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HYBRID SOLAR REACTOR AND HEAT STORAGE SYSTEM

Abstract

A hybrid solar reactor and a heat storage system are disclosed. The hybrid solar reactor includes one or more heaters and a solar light guide assembly coupled to a shell of the reactor. The solar light guide assembly includes a solar light guide to direct solar energy to, for example, one or more reactor tubes within the shell.

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Goverment Interests

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] This invention was made with government support under contract number DE-AR0000404 awarded by the U.S. Department of Energy. The government has certain rights in the invention.

Claims

1. A hybrid solar reactor comprising: a shell comprising an aperture; insulating material within the shell, the insulating material comprising an interior surface; one or more heaters within the shell; and a solar light guide assembly mechanically coupled to the shell, the solar light guide assembly comprising a solar light guide that directs solar energy from outside the shell to the interior surface.

2. The hybrid solar reactor of claim 1, further comprising one or more reactor tubes within the shell.

3. The hybrid solar reactor of claim 1, wherein the solar light guide assembly comprises insulation.

4. The hybrid solar reactor of claim 3, wherein the solar light guide and the insulation are selectably engaged with a portion of the shell.

5. The hybrid solar reactor of claim 1, wherein the shell comprises a partial cylinder.

6. The hybrid solar reactor of claim 1, wherein the reactor further comprises a window coupled to the solar light guide assembly.

7. The hybrid solar reactor of claim 1, wherein the window is sealably coupled to the solar light guide assembly.

8. The hybrid solar reactor of claim 1, wherein the one or more heaters comprise a resistive heater.

9. The hybrid solar reactor of claim 1, wherein the one or more heaters comprise a combustion heater.

10. The hybrid solar reactor of claim 1, wherein the insulating material comprises one or more of alumina, zirconia, silica, and graphite.

11. The hybrid solar reactor of claim 1, wherein the insulating material comprises porous foam.

12. The hybrid solar reactor of claim 1, wherein the reactor runs under vacuum conditions, and wherein the reactor material is not graphite.

13. The hybrid solar reactor of claim 1, wherein an operating pressure of the reactor ranges from about 1 mbar to about 10 bar absolute pressure.

14. The hybrid solar reactor of claim 1, wherein the reactor runs at ambient pressure.

15. The hybrid solar reactor of claim 1, wherein the reactor tube comprises graphite.

16. The hybrid solar reactor of claim 1, wherein the reactor tube comprises material selected from the group consisting of silicon carbide, alumina, zirconia, quartz, and combinations thereof.

17. The hybrid solar reactor of claim 1, wherein sunlight exits the solar light guide proximate a junction between

the solar concentrator and the interior surface.

18. The hybrid solar reactor of claim 1, wherein one or more of the insulation and the reactor tube comprise graphite.

19. A hybrid solar reactor comprising: a shell comprising an aperture; insulating material within the shell, the insulating material comprising an interior surface; one or more heaters within the shell; and a solar light guide assembly mechanically coupled to the shell, the solar light guide assembly comprising a solar light guide that directs solar energy from outside the shell to the interior surface, wherein one or more of the reactor tube and the insulating material comprise graphite and the reactor comprises a window sealably coupled to the solar light guide assembly.

20. A system comprising the hybrid solar reactor of claim 1 and one or more primary concentrators.

Description

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority to U.S. Provisional Patent Application No. 62/113,022, entitled "Hybrid Solar Reactor," and filed on Feb. 6, 2016, the contents of which are hereby incorporated herein by reference to the extent such contents do not conflict with the present disclosure.

FIELD OF INVENTION

[0003] The present disclosure generally relates to solar reactor and heat storage systems and to components thereof. More particularly, the disclosure relates to hybrid solar reactors and heat storage systems.

BACKGROUND

[0004] Solar reactors can be used for a variety of applications, including high-temperature chemical reactions. In such applications, solar radiation is generally concentrated to provide heat to the reactor. However, when the reactor is off-sun, the reactor generally cannot provide a desired amount of heat.

[0005] To compensate for periods when solar reactors are off-sun, solar reactors may include an auxiliary means to heat the reactors. While such hybrid solar reactors can overcome some of the shortcomings of solar reactors, the hybrid reactors are generally susceptible to significant heat loss and do not allow for high-temperature reactions while retaining a desired amount of heat, particularly during times when the reactor is off-sun. Heat storage devices can also be desirable for a variety of applications and may suffer from similar shortcomings. Accordingly, improved hybrid solar reactors and heat storage systems are desired.

SUMMARY OF THE DISCLOSURE

[0006] Various embodiments of the disclosure relate to hybrid solar reactors. The hybrid solar reactors may suitably use electricity or other heating sources in addition to or in the absence of solar energy when not enough sunlight is available to provide sufficient heat for desired reactions. The reactors described herein may be used for a variety of applications, including hydrogen or synthesis gas production from methane cracking or biomass gasification, thermal reduction reactions to carry out pyrolysis or oxygen release, carbothermal reduction processes to produce non-oxide ceramics and metals, and redox reactions using reactive particles. Further embodiments of the disclosure relate to energy storage systems in which solar energy is used to heat a medium, such as phase change material (e.g., material that changes phase at or about 700.degree. C.). The phase change material can be used to store heat that can be used when, for example, the energy storage system is off sun. The disclosure is not limited to such uses.

[0007] In accordance with various exemplary embodiments of the disclosure, a hybrid solar reactor includes a shell including an aperture, insulating material within the shell, heaters within the shell (e.g., between a reactor tube and the insulating material or embedded in the insulating material), and a solar light guide assembly mechanically coupled to the shell. The solar light guide assembly includes a light guide that includes reflecting surfaces to direct solar radiation to a reactor tube. By way of examples, the light guide can be an optical mixer or a solar concentrator. Besides guiding the light into the reactor, the light guide can homogenize the flux profile of the highly concentrated solar radiation and thus reduce thermal stresses on the reactor walls and reactor tube. The reactor can also include one or more reactor tubes in which desired reactions take place. In accordance with various aspects of these embodiments, the light guide assembly includes an insulator. The insulator and the light guide can be selectively engaged with a portion of the shell, such that the reactor can retain heat when the hybrid solar reactor is off-sun.

[0008] The insulator, insulating material and/or the reactor tube can be formed of graphite. Forming the insulator, insulating material and/or the reactor tube of graphite allows the hybrid solar reactor to operate at relatively high temperatures (up to about 2400.degree. C.). However, the graphite can be relatively porous, and thus when graphite is used to form one or more of these components, the solar reactor can run at or near ambient pressure. Further, when the insulating material and/or reactor tube include graphite, an inert or otherwise compatible/non-oxidative gas can be used between the reactor tube and the shell to prevent or mitigate undesired oxidation of the graphite. In these cases, the reactor can suitably include a window to allow solar radiation to the solar light guide, while retaining the inert/compatible gas within the reactor.

[0009] In accordance with further exemplary embodiments of the disclosure, the insulator, insulating material and the reactor tube are formed of an oxidation-resistant material, such as silicon carbide, alumina, zirconia, or quartz. Use of such materials may be desirable over graphite, because such materials are relatively less porous, and thus the reactor tube can be run under vacuum or pressurized conditions, if desired, and an inert or compatible gas between the reactor tube and the shell is generally not required. