A system and method provide a solar energy capture and storage (SECS) system/facility with a ground-based, integrated volumetric receiver-storage container for efficient solar energy concentration, capture and storage. The SECS system comprises a storage container with a working fluid volume. The storage container has an enclosure with surrounding insulated walls, including a first wall in which one or more openings are disposed. The working fluid is held exclusively within the storage container and absorbs light energy from captured incident light as thermal energy and stores the absorbed thermal energy within the working fluid. The working fluid completes the absorption of light energy and storage of thermal energy without being transported out of the storage container. The SECS system obviates transportation of the working fluid, while completing the light energy absorption and thermal energy storage. A light re-direction/concentration facility, redirects sunlight into the openings of the storage container.
GROUND-BASED, INTEGRATED VOLUMETRIC RECEIVER-STORAGE SYSTEM
FOR CONCENTRATED SOLAR POWER

CROSS REFERENCE TO RELATED APPLICATIONS


BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The illustrative embodiment of the present invention relates generally to solar power systems and specifically to an improved method and system for harnessing solar energy for electric power generation.

2. Description of the Related Art

[0002] Electrical power generation from solar energy is a fast growing and evolving technology, with untapped commercial applications. Power generation from solar energy also provides many environmental and climatic advantages over traditional power generation using fossil fuels.

[0003] Practical applications for harnessing this renewable resource to generate electrical power present certain challenges, which challenges are, in part, a result of the low incident solar flux measured at the earth's surface and the diurnal character of the solar flux. The challenges related to low incident solar flux occurs even in optimal locations and conditions and can be addressed in principal by sufficiently concentrating the incident solar light by mirrors or lenses. However, such techniques for concentrating incident solar light must satisfy requirements for/of efficiency, economics, and maintenance. The challenges related to the diurnal character of solar flux require storage of the captured solar energy for non-sunlight electricity generation. This requirement to enable non-sunlight electricity generation is not addressed by many solar energy generation approaches currently under deployment or development. This shortcoming inevitably restricts these conventional solar applications/approaches to real-time power application. The real-time
power applications are at best extended through the use of "smart" distribution, designed to	
distribute power over markets having differing temporal demands.

[0004] One presently available solar technology that is capable of addressing both of the above challenges utilizes a field of heliostat-mounted mirrors arranged in an optical configuration to collect and concentrate incident sunlight onto a tower-based receiver. This optical configuration can achieve a concentration ratio of several thousands. At the receiver, the light energy is converted to thermal energy using suitable heat-absorbing technology. The thermal energy is subsequently removed using a working fluid such as a molten salt or water/steam. Because of the high temperature and heat capacity of molten salt, when molten salt is used as the working fluid, the energy captured within the molten salt may either be converted directly to electricity or stored as thermal energy for later conversion.

[0005] Conventional designs for solar energy capture and conversion, which utilize tower-based receiver systems, place the receiver at the top of a tower that is sufficiently tall for the receiver to be visible by the entire heliostat field. FIG. 1 illustrates such a conventional design. As also illustrated by FIG. 1, when molten salt is utilized as the working fluid, in addition to receiver 105, two storage tanks are required, cold salt storage tank 110 and hot salt storage tank 115, to respectively store a first volume of cold salt and a second volume of hot salt. Also, a pumping mechanism (not specifically shown) and a piping system are required to move the salt through the various stages of the conventional receiver system. During operation of the conventional tower-based receiver system, the pumping mechanism pumps the cold salt from the cold salt storage tank 110 up to the receiver 105, where the salt absorbs the energy of the incident light. The heated salt is then piped into the hot salt storage tank 115, from which the hot salt is forwarded to a steam generation facility 120. At each stage, the working fluid is moved through the piping, and the overall solar energy capture and conversion system is complex and relatively expensive to implement.

[0006] Currently, receivers are either of an external-tube or a cavity design, and the receivers are heavy. Both receiver designs necessitate building a substantial and structurally solid tower to support the heavy receiver. Such a tower-based receiver system thus requires greater amounts of capital, plumbing, pumping and maintenance costs to implement. These added costs and other
concerns are magnified when molten salt is adopted as the working fluid within the conventional tower-based system. With molten salt, there are additional requirements/considerations for insulation of the transfer pipes and other plumbing associated with the receiver, as well as for draining or for reheating the salt to prevent the salt from freezing and/or to enable the salt to recover from freezing during periods of extended loss of solar energy.

**SUMMARY**

[0007] Described are a method and system for providing a solar energy capture and storage (SECS) system/facility with a ground-based, integrated volumetric receiver-storage container for efficient solar energy concentration, capture and storage. The SECS system comprises a storage container (tank) with a working fluid volume. The storage container comprises an enclosure with surrounding walls, including a first wall in which one or more openings are disposed. The working fluid is held exclusively within the storage container and absorbs light energy from captured incident light as thermal energy and stores the absorbed thermal energy within the working fluid. Thus, the working fluid held within the storage container serves as both a light energy capture/collection medium and as a storage medium for the thermal energy converted from the light energy. The working fluid completes the absorption of light energy and storage of thermal energy without being transported out of the storage container. The storage container thus operates as a filled-cavity volumetric receiver, and the SECS system obviates transportation of the working fluid, while completing the light energy absorption and thermal energy storage.

[0008] According to the described embodiment, the SECS system further comprises or is associated with a light re-direction and concentration facility, which redirects sunlight from an environment proximate to the storage container into the one or more openings disposed in the first wall of the storage container. The light redirection facility comprises a secondary reflector, which is fixed at a location at which incident sunlight is received from a surrounding heliostat field and which is shaped to reflect/redirect the incident sunlight towards the one or more openings of the storage container. In one embodiment, the light redirection facility further comprises a concentrator positioned between the secondary reflector and the one or more openings of the storage container. The concentrator receives multiple rays of reflected/redirected
light from the secondary reflector and refocuses the multiple rays to provide a concentration of the multiple rays traveling through the one or more openings into the working fluid.

[0009] With the SECS system, the captured incident light is directed at a location below the surface of the working fluid. In one embodiment, a graphite block is submerged within the working fluid internal to the storage container, where the graphite block provides enhanced absorption of light energy from the captured incident light entering the storage container through the one or more openings. In another related embodiment, one or more particles are mixed into the working fluid to change the opacity of the working fluid, which opacity affects a penetration depth of the captured incident light and an amount of working fluid absorption of the light energy. The one or more particles are graphite particles in one implementation.

[0010] In various different embodiments, the SECS system further comprises and/or is associated with one or more mechanisms associated/interconnected with the storage container to enable utilization of the stored thermal energy to provide one or more uses of the thermal energy for one or more processes requiring thermal energy within the range of temperatures at which the working fluid exists. These one or more processes comprise: electric power generation; water desalination; absorption chiller/refrigeration; enhanced oil recovery; potential replacement of natural gas as a heat source for existing gas-fired steam cycle power systems; and hydrogen production to enhance and/or replace other manufacturing processes for hydrogen driven transportation options.

[0011] All objects, features, and advantages of the present invention will become apparent in the following detailed written description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] This invention is described with illustrative embodiments in the following specification with reference to the drawings, in which like numbers represent the same or similar elements, as follows:

[0013] FIG. 1 illustrates a conventional solar-to-electric energy conversion plant/facility/operation, which utilizes a tower-based solar energy receiver and multiple storage
tanks and pipes for piping cold and hot working fluids into and out of the receiver, according to the prior art;

[0014] FIG. 2 is a system diagram illustrating the solar energy capture and storage (SECS) system having a fluid filled, volumetric receiver-storage container located within a light concentration and redirection facility, according to one embodiment of the invention;

[0015] FIG. 3A illustrates a first cross-sectional view of the internal and external structure of a volumetric receiver-storage container sub-system of the SECS system, containing the working fluid, stirring/agitating mechanism, as well as an example energy transfer mechanism, in accordance with embodiments of the invention;

[0016] FIG. 3B, illustrates a second cross-sectional view of the internal and external structure of a volumetric receiver-storage container sub-system similar to FIG. 3A, and further containing a graphite block for enhanced light energy absorption, in accordance with one embodiment of the invention;

[0017] FIG. 4 is a block diagram representation of the utilization of a SECS system with representative heat transfer mechanism (pipes) for transferring stored thermal energy to a turbine, for electric power production, according to one embodiment of the invention;

[0018] FIG. 5 provides a method for designing, manufacturing or setting up a SECS system/facility with a ground-based, integrated volumetric receiver-storage container for efficient solar energy concentration, capture and storage, according to various embodiments of the invention; and

[0019] FIG. 6 provides an example process diagram of a method by which the processes of utilizing/transferring the captured and stored thermal energy from the SECS system for energy conversion or other usage is performed, according to embodiments of the invention.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0020] In the following detailed description of exemplary embodiments of the invention, specific exemplary embodiments in which the invention may be practiced are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that
other embodiments may be utilized and that architectural, mechanical, and other changes may be made without departing from the spirit or scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims.

[0021] Similarly, it is understood that the use of specific component, material, device and/or parameter names are for example only and not meant to imply any limitations on the invention. The invention may thus be implemented with different nomenclature/terminology utilized to describe the components/material/devices/parameters herein, without limitation. Each term utilized herein is to be given its broadest interpretation given the context in which that term is utilized.

[0022] Within the descriptions of the figures, similar elements are provided similar names and reference numerals as those of the previous figure(s). Where a later figure utilizes the element in a different context or with different functionality, the element is provided a different leading numeral representative of the figure number (e.g., lxx for Figure 1 and 2xx for Figure 2). The specific numerals assigned to the elements are provided solely to aid in the description and not meant to imply any limitations (structural or functional) on the invention.

[0023] Several descriptive terms are utilized to describe certain functional characteristics of the SECS system. To facilitate the understanding of the described embodiments of the present invention described below, the following terminology will be used as described below.

(a) reflector/mirror/reflective device: a device with a physical surface that reflects incident light away from the surface;

(b) working fluid: describes the material within the storage container that is utilized to absorb the solar light energy received at/through the opening of the storage container; the working fluid may exist in fluid form or in solid form or as a combined form (admixture) having some volume of fluid and a remaining volume of solid material; the working fluid may include a secondary substance added to the working fluid to change the working fluid's opaqueness.
(c) melting temperature: the temperature at which the working fluid transforms from solid form to liquid form; and

(d) energy dissipation/absorption region(s): one or more regions within the volume of working fluid (possibly including portions of the storage container walls and/or one or more inserted light absorbing targets) in which the largest concentration of light energy absorption in the working fluid occurs, making the volume of working fluid in such region(s) within the storage container the most likely to be in fluid form when the material is at or above the operating temperature.

(e) operating temperature: the predetermined temperature or temperature range at which the working fluid remains in fluid form or in some combination/admixture of fluid and solid form and is able to achieve a predetermined maximum energy storage without compromising the energy containment system.

(f) cold startup: refers to the process by which heat is applied to the working fluid to increase the temperature of the working fluid up to or closer to the operating temperature; the process applies to conditions in which the working fluid is not sufficiently viscous (i.e., not enough of the working fluid is in a fluid state versus solid state to begin the full scale capture of light energy without causing localize boiling), and during the cold startup process, the temperature of the working fluid is slowly increased to cause melting of the solid material until sufficient fluid material exists within the admixture to allow stirring and/or prevent localized boiling.

[0024] The illustrative embodiments provide a method and system for providing a solar energy capture and storage (SECS) system/facility with a ground-based, integrated volumetric receiver-storage container for efficient solar energy concentration, capture and storage. The SECS system comprises a storage container (tank) with a working fluid volume. The storage container comprises an enclosure with surrounding walls, including a first wall in which one or more openings are disposed. The working fluid is held exclusively within the storage container and absorbs light energy from captured incident light as thermal energy and stores the absorbed thermal energy within the working fluid. Thus, the working fluid held within the storage container serves as both a light energy capture/collection medium and as a storage medium for
the thermal energy converted from the light energy. The working fluid completes the absorption of light energy and storage of thermal energy without being transported out of the storage container.

[0025] The storage container comprises an insulation layer disposed on the walls of the storage container. The insulation layer substantially reduces losses of thermal energy from working fluid inside the storage container via the walls of the storage container. With this configuration, the storage container is a filled-cavity volumetric receiver, and the SECS system obviates transportation of the working fluid, while completing the light energy absorption and thermal energy storage.

[0026] The storage container further comprises one or more insulated covers which are selectively placed over the one or more openings, respectively, based on a detection of one or more pre-identified conditions, which trigger a closure off the one or more openings via the one or more insulated covers. These pre-identified conditions comprise one or more of: detecting a weather condition that is not conducive to continued sunlight redirection; detecting a weather condition that would adversely affect thermal energy absorption or lead to thermal energy loss from the working fluid; and detecting when the working fluid has achieved a pre-identified threshold level of thermal energy storage. Other conditions may also trigger the closure of the one or more openings, or the closure may be initiated by operator request, in one embodiment.

[0027] According to the described embodiment, the SECS system further comprises and/or is associated with a light re-direction and concentration facility, which redirects sunlight from an environment proximate to the storage container into the one or more openings disposed in the first wall of the storage container. The light redirection facility comprises a secondary reflector, which is fixed at a location at which incident sunlight is received from a surrounding heliostat field and which is shaped to reflect/redirect the incident sunlight towards the one or more openings of the storage container. The elevated secondary reflector redirects substantially all of the light received from the heliostat field of primary mirrors downwards into an opening in the storage container.

[0028] In one embodiment, the light redirection facility further comprises a concentrator positioned between the secondary reflector and the one or more openings of the storage
container. The concentrator receives multiple rays of reflected/redirected light from the secondary reflector and refocuses the multiple rays to provide a concentration of the multiple rays traveling through the one or more openings into the working fluid. The described and illustrated embodiment provides that the storage container has a single opening positioned in a top surface of the storage container and the secondary reflector is located at a position above the single opening that enables the rays of incident sunlight reflected by the secondary reflector to be travel towards the single opening.

[0029] In one embodiment, the light redirection facility includes a support structure to which the secondary reflector is attached at a position relative to the storage container and to the heliostat field, which position enables the secondary reflector to receive reflected rays of incident sunlight from reflective mirrors of the heliostat field and re-direct the reflected rays towards the one or more openings of the storage container. The heliostat field comprises a plurality of heliostats each having multiple reflective mirrors mounted thereon and positioned at angles to reflect rays of incident sunlight towards the secondary reflector. The secondary reflector is one of a convex or a concave shape based on an angle at which received incident sunlight from the heliostat field are to be reflected towards one or more openings.

[0030] In the described embodiments, the working fluid is a salt in one or more states from among a fluid, a solid and an admixture of fluid and solid, and in one particular implementation, the salt is sodium chloride (NaCl). With the SECS system, the captured incident light is directed at a location below the surface of the working fluid. In one embodiment, a graphite block is submerged within the working fluid internal to the storage container, where the graphite block provides enhanced absorption of light energy from the captured incident light entering the storage container through the one or more openings. In another related embodiment, one or more particles are mixed into the working fluid to change the opacity of the working fluid, which opacity affects a penetration depth of the captured incident light and an amount of working fluid absorption of the light energy. The one or more particles are graphite particles in one implementation.

[0031] The working fluid has a volume that is less than a total internal volume of the storage container. The heat energy is retained by the working fluid until used for generation of other
forms of energy, such as electricity. During light energy capture operations, a substantial majority of the light rays passing through the opening is received and captured within the volume of the working fluid by scattering and absorption, and light energy is dispersed as heat and stored as thermal energy throughout the working fluid via convection. In one embodiment, the opacity of the working fluid is adjusted through the introduction of another substance, which controls a first amount of light energy that is volumetrically absorbed versus a second amount of light energy that is first absorbed by the walls of the storage container before being conductively transferred to the working fluid. The working fluid retains the absorbed thermal energy within the storage container until the thermal energy is later transferred out of the storage container by a transfer mechanism for utilization in generation of other forms of energy or for other uses. The transfer mechanisms utilized do not involve the transportation of the working fluid.

[0032] According to yet another embodiment, the SECS system further comprises a mechanism for stirring the working fluid, with the mechanism having a first component located external to the storage container and a second stirring component located internally to the storage container and attached to the first component. The stirring mechanism is activated to agitate and move the working fluid around the storage container to enable spreading of the thermal energy within the working fluid by convection. Additionally, the SECS system may have a separate mechanism or utilize the same stirring component to agitate a surface layer of the working fluid and prevent reflection/refraction of the received light rays back out through the one or more openings.

[0033] During operation of the SECS system, the temperature at which the working fluid exists is within a range of temperature proximate to a melting temperature of the working fluid. Absorbed thermal energy is stored within the working fluid as latent heat or a combination of latent and sensible heat. When the thermal energy is stored as latent heat, the working fluid is maintained at or near the melting temperature of the working fluid (e.g., within ~ ten degrees of), wherein the working fluid is an admixture of solid and molten states, with a relative amount of each state within the working fluid based on a proportion/amount of heat energy stored within the working fluid. However, when the thermal energy is stored as sensible heat, the working fluid is maintained in the range of temperatures above (e.g., within a hundred degrees of), the melting temperature. The amount of heat stored or extracted from the working fluid is then affected by changes in that temperature.
According to one embodiment, the SECS system further comprises several feedback/control mechanisms. These feedback mechanisms include: a first feedback mechanism, which responsive to activation of a cold startup process for the working fluid, selectively directs a subset of a total number of reflective mirrors of the heliostat field towards the secondary reflector. With this feedback process, less than a full concentration of incident sunlight is directed into the working fluid to enable a controlled heating of the working fluid up to a desired operating temperature during cold startup. In one embodiment, which may be a further extension to the cold startup feedback mechanism or provided as a separate mechanism for cold startup, the SECS system comprising one or more external heating components coupled to a feedback mechanism. This feedback mechanism activates the one or more heating components to apply external heat to the storage container, responsive to activation of a cold startup process. The feedback mechanism also halts the application of external heat when the working fluid within the storage container reaches a pre-determined startup operating temperature.

Other embodiments of the SECS system provides a second feedback mechanism, which responsive to a detection of one or more conditions which require closing off the one or more openings, triggers a set of functions including: redirecting the heliostat field away from the secondary reflector; and triggering a mechanical closure of the one or more openings by mechanically affixing one or more insulated covers over the one or more openings. Similarly, a third feedback mechanism, which may be associated with the first feedback mechanism detects when the amount of thermal energy stored within the working fluid reaches a predetermined threshold, and responds to the detection that the amount of stored thermal energy has reached the predetermined threshold by triggering redirection of the heliostat field to substantially reduce the amount of incident sunlight received at the secondary reflector.

According to one embodiment, the SECS system further comprises and/or is associated with a heat exchange mechanism interconnected with the storage container. The heat exchange mechanism enables transfer of the stored thermal energy to a secondary device/system/mechanism which utilizes the thermal energy and/or converts the thermal energy to a next form of energy. In various different embodiments, the SECS system further comprises and/or is associated with one or more mechanisms associated/interconnected with the storage
container to enable utilization of the stored thermal energy to provide one or more uses of the thermal energy for one or more processes requiring thermal energy within the range of temperatures at which the working fluid exists. These one or more processes comprise: electric power generation; water desalination; absorption chiller/refrigeration; enhanced oil recovery; potential replacement of natural gas as a heat source for existing gas-fired steam cycle power systems; and hydrogen production to enhance and/or replace other manufacturing processes for hydrogen driven transportation options.

[0037] Referring now to FIG. 2, there is illustrated an example SECS system, according to one embodiment. SECS system 200 comprises a large storage container (or tank) 220, which contains working fluid 230. Storage container 220 has one or more openings of which opening 227 is illustrated.

[0038] SECS system 200 also comprises and/or is affiliated with a sunlight concentration and redirection facility, which includes an elevated reflector (e.g., a mirror or a reflective device), referred to herein as secondary reflector 205, which is held in the elevated position by a solid frame structure 210 that extends from the ground (or other base/flooring representing a lower surface). In one alternate implementation, the secondary reflector 205 may be held in place by an overhead structure or cables, rather than the frame structure 210. The elevated reflector is the secondary reflector 205 and operates as one component of a light redirecting/concentrating system for receiving and concentrating received light beams to a single high energy dissipation region within the working fluid 230, as described below. The secondary reflector 205 can be concave or convex, as seen by the incident heliostat light (described below).

[0039] Storage container 220 is illustrated as physically located on the ground (or on a base surface lower than the secondary reflector 205) and the opening 227 of storage container 220 is positioned to receive light rays reflected/redirected by secondary reflector 205. In the illustrative embodiment, located above the storage container 220 (and more specifically above the opening 227) is a suitably geometric shaped concentrating mirror/reflector (concentrator) 225, operating qualitatively as a non-imaging light funnel. The concentrator 225 is designed to direct and concentrate light reflecting off/redirected by the secondary reflector 205 into the opening 227 of storage container 220, with the maximum concentration of incident light rays occurring deep in
the working fluid volume or on the submerged walls of the storage container 220 (as described in greater detail below). With the utilization of the concentrator 225, the SECS system 200 enables a very high incident flux of sunlight to be concentrated in and absorbed throughout a volume of working fluid that operates as a light energy-absorbing and energy storage medium.

[0040] The (non-imaging) concentrator 225 may consist of one or more funnel-shape mirrors to further concentrate the incident power into a minimum deposition footprint within the primary energy dissipation region (335, FIG. 3) of the working fluid 230. Where multiple openings are provided within the storage container for receiving redirected light into the working fluid, multiple corresponding concentrators may be provided within the SECS system, above the multiple individual openings, according to one embodiment.

[0041] In one embodiment, the concentrator 225 is geometrically shaped in order to direct the light through the opening of the storage container, towards a location below the surface of the working fluid. Thus, the light penetrates through the surface layer of the working fluid contained within the storage container. In an alternate embodiment, the concentrator may have the bottom end extended into the working fluid, below the surface of the fluid. This placement of the concentrator 225 forces the concentration of light rays to be directed below the surface of the working fluid, reducing or substantially eliminating the likelihood of reflected light at the surface of the working fluid escaping back through the opening. The combination of the secondary reflector 203 and concentrator 225 provides a light-collection system that is designed to direct substantially all of the light into the volume of working fluid, exploiting the transparency of the working fluid, so that the collected light is absorbed by the volume of the working fluid and/or by the tank's interior walls surrounding the working fluid. This volumetric absorption permits complete capture of the solar energy while avoiding localized heating of receiver components and the need to pump or transport the working fluid between separate receiver and storage systems.

[0042] While the concentrator 225 is illustrated as conically shaped, it is contemplated that the concentrator 225 may be of a different geometric shape, and the illustration of a conical shaped concentrator is not intended to limit or restrict the invention from being practiced with other configurations of concentrators, having other shapes and dimensions. Also, while illustrated as a
separate component, other embodiments may allow for the concentrator to be an extension of opening, as a single geometric shaped opening of a particular height and dimension to provide for concentration of the received light into the working fluid. The type, shape, dimension and relative location of the opening 227 illustrated is not intended to limit the applicability of the invention to other types, shapes, dimensions and/or locations of openings for the concentrator 225. Functionality attributable to the concentrator and/or opening being conical in shape (e.g., further redirection or reflection of light impinging on the opening's inner surface towards the inside of the storage container) also apply to these other physical configurations of the concentrator 225.

[0043] Surrounding the elevated secondary reflector 205 of the SECS system 200 and positioned at specific locations, relative to the secondary reflector 205 and at pre-determined angles are a series of smaller mirrors 250 attached to/mounted on heliostats and creating a heliostat field of mirrors around the secondary reflector 205. The heliostat field of mirrors is represented in FIG. 2 by two representative heliostat-mounted mirrors 250a and 250b, although it is understood that a much larger number (in the tens or hundreds) of heliostat-mounted mirrors may be provided in actual implementation. These heliostat-mounted mirrors 250 receive rays of sunlight from the sun 260 and reflect those rays towards the secondary reflector 205. In one embodiment, the system of heliostat-mounted mirrors are instrumented and powered to reflect sunlight towards the secondary reflector 205 throughout the daylight periods (i.e., when the sun's rays are of sufficient strength to provide a net positive increase in the amount of thermal energy stored based on absorption of light energy versus the thermal energy being lost by keeping the insulated cover (see FIG. 3) off of the opening). The secondary reflector 205 receives the reflected light rays 255 from the entire heliostat field of mirrors 250 and reflects/redirects each beam/ray of received sunlight into the opening 227 of storage container 220 via concentrator 225.

[0044] In the illustrated and described embodiment of FIG. 2, the SECS system 200 is provided without an electricity generation component or any other energy exchange mechanism. The details of such components/mechanism are not covered in great detail within the present disclosure, although certain of the required/anticipated characteristics related to the usage of the stored thermal energy in a series of different applications are discussed herein.
[0045] The method and system provided by the embodiments described herein provides a
significant simplification to the conventional use of an elevated receiver system, which requires
the piping of the working fluid using hot and cold storage tanks as illustrated by FIG. 1. Rather
than utilize a separate receiver, the embodiments described herein incorporates the solar light
receiving/absorption function into the light energy capture and energy storage functionality
performed by the working fluid 230 within the storage container 220. As shown by FIG. 2, the
enhancement involves providing a secondary reflector to redirect the incident heliostat-directed
light downward and a concentrating reflector (i.e., the conical/geometric shaped
opening/structure above the storage container) to further "funnel" the light flux directly to the
working fluid (the energy storage material/facility). There is no separate receiver or piping of
the working fluid required by the design provided by the SECS system 200.

[0046] Referring now to FIGs. 3A and 3B, which respectively illustrate two cross sectional
views of example storage container 220, and in particular several internal and external
components that assist with the light energy capture and the energy storage features of the SECS
system, as well as the energy exchange features of the SECS system. For each figure (3A-3B),
the storage container 220 comprises a base wall, an enclosed cylindrical (or other shaped) side
wall/surface, and a top wall/surface in which is disposed an opening 227. The walls of the
storage container 220 are made from one or more solid materials from among steel, ceramic,
graphite, or other material, including a composite material. The walls of storage container 220
are insulated by a high-temperature insulation material 310, such as firebrick, or other suitable
insulator. While indicated as insulated on an exterior surface, other embodiments of the
invention may provide for an internal insulation of the storage container 220 or for a
combination of both internal and external insulation. According to the invention, the storage
container is made of a non-corrosive material, and is both insulated and specially shaped to assist
with heat redistribution within the working fluid 230.

[0047] According to one embodiment, the storage container 220 may be constructed with
graphite blocks lining a metal tank. A suitable design would line a metal tank with graphite
blocks, oriented so that the direction of low thermal conductivity in the graphite would be from
the interior of the tank toward the metal exterior of the tank, together with insulating backing
material. Such a design would help minimize thermal losses through the exterior of the tank.
[0048] While the storage container 220 is illustrated as cylindrically shaped, it is contemplated that the storage container 220 may be of a different geometric shape, and the illustration of a cylindrically-shaped storage container are not intended to limit or restrict the invention from being practiced with other configurations of storage containers, having other shapes and dimensions. Additionally, the type, shape, dimension and relative location of the opening 227 illustrated is not intended to limit the applicability of the invention to other types, shapes, dimensions and/or locations of openings for a storage container.

[0049] During operation of the SECS system, the working fluid 230 is heated by concentrated solar light entering the opening 227 in the storage container 220. The opening 227 in the top of storage container 220 enables passage of incident light to the interior of the working fluid. While shown with an angled interior surface with measurable height, it is appreciated that the opening 227 is not necessarily of any particular shape or dimension, and that the design of the size and shape of the opening 227 is such that substantially all of the incident (or re-directed) light from the secondary reflector 205 and/or concentrator 225 passes through the opening 227 at an angle that allows the maximum amount of redirected light to be received below the surface of the working fluid 230 and absorbed into the working fluid 230.

[0050] The combination, relative placement and structural design of the heliostat field of mirrors 250, the elevated primary reflector 205 and conical/geometric concentrator 225, along with the use of the working fluid 230 within a single storage container 220 to both (a) capture and convert the light into thermal energy and (b) store the thermal energy, collectively provide a highly effective solar power/energy collection system. This system enables capturing/collecting and storing of solar energy in a single tank configuration that integrates the functions of light energy absorption and thermal energy storage without causing excessive heat loads on unprotected material surfaces and without requiring transfer of the working fluid.

[0051] As shown by FIGs. 3A-3B, the storage container 220 is provided with a movable, insulated cover 390 for covering the opening 227. The insulated cover 390 is capable of being mechanically (or manually) affixed/placed over the opening 227, based on the occurrence/detection of one or more pre-determined conditions. In one embodiment, opening and closing of the insulated cover 390 may be controlled by a mechanical motor (not shown)
communicatively connected to an appropriate feedback/monitoring mechanism (or feedback controller) 395.

[0052] In the latter embodiment, where the closing of the opening 227 occurs because the maximum amount of energy has been stored within the working fluid or storage container, the heliostat field is defocused from the secondary reflector, preventing a concentration of the light energy on the insulated cover 390 placed over the opening 227 from occurring. As a consequence of these design features, the working fluid 230 will remain substantially within a small temperature range at/above the freezing or melting point temperature such that the working fluid remains in a partially fluid state and never completely freezes.

[0053] Referring again to FIG. 3A, within storage container 220 is the volume of working fluid 230. According to one embodiment, the working fluid 230 is a transparent/opaque fluid, such as molten salt, and is of sufficient volume (relative to the size of the storage container) to capture and store a pre-determined amount of solar energy as thermal energy. The amount of working fluid placed within the container ensures that the surface layer 332 of the working fluid is sufficiently high so that light beams/rays entering the opening 227 terminate within the fluid volume or on the portions of the container walls that are immersed in the fluid.

[0054] When (or if) a different absorption depth is desired for the light energy absorption in the working fluid, the depth at which the light energy absorption occurs can be controlled by adjusting the opacity of the working fluid by the use of suspended graphite power. This use of graphite power can be provided in conjunction with the graphite absorber described above. One alternate embodiment provides for an adjustment in the location or size of the concentrator relative to the opening in order to change the resulting depth within the working fluid at which the received light is concentrated. Additionally, in yet another embodiment, a reflecting conical surface may be placed within the volume of the working fluid to reflect the incident light to the walls where the light energy can be absorbed at reduced flux intensity.

[0055] Depending on the opacity of the working fluid, the light energy absorption (i.e., the amount of absorption of the incoming light particles (photons)) can occur (a) in a volume near the surface, (b) entirely on the walls of the storage container, and/or (c) somewhere in between. In one embodiment, the opacity of the working fluid is deliberately manipulated by the
introduction of one or more high absorption substances/materials, such as graphite powder, to achieve the desired absorption characteristics.

[0056] In one implementation, as illustrated by FIG. 3A, the region of the working fluid in which the majority of the light energy absorption occurs is referred to as the principal energy dissipation/absorption region. Although the principal energy dissipation/absorption region may be a volume of fluid less than that of the full volume of working fluid 230, no limitations are imposed which would prevent the principal energy dissipation/absorption region from being the entire fluid volume. With low opacity working fluid, the principal energy dissipation/absorption region may also be the volume of fluid in close proximity to the internal walls of the storage container, as the received light would travel through the working fluid and be initial absorbed by the container walls before the thermal energy is passed to the fluid in proximity to the container walls.

[0057] During operation, the light reflecting off/redirected by the elevated secondary reflector 205 (FIG. 2) is further concentrated at concentrator 225. Then the concentrated light rays passes through the opening 227 of the storage container 220 and penetrates through the surface layer 332 of the working fluid 230 contained within the storage container 220. The working fluid 230 absorbs the light energy at a point below the surface 332 of the working fluid 230. By the above process, the light-collection/capture process of the SECS system 200 has the full light energy dissipation/absorption region 335 lying within the volume of working fluid 230. The design of the SECS system 200 thus exploits the good transparency of molten salt, so that the light energy dissipation region 335 lies deep in the volume of the working fluid 230, and not at the surface 332. The temperature of the working fluid 230 increases due to the absorption of concentrated light energy, and the working fluid 230 performs the functions of both a light energy capture material/component and an energy storage material/component.

[0058] In the embodiment illustrated by FIG. 3B, a graphite (block) absorber 345 is provided within the working fluid 230 and positioned at the principal light energy dissipation/absorption region 335, such that the incident light impacts the graphite absorber 345 and the light energy from the incident light is absorbed by the graphite absorber 345. The use of the graphite absorber 345 is a design choice, but may be required in some implementations to
enhance/increase/facilitate the absorbing of the light energy within the working fluid. Since the graphite absorber 345 is immersed in the working fluid, the absorbed light energy is eventually transferred to the molten salt as heat energy, without losses outside of the working fluid 230. The selection of graphite as the material for absorption is due to graphite having very high light absorption characteristic, as well as very good thermal conductivity. Further, graphite is chemically inert with salt, which allows for the usage of a graphite block when salt is utilized as the working fluid.

