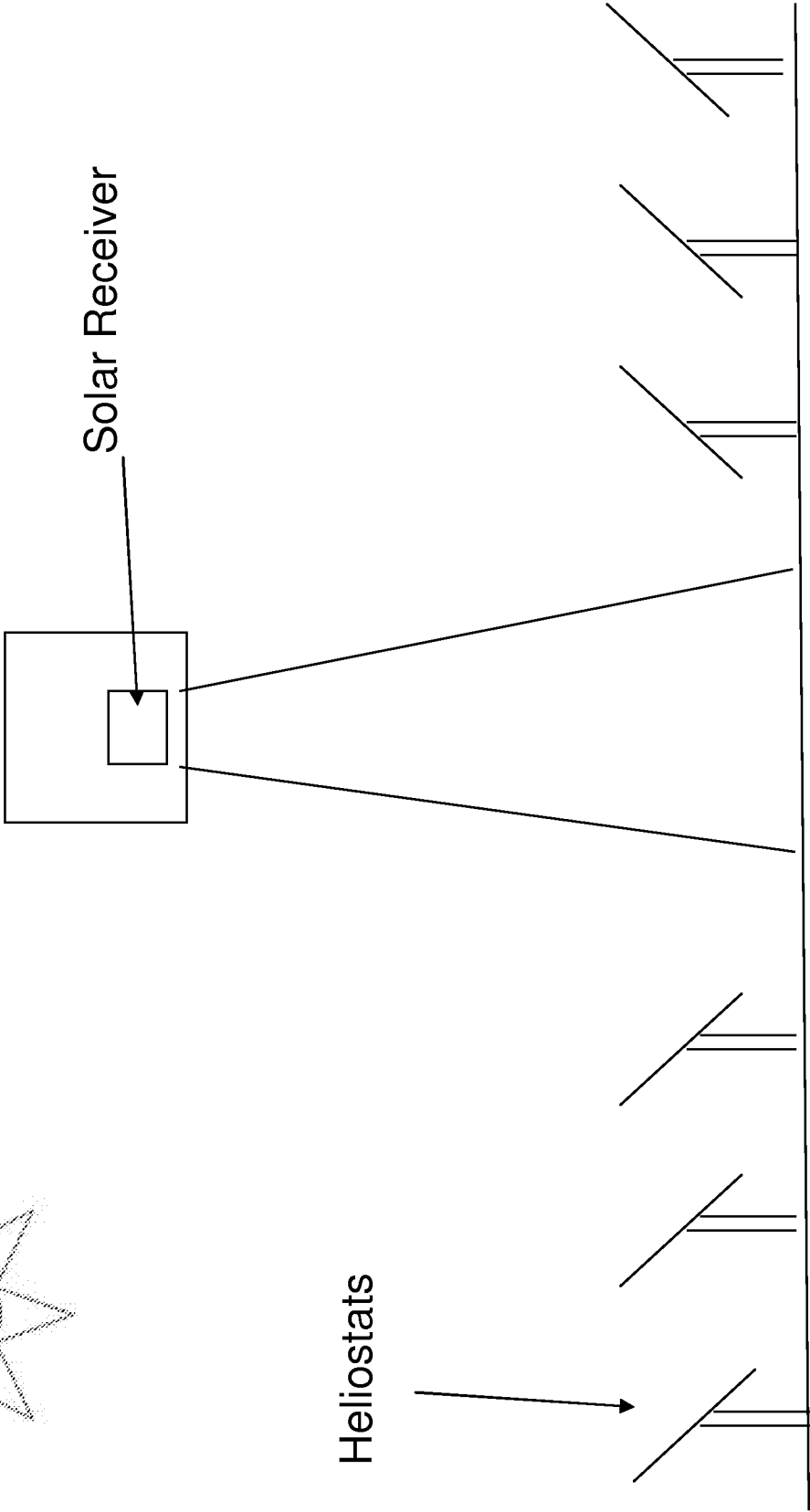
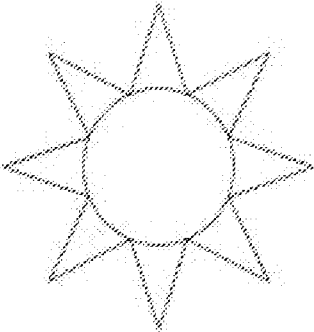


FIG. 5B

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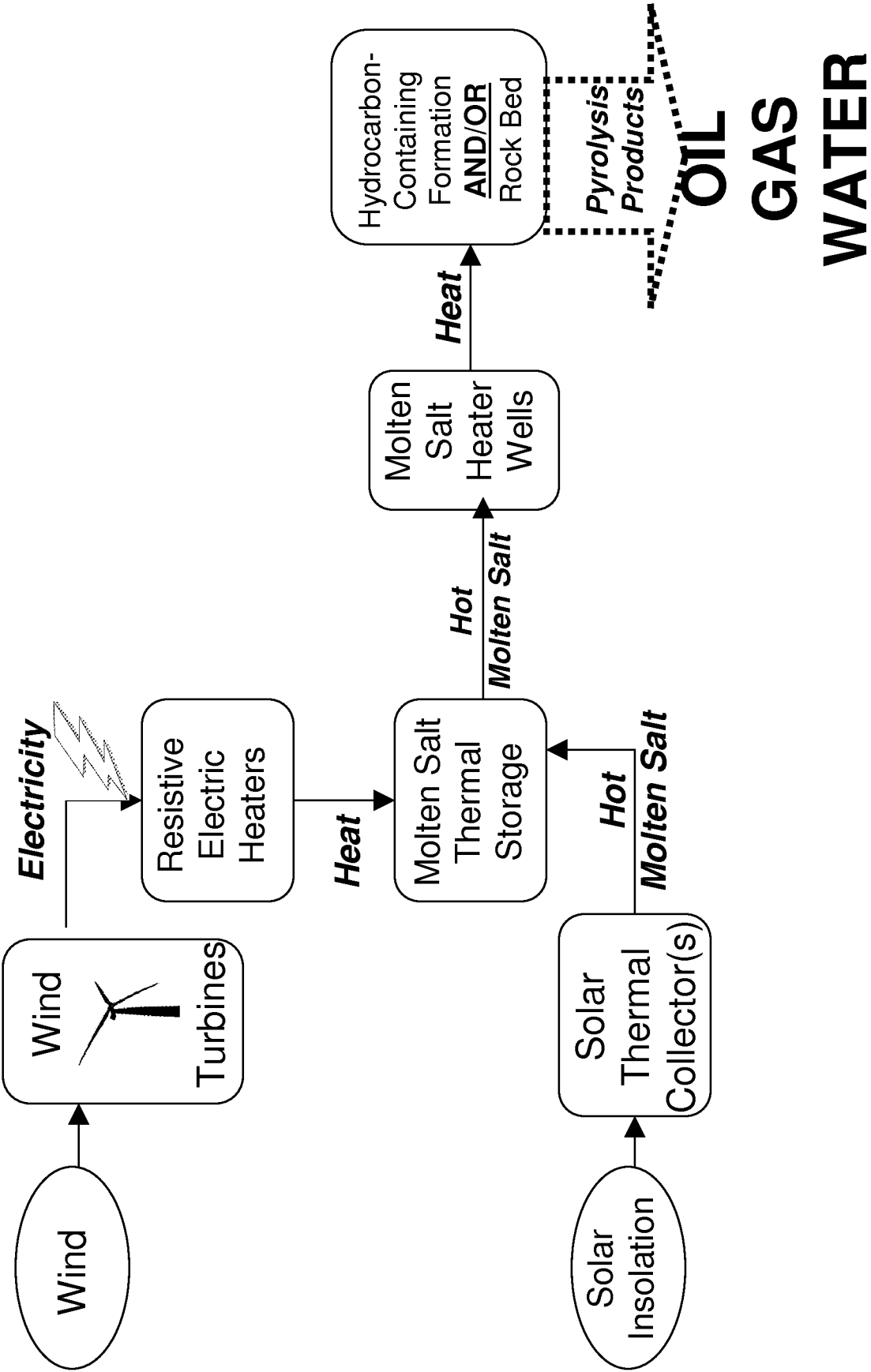


FIG. 6A

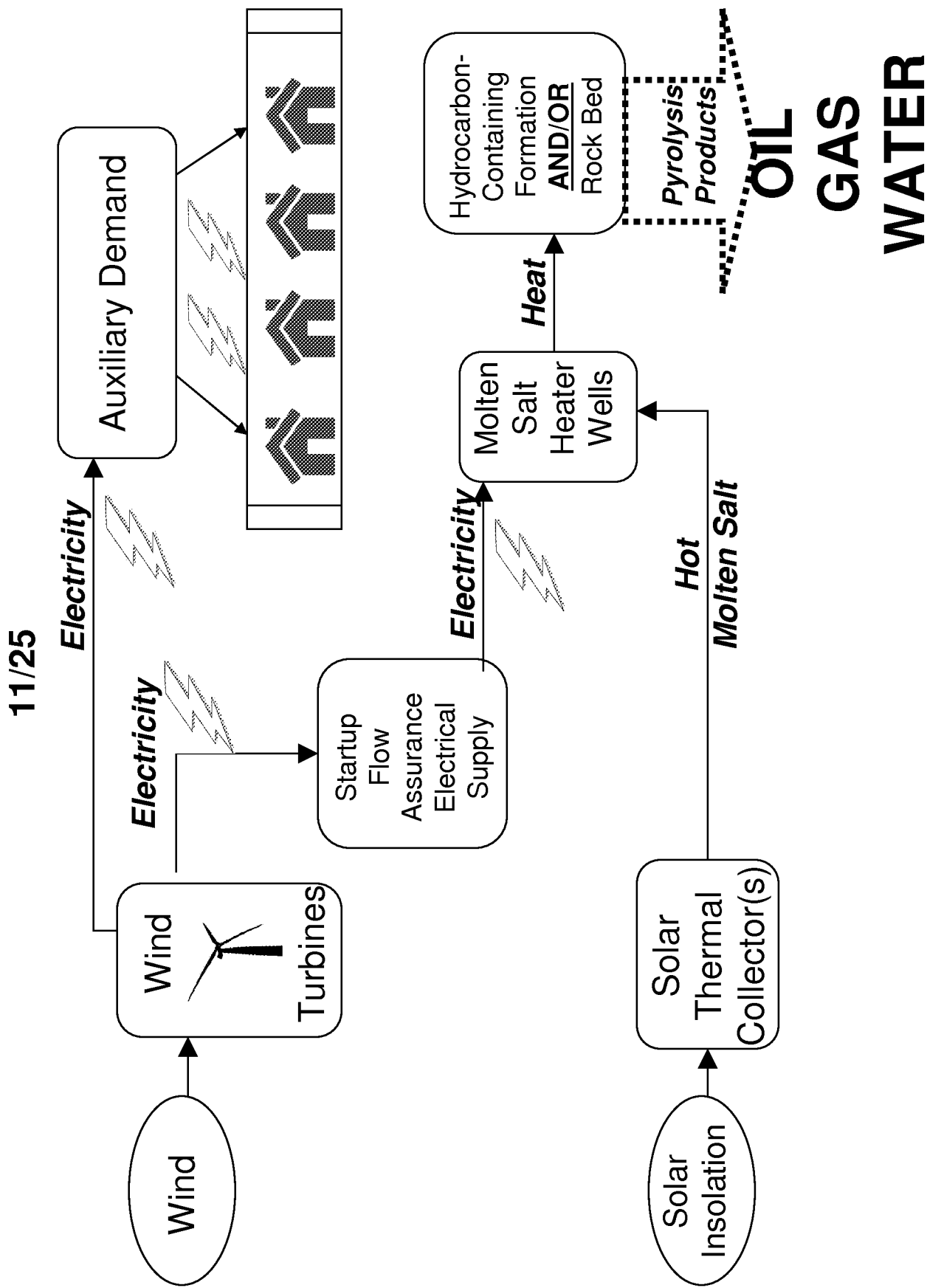


FIG. 6B

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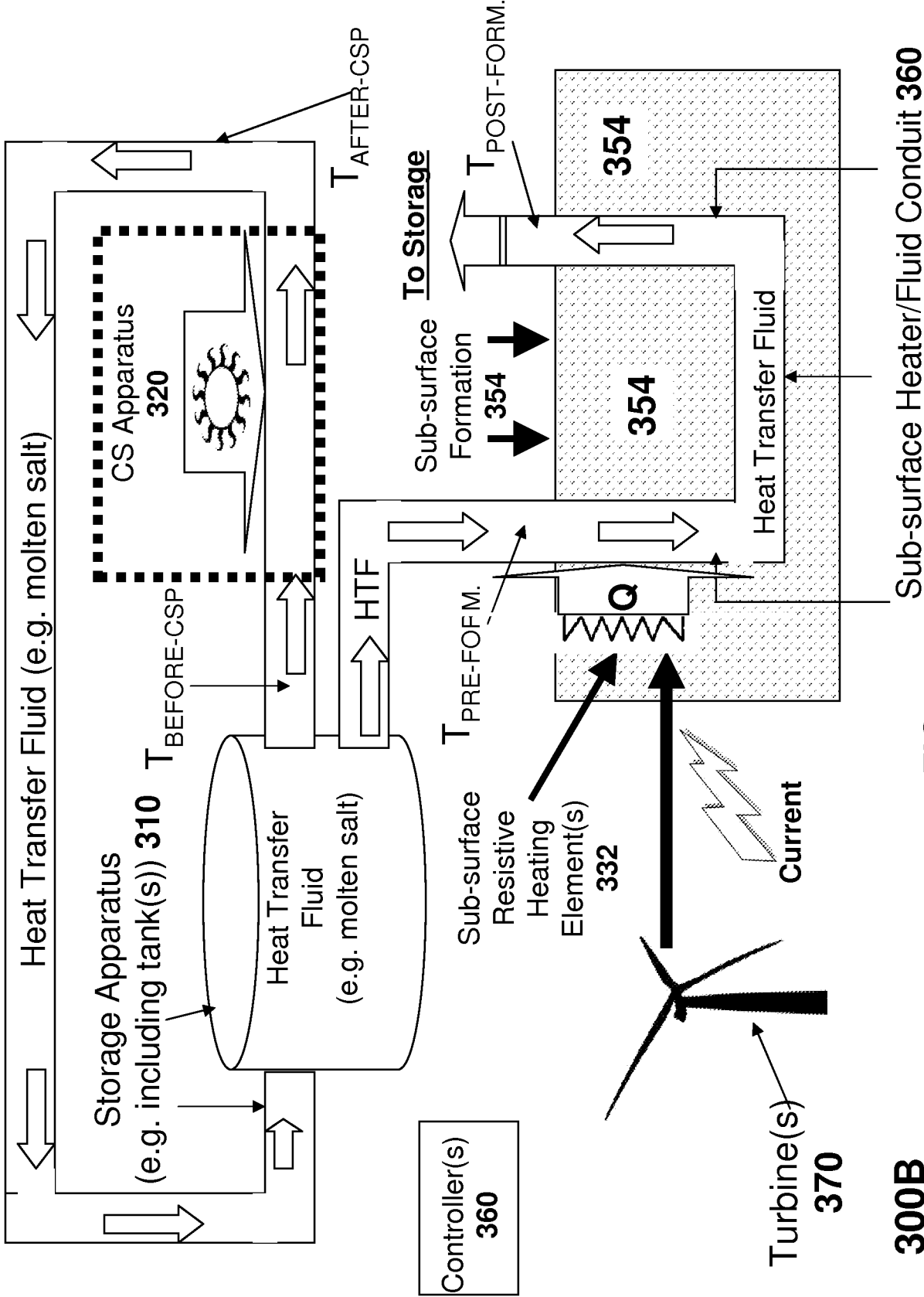


FIG. 7

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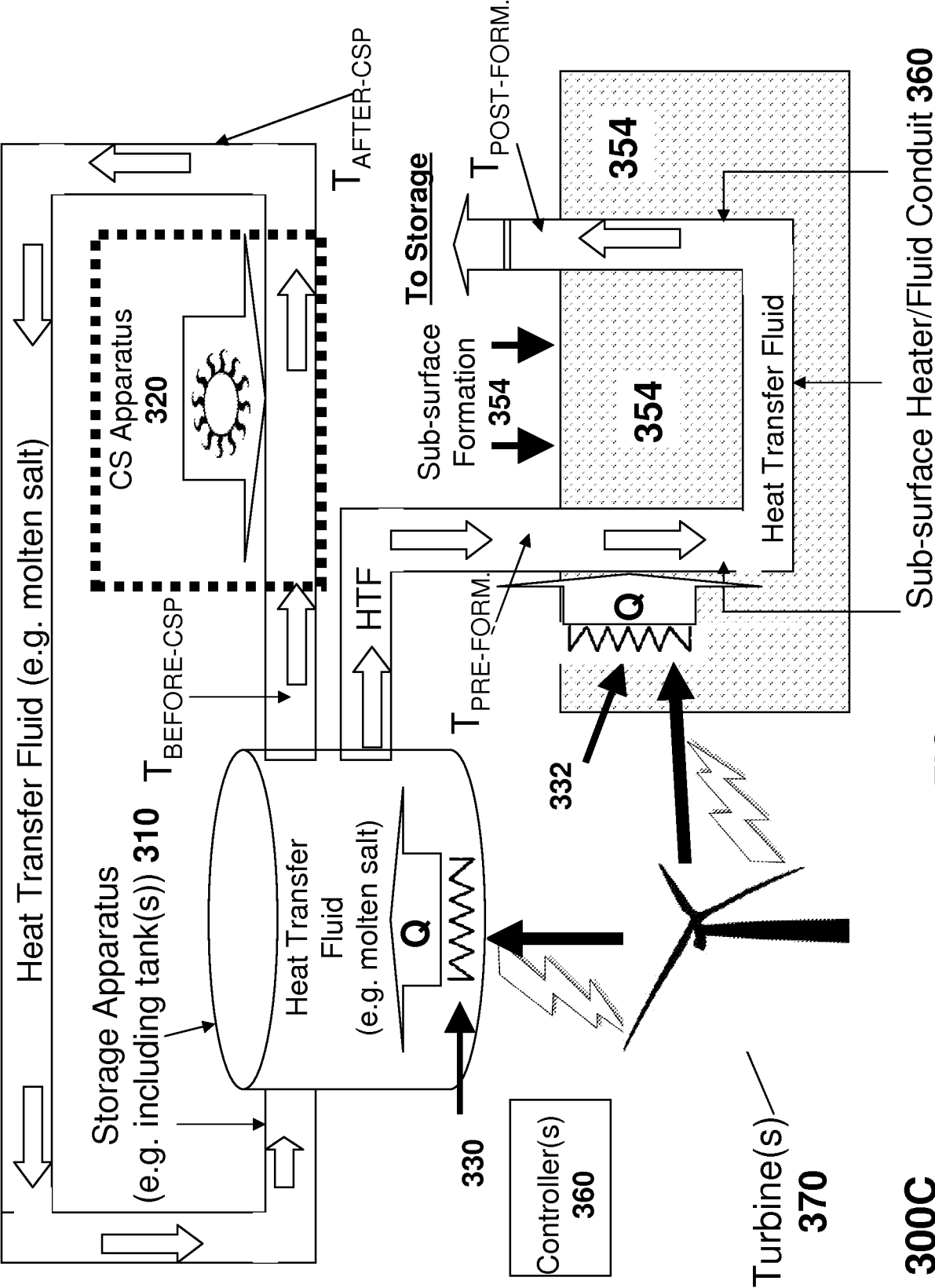
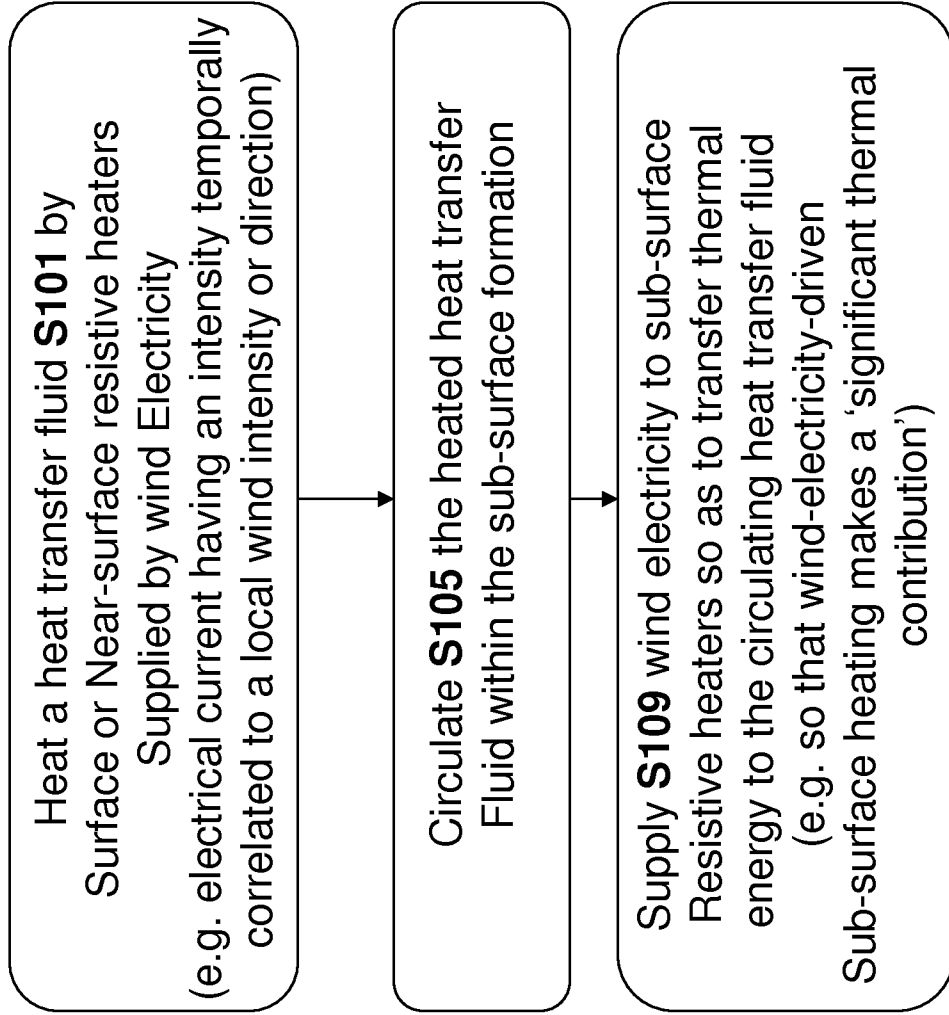


FIG. 8

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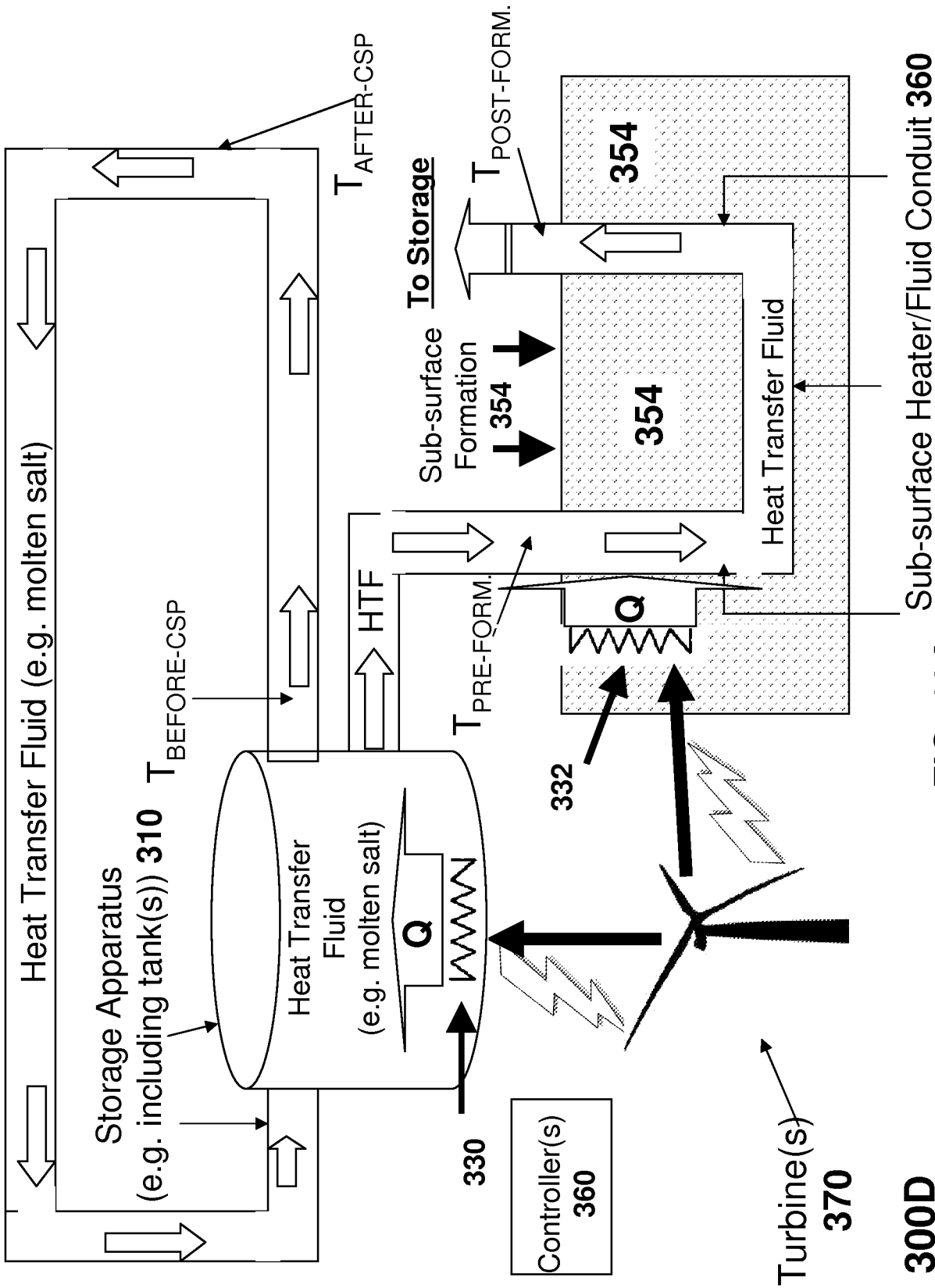