[0059] In one embodiment, reflection of the received rays of light at the free surface of the working fluid within the storage container is substantially reduced (and/or substantially eliminated) by an admixture of graphite dust and/or by agitating the surface of the working fluid to produce a complex rather than smooth planar surface. The mechanism utilized for agitating the surface of the working fluid produces multiple reflections, but reduces undesirable specular (i.e., mirror-like) reflection. This reduction of specular reflection substantially eliminates losses of light energy that would otherwise be reflected off the surface 332 of the working fluid 230 and back out the opening 227. In one embodiment, stirring handle 344 (FIG. 3A-3B) is utilized as the mechanism for agitating the surface of the working fluid.

[0060] Heat is dispersed though the volume of working fluid 230 by natural convection. In one embodiment, natural convection is supplemented by a low-velocity stirring (or pumping) mechanism 340 with a drive/motor 342 located external to the storage container 220 and a stirring handle 344 coupled to the drive/motor 342 and located internal to the storage container 220. The design of the stirring mechanism 340 will depend on many of the parameters mentioned above and others, such as the rate of circulation desired for the working fluid and the magnitude of the temperature gradients that can be tolerated. These parameters are in turn determined by other system design parameters. However, as illustrated by FIG. 3A, the modest pumping rates required for stirring the working fluid to assist with convection can be obtained by a design in which the drive motor 342 for the stirring system/mechanism 340 lies outside the storage container 225. This design of stirring mechanism 340 enables easy maintenance and eliminates the need for a motor and complex pump mechanism that can tolerate the high temperatures and salt chemistry within the storage container itself.
[0061] For the embodiments in which the working fluid 230 is molten salt, the molten salt functions as the medium for light energy absorption and thermal energy storage in the temperature range of 800-1200 °C. The volume of the salt provided within the storage container is matched to the thermal capacity of the solar field (i.e., the heliostat field) and to a desired energy-storage interval. The type of salt utilized is determined by one or more factors, including but not limited to: economics, melting point, opacity, heat capacity, and predetermined and desirable thermal and optical characteristics, for example. In one implementation, potassium and sodium salt mixtures, such as the mixture commonly used in molten salt storage systems, are utilized as the working fluid 230. In another implementation, Sodium Chloride (NaCl) is utilized as the working fluid 230. For NaCl, whose heat of fusion is $4.15\times10^5$ J/kg, 100 MW-hrs of energy can be stored by using approximately 900 metric tons of salt, which will occupy a volume of 400 m$^3$. The storage container utilized will be of a somewhat larger volume to provide for an allowance to assure safety against total freeze-up of the salt. This modest volume integrates well with the optical collection of the SECS system designs provided herein.

[0062] The choice of the type of salt will be determined by cost, melting point, thermal capacity, opacity, and other characteristics/factors. Molten salt does not interact with the atmosphere. Also, stress and other issues of thermal expansion common to solid-material storage schemes are avoided with the SECS system by using molten salt operating at/near its melting point as the thermal storage medium. Direct absorption of concentrated sunlight volumetrically within the molten salt also avoids issues of high-power surface heating.

[0063] The absorbed thermal energy can be stored as either latent or sensible heat or as a combination of both. The choice of storage technique will be determined by system parameters dependent on the intended use of the stored energy. For the latent heat storage case, the salt is maintained at its melting temperature (e.g., approximately 800 °C for NaCl), and the salt in the storage container will be an admixture of solid and molten salt, with the proportions of each determined by the amount of heat stored. As heat is added to the working fluid, the solid salt melts, increasing the fraction of molten salt (relative to the solid salt) and increasing the total thermal energy of the mixture. Removing heat will increase the proportion of solid salt. The location within the storage container at which the freezing of the salt occurs will depend upon the
detailed design of the heat removal system, the rate of heat removal, and the rate at which the molten salt is circulated throughout the storage container.

[0064] To allow the stored thermal energy within the SECS system 200 to be utilized, an energy transfer subsystem is associated with the storage container in one of multiple possible embodiments. The storage container 220 is fitted with appropriate energy/heat transfer equipment, either external or internal to the tank, the specific design of which is not important to the description of the SECS system 200. Key to the various embodiments, however, is that fact that the working fluid 230 is not transported out of the storage container 220 when completing the energy transfer or energy usage function. FIGs. 3A-3B illustrates one possible configuration of an energy transfer/exchange mechanism, referred to herein as a heat transfer system 370, which comprises a network of pipes/tubes extending from the outside of the storage container 220 into the storage container 220. The transporting tubes/pipes of the heat transfer system 370 extending inside the storage container 220 may be made of metal, ceramic, or graphite, for example. In one implementation, which supports energy storage and retrieval with latent heat, the tubes/pipes extend in the space of hot air directly above the working fluid. When air/gas is used as the transport medium for the thermal energy transfer, as provided by each of the illustrated embodiments, the heat transfer system 370 may comprise a compressor and an on/off switching mechanism, which controls when access to/use of the stored thermal energy in the storage container occurs.

[0065] Referring to FIG. 4, the heat transfer pipes/tubes running through the SECS system 200 are illustrated coupled to an electric energy generation facility 410 to produce electricity from the captured and stored solar light energy. A compressor 420 pushes compressed air into the tubes going into the storage container 220 and the compresses air is heated and forwarded to a steam turbine or other electricity/power generation device 410, which converts the received thermal energy into electrical power. In the illustrated embodiment, both ambient air as well as return air from the steam turbine may be fed into the compressor 430, in an open and a closed heat transfer cycle, respectively. The gas turbine generator 410 utilized with the SECS system 220 would be designed to operate with heated gas or steam at/within a specific range of temperatures equal to the temperature range of the SECS system 200. This enables the gas turbine to operate continuously at its high design efficiency during both sunlight and non-sunlight periods. In one
embodiment, a Brayton cycle turbine is utilized because of the turbine's high conversion efficiency at the gas temperatures that can be achieved by the SECS system.

[0066] The simplicity of the storage configuration provides the option of integrating the Brayton-cycle turbine system with the storage of the energy, in one embodiment. In so doing, the affixed heat exchanger would play the role of the Brayton combustion chamber, heating turbine gas passing through the exchanger. Use of an open gas-turbine system enables ambient air to be taken directly from the atmosphere at an intake point 420 to be utilized as the heat/energy transfer medium (see FIG. 4), with no preparation or pre-storage of the gas required. The gas would be externally compressed, passed through the exchanger for heating, used to drive the external turbine, have the heat energy recaptured (or recuperated, common in Brayton systems) and released back to the environment, with no waste product generation and no negative environmental impact. With this extension of the SECS system to include a Brayton system, no piping of the working fluid 230 is required. Also, because the heat exchanger transfers power directly to the working turbine gas, no use of a separate heat transfer fluid, such as water to produce steam for a steam turbine, is required.

[0067] When the SECS system 200 is first being put online, some mechanism for performing cold start up is required to heat the working fluid close to the SEC system's operating temperature, without having localized boiling/overheating of the working fluid. According to one embodiment, one option for cold startup of the SECS system, prior to light energy absorption, utilizes auxiliary heat sources to bring the working fluid to its working temperature. These auxiliary heat sources may include, but are not limited to, electric heaters (internal or external to the storage container) or gas-fired heaters (external to the storage container). According to one embodiment, and as illustrated by FIGs. 3A-3B, certain characteristics of the working fluid (e.g., one or more of viscosity, temperature, ratio of solid (crystal salt) to liquid (liquid salt) in working fluid mixture, and/or height of fluid in tank) are monitored using some form of monitoring/feedback mechanism. The feedback mechanism includes a sensor 385 and a feedback controller 395.

[0068] According to a more desirable embodiment, cold-startup is provided via controlled injection of solar light energy into the working fluid volume at a pre-determined rate that is
determined to allow melt-spreading within the working material, while preventing local boiling. This implementation of measured injection of solar light energy enables the system (working fluid) to be brought to working temperature without the need for an auxiliary heating system. It can be done either by injecting the captured/concentrated sunlight at low intensity (e.g., in the early morning), reducing the need for external control of the system, or by selectively directing the amount of heliostat power incident on the secondary reflector.

[0069] Turning now to the flow charts (or functional block diagrams) of FIGs. 5 and 6 there are illustrated two methods by which a SECS system is created and utilized, according to various described embodiments. FIG. 5 generally provides a method for setting up the SECS system for efficient collection and storage of solar energy as thermal energy. More specifically, FIG. 5 provides a method for designing, manufacturing or setting up a SECS system/facility with a ground-based, integrated volumetric receiver-storage container for efficient solar energy concentration, capture and storage. FIG. 6 describes some of the processes of utilizing/transferring the captured and stored thermal energy for energy conversion or other usage. The processes and/or functional steps within these flow charts/diagrams are generally described from the perspective of and with reference to the embodiments described above and illustrated by FIGs, 2-4; However, the processes may equally apply to or be completed with/by other configurations of SECS systems and any equivalents thereof.

[0070] In the flow charts and/or functional block diagrams below, certain processes of the methods may be combined, performed simultaneously or in a different order, or perhaps omitted, without deviating from the spirit and scope of the invention. Thus, while the method processes are described and illustrated in a particular sequence, use of a specific sequence of processes is not meant to imply any limitations on the invention. Changes may be made with regards to the sequence of processes without departing from the spirit or scope of the present invention. Use of a particular sequence is therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims.

[0071] The method of FIG. 5 begins at block 500 and proceeds to block 505, which presents the process of providing a storage container with a working fluid that is held exclusively within the storage container. The working fluid is preselected according to design parameters in order to
absorb light energy from captured incident light as thermal energy and store the absorbed thermal energy within the working fluid. As described herein, the storage container provided includes a first wall in which one or more openings are disposed. More importantly, the working fluid held within the storage container serves as both a light energy capture/collection medium and as a storage medium for the thermal energy converted from the light energy, and the working fluid completes both of these functions without being transported out of the storage container. With the storage container having working fluid provided, the method moves to block 510, describes positioning/placing the storage container containing the working fluid within a light redirection and concentration facility, which redirects sunlight from an environment proximate to the storage container into the one or more openings disposed in the first wall of the storage container. According to the illustrated embodiments, the method includes (block 515) the process of enabling receipt and capture of rays of the incident sunlight that is redirected towards the one or more openings, by selectively placing the secondary reflector of the light redirection and concentration facility and the storage container in positions relative to each other and to the surrounding heliostat field to accomplish the redirection of the incident sunlight through the one or more openings. The secondary reflector is fixed at a location, relative to the storage container, at which the secondary reflector receives incident sunlight from a surrounding heliostat field and from which location the incident sunlight is reflected/redirected towards the one or more openings of the storage container. At block 520, the method includes positioning a concentrator between the secondary reflector and the one or more openings of the storage container. The concentrator which receives multiple rays of reflected/redirected light from the secondary reflector and refocuses the multiple rays to provide a concentration of the multiple rays traveling through the one or more openings into the working fluid.

[0072] As shown at block 525, the method may include submerging a graphite block within the working fluid in the storage container to provide enhanced absorption of light energy from the captured incident light entering the storage container. Alternatively, or in addition, the method may include block 530 at which the process includes mixing one or more particles into the working fluid to change the opacity of the working fluid. The opacity of the working fluid affects a penetration depth of the captured incident light and an amount of working fluid absorption of the light energy. In one embodiment, the particles are graphite particles. Thus, the opacity of the working fluid is adjusted through an introduction of another substance, which
controls a first amount of light energy that is volumetrically absorbed versus a second amount of light energy that is first absorbed by the walls of the storage container before being conductively transferred to the working fluid.

[0073] With the physical components in place, the method further provides at block 535 for initiating cold startup of the SECS system. As a part of the cold startup process, the method may provide for stirring and/or agitating the working fluid during operation by powering on/activating a stirring mechanism to agitate and move the working fluid around the storage container to enable spreading of the thermal energy within the working fluid by convection. In one embodiment, the mechanism includes a first component located external to the storage container and a second stirring component attached to the first component and located internally to the storage container. In one embodiment, the method also comprises agitating a surface layer of the working fluid, so that the captured incident light is directed at a location below the surface of the working fluid. However, this process may be completed simultaneously with that provided in block 525. With the SEC system so designed, the process of FIG. 5 ends at termination block 540.

[0074] FIG. 6 briefly illustrates the method by which the thermal energy stored within the working fluid is extracted for use and/or conversion to other forms of energy. Notably, none of the possible transfer mechanisms provided for herein involve the transfer of the working fluid out of the storage container. The method begins at initiation block 600 and proceeds to block 605 at which a designer/manufacturer/user of the SECS system performs the process of associating/interconnecting a transfer mechanism with the storage container. Depending on the stage (design, manufacture, use), the process of associating/interconnecting may involve (a) the actual insertion of transfer pipes/tubes inside (where "inside" may be within the working fluid or in the free space above the working fluid), adjacent to, or wrapped around the heat conductive walls of the storage container. The process of associating/interconnecting may also be simply turning on the mechanism that enables the flow of the heat transfer medium (e.g., water or air) through pre-established energy transfer pipes/tubes. From this process of associating the SECS system with the transfer mechanism, the method provides a series of determinations (block 610 - 640), which affect/direct how the stored thermal energy of the SECS system is ultimately utilized. In the described embodiments, the stored thermal energy is utilized for one or more
processes requiring thermal energy within the range of temperatures at which the working fluid exists. At block 610, the method provides a first determination whether the thermal energy is to be used for electric power generation (perhaps via a heat exchange turbine). If the thermal energy is not to be used for electric power generation and/or if only some of the stored thermal energy is to be used in this manner, the method provides from blocks 615-640 a series of other determinations of whether the stored thermal energy is to be used for: water desalination (615); absorption chiller/refrigeration (620); enhanced oil recovery (625); potential replacement of natural gas as a heat source for existing gas-fired steam cycle power systems (630); hydrogen production to enhance and/or replace other manufacturing processes for hydrogen driven transportation options (635); or some other usage (640). Regardless of the actual usage desired for the thermal energy being retrieved from the SECS system, the method provides at block 645 that the associated heat exchange mechanism interconnected with the storage container performs the transfer of the stored thermal energy to a secondary device/system/mechanism which utilizes the thermal energy and/or converts the thermal energy to a next form of energy, without transferring any of the working fluid out of the storage container. The process then ends at block 650.

[0075] Implementation of one or more of the described embodiments provides a class of ground-based solar/thermal energy collection and storage devices whose design enables maximum benefit to be reaped from use of secondary reflectors and concentrating mirrors to beam and localize the light coming from a heliostat field, without requiring a separate elevated receiver device and the associated costs with such a receiver device. As provided by the described embodiments, the resulting design integrates the reception, absorption and thermal storage of the concentrated optical power/light energy into the single working fluid medium, so as to affect considerable system reductions in both complexity and cost. Thus, the SECS system offers, for both capital and O&M (operations and maintenance), a substantially low cost configuration (compared to the higher cost for implementing conventional light energy collection and storage systems) for converting collected light to thermal energy. The described embodiments provide the following important desiderata of a receiver-storage system without the use of a separate receiver: efficient light-to-thermal power conversion; a storage medium having high heat capacity, low heat loss and good heat dispersal; minimum piping or no piping of molten salt (the working fluid); materials compatibility under extreme conditions; mechanical integrity over a
wide range of temperature; and efficient power coupling to turbine gas. The SECS system enables completion of all of these desiderata, and all at substantially reduced/minimal cost relative to other solar power generation systems.

[0076] While the invention has been described with reference to exemplary embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular system, device or component thereof to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another.
What is Claimed is:

1. A solar energy capture and storage (SECS) system comprising:
   a storage container comprising an enclosure with surrounding walls, including a wall in which one or more openings are disposed; and
   a working fluid held exclusively within the storage container and which absorbs light energy from captured incident light as thermal energy and stores the absorbed thermal energy within the working fluid;
   wherein the working fluid held within the storage container serves as both a light energy capture/collection medium and as a storage medium for the thermal energy converted from the light energy; and
   wherein the working fluid completes the absorption of light energy and storage of thermal energy without being transported out of the storage container.

2. The SECS system of Claim 1, wherein further:
   the storage container comprises an insulation layer disposed on the walls of the storage container, which insulation layer substantially reduces losses of thermal energy from working fluid inside the storage container via the walls of the storage container; and
   the storage container is a filled-cavity volumetric receiver and the SECS system obviates transportation of the working fluid, while completing the light energy absorption and thermal energy storage.