FIG. 10A

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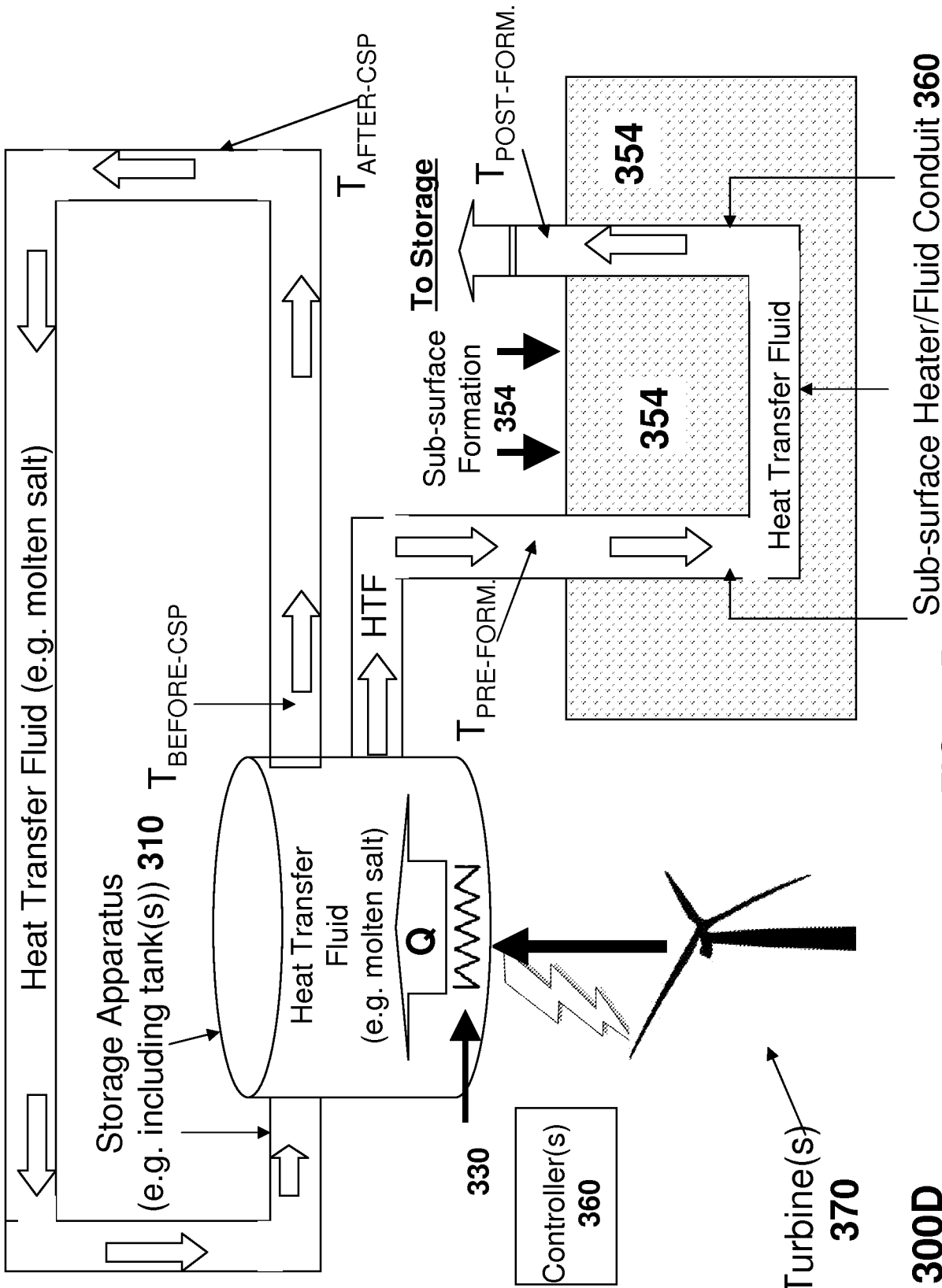
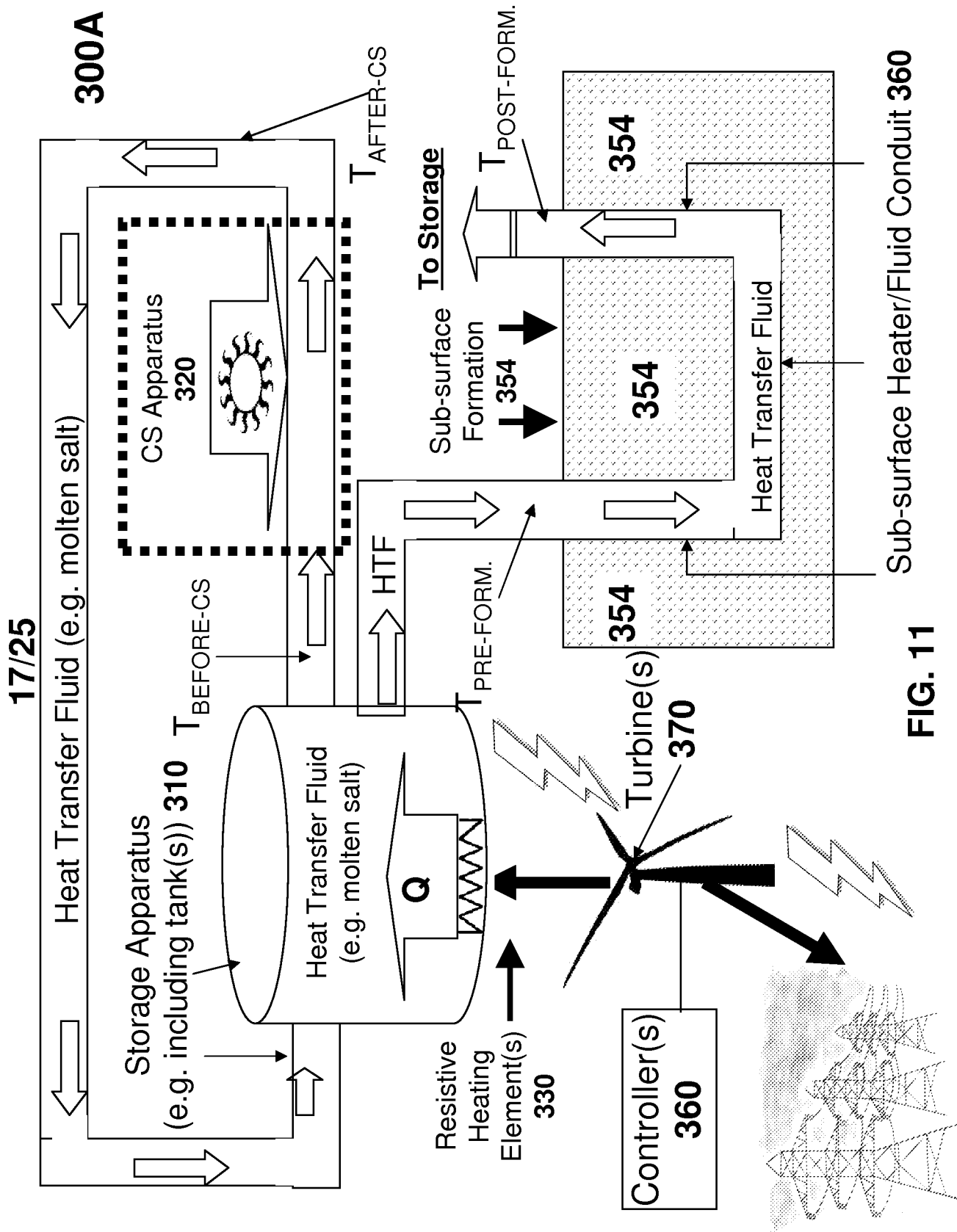


FIG. 10B



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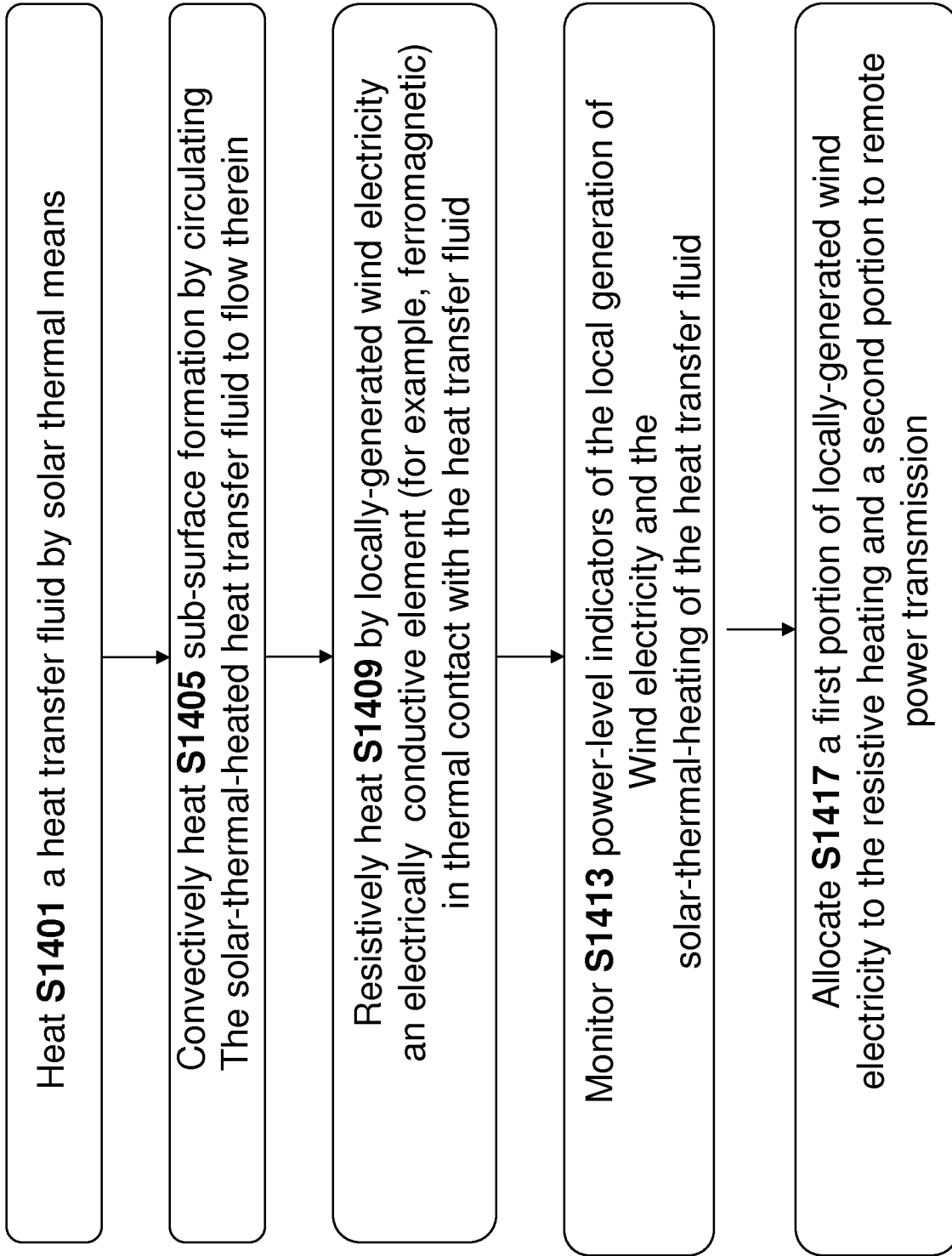