3. The SECS system of Claim 1, further comprising a light re-direction and concentration facility, which redirects sunlight from an environment proximate to the storage container into the one or more openings disposed in the first wall of the storage container.

4. The SECS system of Claim 3, wherein the light redirection facility comprises:
   a secondary reflector fixed at a location at which incident sunlight is received from a surrounding heliostat field and which is shaped to reflect/redirect the incident sunlight towards the one or more openings of the storage container.
5. The SECS system of claim 4, wherein the light redirection facility further comprises:
   a concentrator positioned between the secondary reflector and the one or more openings of the storage container and which receives multiple rays of reflected/redirected light from the secondary reflector and refocuses the multiple rays to provide a concentration of the multiple rays traveling through the one or more openings into the working fluid.

6. The SECS system of claim 1, wherein the working fluid is a salt in one or more states from among a fluid, a solid and an admixture of fluid and solid.

7. The SECS system of Claim 6, wherein the salt is sodium chloride (NaCl).

8. The SECS system of claim 1, further comprising a mechanism for stirring the working fluid, said mechanism having a first component located external to the storage container and a second stirring component located internally to the storage container and attached to the first component, wherein the stirring mechanism is activated to agitate and move the working fluid around the storage container to enable spreading of the thermal energy within the working fluid by convection.

9. The SECS system of Claim 1, further comprising:
   a mechanism for agitating a surface layer of the working fluid; and
   wherein the captured incident light is directed at a location below the surface of the working fluid.

10. The SECS system of claim 1, further comprising a graphite block submerged within the working fluid internal to the storage container, said graphite block providing enhanced absorption of light energy from the captured incident light entering the storage container through the one or more openings.

11. The SECS system of claim at 1, further comprising one or more particles mixed into the working fluid to change an opacity of the working fluid, which opacity affects a penetration depth of the captured incident light and an amount of working fluid absorption of the light energy.
12. The SECS system of claim 11, wherein the one or more particles are graphite particles.

13. The SECS system of Claim 1, further comprising one or more mechanisms associated with or interconnected to the storage container to enable utilization of the stored thermal energy to provide one or more uses of the thermal energy for one or more processes requiring thermal energy within a range of temperatures at which the working fluid exists, wherein the one or more processes comprises: electric power generation; water desalination; absorption chiller/refrigeration; enhanced oil recovery; potential replacement of natural gas as a heat source for existing gas-fired steam cycle power systems; and hydrogen production to enhance and/or replace other manufacturing processes for hydrogen driven transportation options.

14. The SECS system of claim 1, further comprising a heat exchange mechanism interconnected with the storage container, and which enables transfer of the stored thermal energy to a secondary device/system/mechanism which utilizes the thermal energy and/or converts the thermal energy to a next form of energy.

15. The SECS system of claim 1, wherein said storage container further comprises one or more insulated covers which are selectively placed over the one or more openings, respectively, based on a detection of one or more pre-established conditions which trigger a closure of the one or more openings via the one or more insulated covers, said pre-established conditions comprising one or more of: detecting a weather condition that is not conducive to continued sunlight redirection; detecting a weather condition that would adversely affect thermal energy absorption or lead to thermal energy loss from the working fluid; and detecting when the working fluid has achieved a pre-identified threshold level of thermal energy storage.

16. The SECS system of claim 4, further comprising:

a first feedback mechanism which responsive to activation of a cold startup process for the working fluid, selectively directs a subset of a total number of reflective mirrors of the heliostat field towards the secondary reflector, wherein less than a full concentration of incident sunlight is directed into the working fluid to enable a controlled heating of the working fluid up to a desired operating temperature.
17. The SECS system of Claim 1, further comprising one or more external heating components coupled to a feedback mechanism, which activates the one or more heating components to apply external heat to the storage container responsive to a cold startup process and which halts the application of external heat when the working fluid within the storage container reaches a pre-determined startup operating temperature.

18. The SECS system of Claim 4, further comprising:
   a second feedback mechanism which responsive to a detection of one or more conditions which require closing off the one or more openings, triggers a set of functions including:
      redirecting the heliostat field away from the secondary reflector; and
      triggering a mechanical closure of the one or more openings by mechanically affixing one or more insulated covers over the one or more openings.

19. The SECS system of Claim 15, further comprising:
   a third feedback mechanism which detects when the amount of thermal energy stored within the working fluid reaches a predetermined threshold, and responds to a detection that the amount of stored thermal energy has reached the predetermined threshold by triggering redirection of the heliostat field to substantially reduce an amount of incident sunlight received at the secondary reflector.

20. The SECS system of claim 3, further comprising:
   a support structure to which the secondary reflector is attached at a position relative to the storage container and to the heliostat field that enables the secondary reflector to receive reflected rays of incident sunlight from reflective mirrors of the heliostat field and re-direct the reflected rays towards the one or more openings of the storage container;
   wherein the secondary reflector is one of a convex or a concave shape based on an angle at which received incident sunlight from the heliostat field are to be reflected towards one or more openings.

21. The SECS system of claim 3, wherein the one or more openings is a single opening positioned in a top surface of the storage container and the secondary reflector is located at a
position above the single opening that enables the rays of incident sunlight reflected by the secondary reflector to travel towards the single opening.

23. The SECS system of claim 1, wherein the heliostat field comprises a plurality of heliostats each having multiple reflective mirrors mounted thereon and positioned at angles to reflect rays of incident sunlight towards the secondary reflector.

23. The SECS system of Claim 1, wherein:

   the working fluid has a volume that is less than a total internal volume of the storage container;

   a substantial majority of the light rays received within the working fluid are scattered and light energy is dispersed as heat and stored as thermal energy throughout the working fluid via convection;

   an opacity of the working fluid is adjusted through an introduction of another substance, which controls a first amount of light energy that is volumetrically absorbed versus a second amount of light energy that is first absorbed by the walls of the storage container before being conductively transferred to the working fluid; and

   the working fluid retains the absorbed thermal energy within the storage container until the thermal energy is later transferred out of the storage container by a transfer mechanism for utilization in generation of other forms of energy or for other uses, wherein the transfer mechanisms does not involve the transportation of the working fluid.

24. The SECS system of Claim 1, wherein:

   a temperature at which the working fluid exists is within a range of temperature proximate to a melting temperature of the working fluid;

   absorbed thermal energy is stored within the working fluid as one of latent heat or a combination of latent and sensible heat;

   when the thermal energy is stored as latent heat, the working fluid is maintained at or near the melting temperature of the working fluid, wherein the working fluid is an admixture of solid and molten states, with a relative amount of each state within the working fluid based on a proportion/amount of heat energy stored within the working fluid; and
when the thermal energy is stored as sensible heat, the working fluid is maintained in a range of temperatures above, but near, the melting temperature, with the amount of heat stored or extracted from the working fluid affected by changes in that temperature.

25. A method for generating electrical energy comprising a heat/steam to electricity conversion facility and a heat transfer mechanism that is arranged to retrieve thermal energy from the storage container of the SECS system of Claim 1 without transporting the working fluid out of the storage container.

26. A method for generating electrical energy comprising a heat/steam to electricity conversion facility and a heat transfer mechanism that is arranged to retrieve thermal energy from the storage container of the SECS system of Claim 4 without transporting the working fluid out of the storage container.

27. A method for efficient collection and storage of solar energy as thermal energy, the method comprising:

- providing within a storage container a working fluid held exclusively within the storage container and which absorbs light energy from captured incident light as thermal energy and stores the absorbed thermal energy within the working fluid;
- wherein the storage container comprises an enclosure with surrounding walls, including a first wall in which one or more openings are disposed;
- wherein the working fluid held within the storage container serves as both a light energy capture/collection medium and as a storage medium for the thermal energy converted from the light energy;
- wherein the working fluid completes the absorption of light energy and storage of thermal energy without being transported out of the storage container; and
- wherein the storage container with working fluid provides a solar energy concentration and storage (SECS) system.

28. The method of Claim 27, wherein:
the storage container comprises an insulation layer disposed on the walls of the storage container, which insulation layer substantially reduces losses of thermal energy from the interior of the storage container through the walls of the storage container; and

the storage container is a filled-cavity volumetric receiver and the SECS system obviates transportation of the working fluid, while completing the light energy absorption and thermal energy storage.