FIG. 12

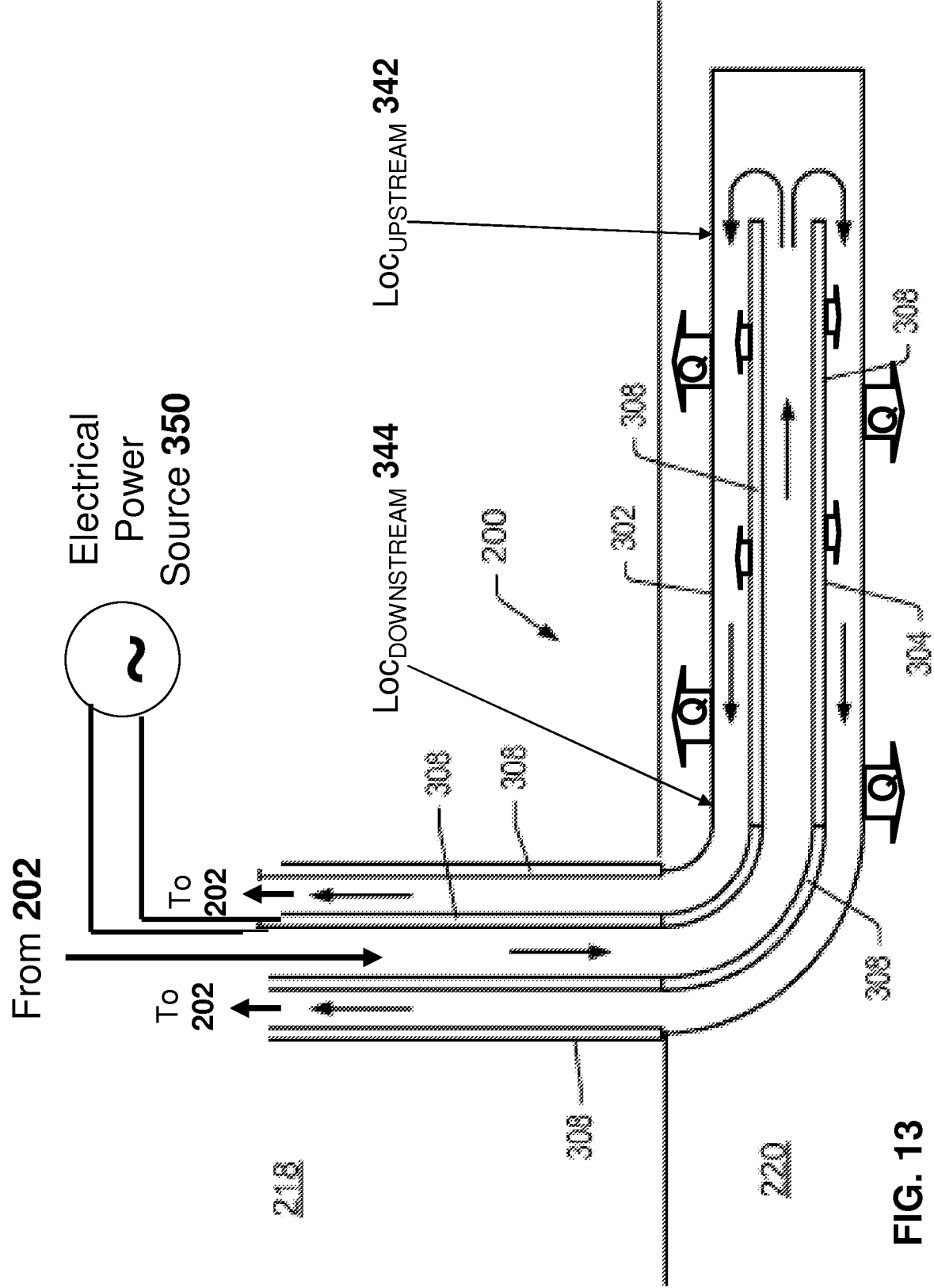
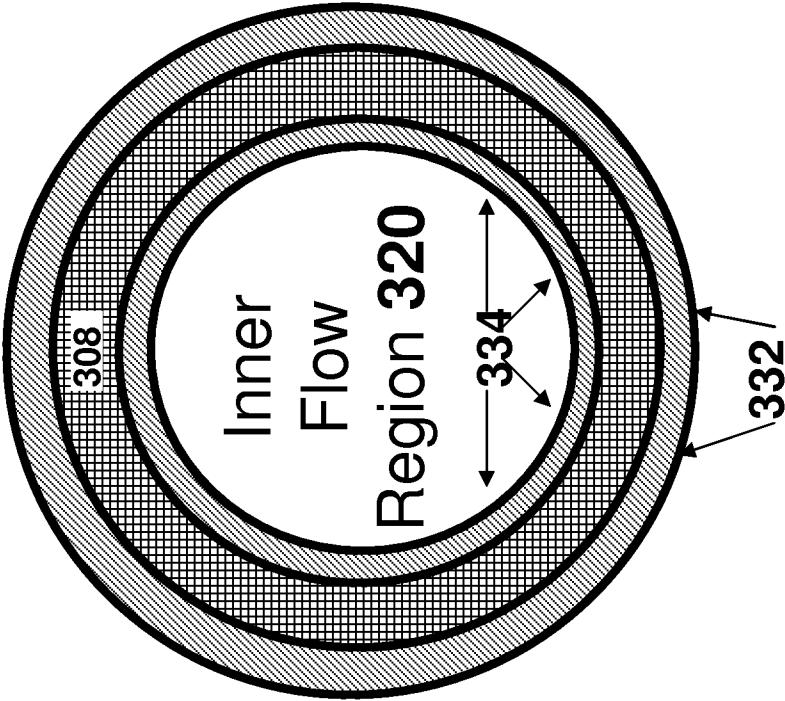


FIG. 13

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Inner Conduit Assembly 304



Insulation 308
(microporous
Insulation)

332 =
Outer Conduit
Of the inner conduit
Assembly 304
(e.g. electrically
conducting through
Which current flows)

334=
Inner Conduit
Of the inner conduit
assembly 304
(e.g. electrically conducting
Through which current flows)