29. The method of Claim 27, further comprising:

placing the storage container containing the working fluid within a light re-direction and concentration facility, which redirects sunlight from an environment proximate to the storage container into the one or more openings disposed in the first wall of the storage container.

30. The method of Claim 29, wherein the light redirection and concentration facility comprises:

a secondary reflector fixed at a location at which incident sunlight is received from a surrounding heliostat field and which is shaped to reflect/redirect the incident sunlight towards the one or more openings of the storage container; and

wherein said method comprises enabling receipt and capture of rays of the incident sunlight that is redirected towards the one or more openings by selectively placing the secondary reflector and the storage container in positions relative to each other and to the surrounding heliostat field to accomplish the redirection of the incident sunlight through the one or more openings.

31. The method of claim 30, wherein the light redirection facility further comprises:

a concentrator positioned between the secondary reflector and the one or more openings of the storage container and which receives multiple rays of reflected/redirected light from the secondary reflector and refocuses the multiple rays to provide a concentration of the multiple rays traveling through the one or more openings into the working fluid.

32. The method of claim 27, wherein the working fluid is a salt in one or more states from among a fluid, a solid and an admixture of fluid and solid.

33. The method of claim 32, wherein the salt is sodium chloride (NaCl).
34. The method of claim 27, wherein SECS system further comprises a mechanism for stirring the working fluid, said mechanism having a first component located external to the storage container and a second stirring component located internally to the storage container and attached to the first component, said method further comprising activating the stirring mechanism to agitate and move the working fluid around the storage container to enable spreading of the thermal energy within the working fluid by convection.

35. The method of claim 27, wherein the SECS system further comprises a mechanism for agitating a surface layer of the working fluid, wherein the captured incident light is directed at a location below the surface of the working fluid.

36. The method of claim 27, wherein the SECS system further comprises a graphite block submerged within the working fluid internal to the storage container, said graphite block providing enhanced absorption of light energy from the captured incident light entering the storage container through the one or more openings.

37. The method of claim at 27, wherein the SECS system further comprises one or more particles mixed into the working fluid to change an opacity of the working fluid, which opacity affects a penetration depth of the captured incident light and an amount of working fluid absorption of the light energy.

38. The method of claim 37, wherein the one or more particles are graphite particles.

39. The method of claim 38, wherein the SECS system further comprises one or more mechanisms associated with or interconnected to the storage container to enable utilization of the stored thermal energy to provide one or more uses of the thermal energy for one or more processes requiring thermal energy within the range of temperatures at which the working fluid exists, wherein the one or more processes comprises: electric power generation; water desalination; absorption chiller/refrigeration; enhanced oil recovery; potential replacement of natural gas as a heat source for existing gas-fired steam cycle power systems; and hydrogen production to enhance and/or replace other manufacturing processes for hydrogen driven transportation options.
40. The method of claim 26, further comprising a heat exchange mechanism interconnected with the storage container, and which enables transfer of the stored thermal energy to a secondary device/system/mechanism which utilizes the thermal energy and/or converts the thermal energy to a next form of energy.

41. The method of claim 26, wherein said storage container further comprises one or more insulated covers which are selectively placed over the one or more openings, respectively, based on a detection of one or more pre-established conditions which trigger a closure off the one or more openings via the one or more insulated covers, said pre-established conditions comprising one or more of: detecting a weather condition that is not conducive to continued sunlight redirection; detecting a weather condition that would adversely affect thermal energy absorption or lead to thermal energy loss from the working fluid; and detecting when the working fluid has achieved a pre-identified threshold level of thermal energy storage.

42. The method of claim 29, further comprising:

a first feedback mechanism which, responsive to activation of a cold startup process for the working fluid, selectively directs a subset of a total number of reflective mirrors of the heliostat field towards the secondary reflector, wherein less than a full concentration of incident sunlight is redirected into the working fluid to enable a controlled heating of the working fluid up to a desired operating temperature.

43. The method of Claim 26, wherein the SECS system further comprises one or more external heating components coupled to a feedback mechanism, which activates the one or more heating components to apply external heat to the storage container responsive to a cold startup process and which halts the application of external heat when the working fluid within the storage container reaches a pre-determined startup operating temperature.

44. The method of Claim 29, further comprising:

a second feedback mechanism which responsive to a detection of one or more conditions which require closing off the one or more openings, triggers a set of functions including:

- redirecting the heliostat field away from the secondary reflector; and
triggering a mechanical closure of the one or more openings by mechanically affixing one or more insulated covers over the one or more openings.

45. The method of Claim 29, further comprising:

a first feedback mechanism which detects when an amount of thermal energy stored within the working fluid reaches a predetermined threshold, and in response to a detection that the amount of stored thermal energy has reached the predetermined threshold triggers redirection of the heliostat field to substantially reduce the amount of incident sunlight received at the secondary reflector.

46. The method of claim 29, wherein said SECS system further comprises:

a support structure to which the secondary reflector is attached at a position relative to the storage container and to the heliostat field that enables the secondary reflector to receive reflected rays of incident sunlight from reflective mirrors of the heliostat field and re-direct the reflected rays towards the one or more openings of the storage container;

wherein the secondary reflector is one of a convex or a concave shape based on an angle at which received incident sunlight from the heliostat field are to be reflected towards one or more openings.

47. The method of claim 26, wherein the one or more openings is a single opening positioned in a top surface of the storage container and the method comprises positioning the secondary reflector at a location above the single opening that enables the rays of incident sunlight reflected by the secondary reflector to be directed towards the single opening.

48. The method of claim 29, wherein the heliostat field comprises a plurality of heliostats each having multiple reflective mirrors mounted thereon and positioned at angles to reflect rays of incident sunlight towards the secondary reflector.

49. The method of claim 26, wherein:

the working fluid has a volume that is less than a total internal volume of the storage container;
a substantial majority of the light rays received within the working fluid are scattered and light energy is dispersed as heat and stored as thermal energy throughout the working fluid via convection;

an opacity of the working fluid is adjusted through an introduction of another substance, which controls a first amount of light energy that is volumetrically absorbed versus a second amount of light energy that is first absorbed by the walls of the storage container before being conductively transferred to the working fluid; and

the working fluid retains the absorbed thermal energy within the storage container until the thermal energy is later transferred out of the storage container by a transfer mechanism for utilization in generation of other forms of energy or for other uses, wherein the transfer mechanisms does not involve the transportation of the working fluid.

50. The method of claim 26, wherein:

a temperature at which the working fluid exists is within a range of temperature proximate to a melting temperature of the working fluid;

absorbed thermal energy is stored within the working fluid as one of latent heat or a combination of latent and sensible heat;

when the thermal energy is stored as latent heat, the working fluid is maintained at the melting temperature of the working fluid, wherein the working fluid is an admixture of solid and molten states, with a relative amount of each state within the working fluid based on a proportion/amount of heat energy stored within the working fluid; and

when the thermal energy is stored as sensible heat, the working fluid is maintained in the range of temperatures above, but near, the melting point, with the amount of heat stored or extracted from the working fluid affected by changes in that temperature.
START

500

Provide volumetric storage container of working fluid with no transfer of working fluid

505

Position storage container in light redirection/concentration facility

510

Selectively placing secondary reflector or opening of storage container to enable receipt of light through storage container opening

515

Positioning concentrator between secondary reflector and opening of storage container

520

Submerging graphite block in working third volume

525

Mixing in particles into working fluid to change opacity and increase absorption

530

Initiating cold startup agitating working fluid using stirring mechanism during operation

535

END

540

FIG. 5

SUBSTITUTE SHEET (RULE 26)
INTERNATIONAL SEARCH REPORT

International application No
PCT/US2010/021005

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F24J 2/34 (2010.01)
USPC - 126/572

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - F24J 2/34 (2010 01)
USPC - 126/572

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

MicroPatent, Google Patents

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>US 4,474,171 A (CAPROON et al) 02 October 1984 (02.10.1984) entire document</td>
<td>1-50</td>
</tr>
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<td>Y</td>
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<td>Y</td>
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<tr>
<td>Y</td>
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<td>18, 19, 44, 45</td>
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</table>

Further documents are listed in the continuation of Box C.

* Special categories of cited documents
  "A" document defining the general state of the art which is not considered to be of particular relevance
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  "&" document member of the same patent family

Date of the actual completion of the international search
03 March 2010

Date of mailing of the international search report
9 MAR 2010

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Form PCT/ISA/210 (second sheet) (July 2009)