FIG. 14A

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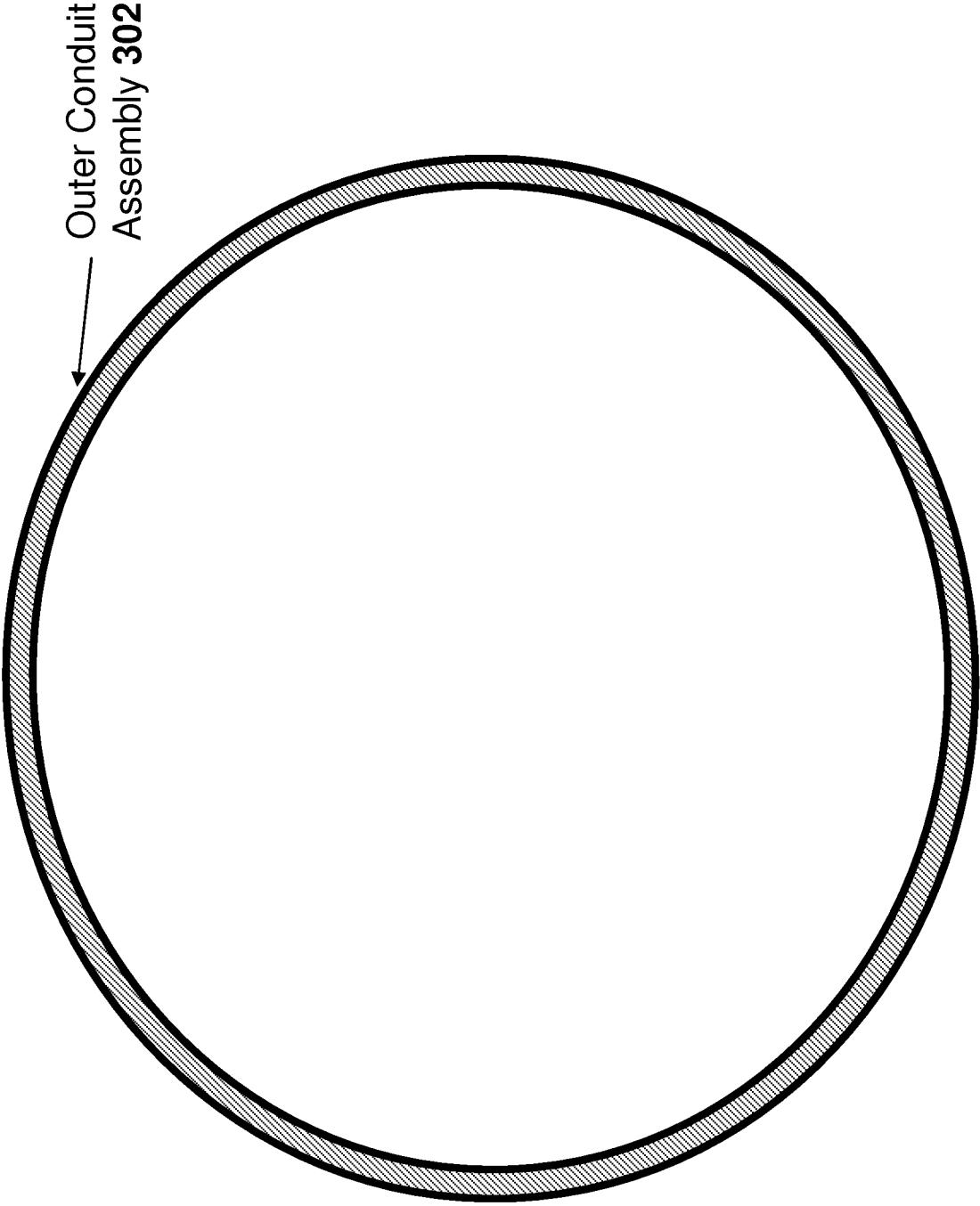
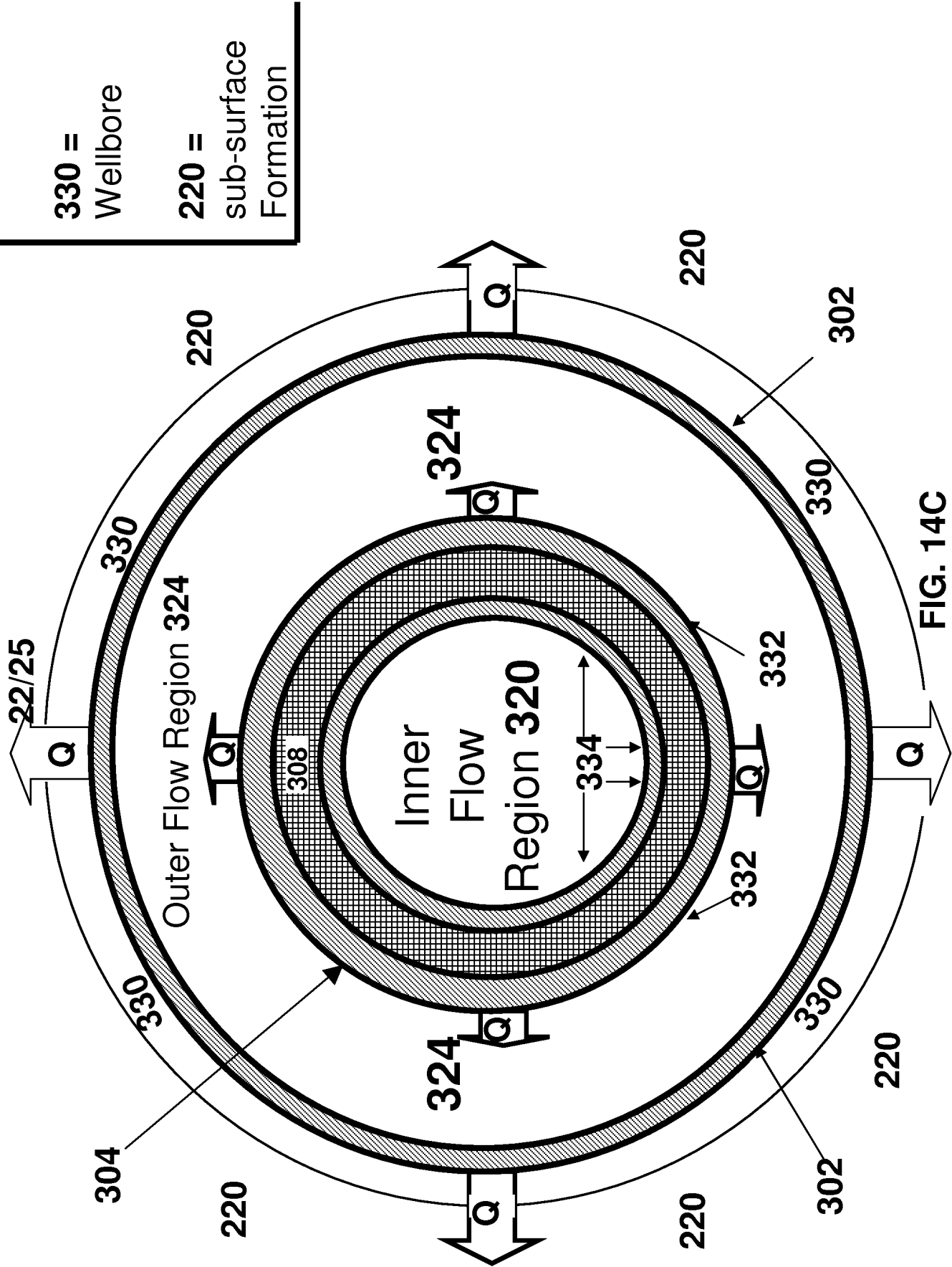


FIG. 14B



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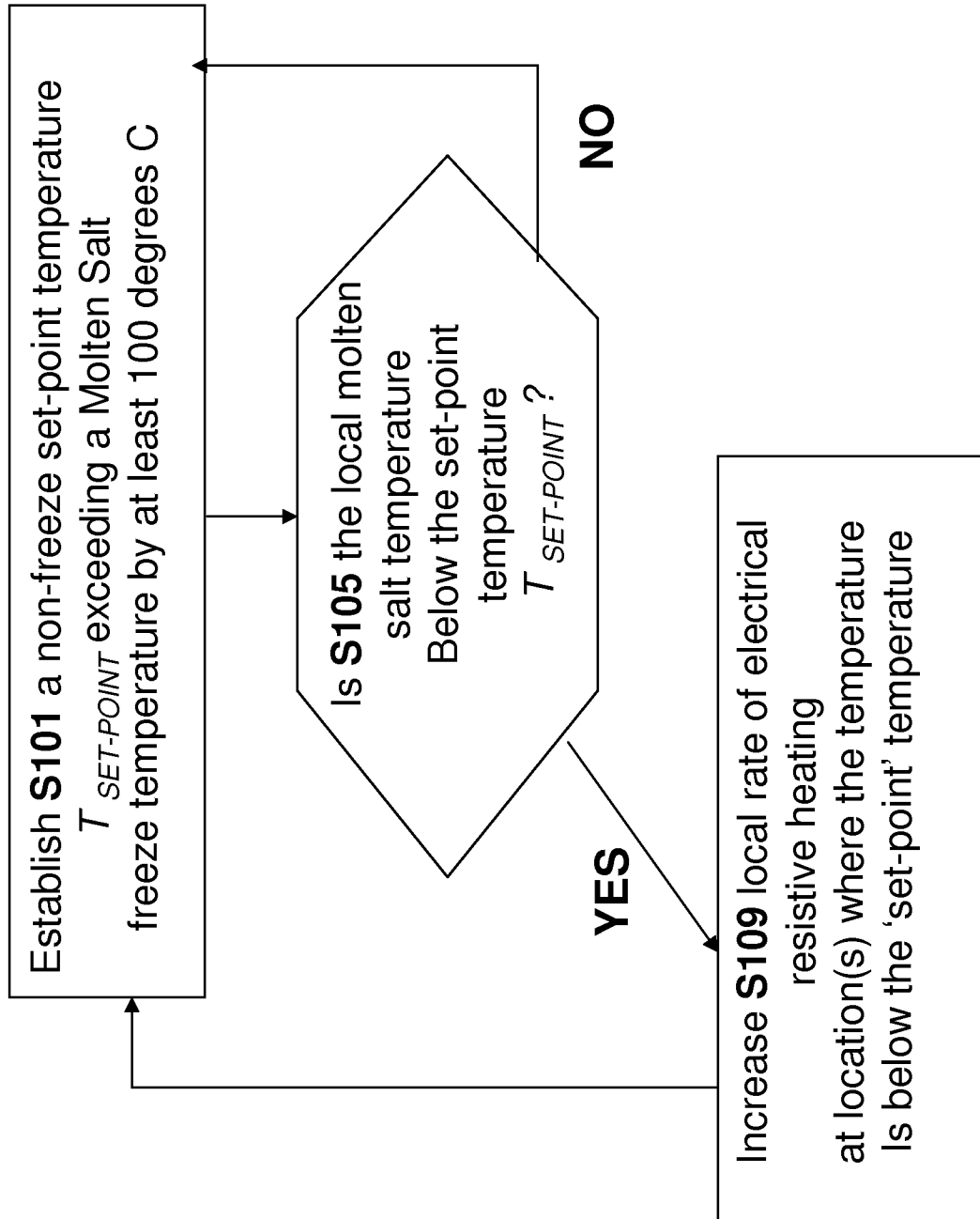


FIG. 15

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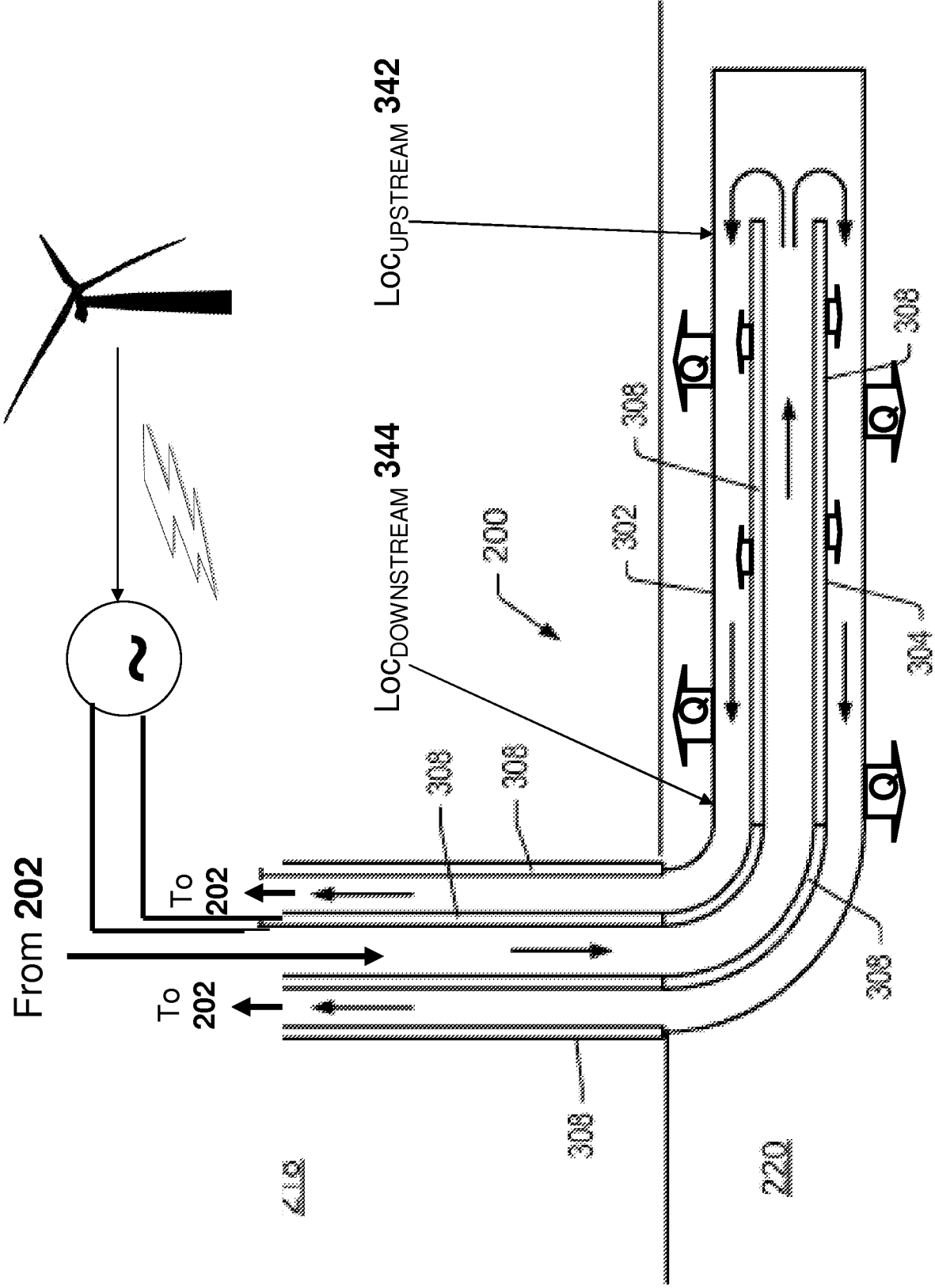


FIG 16

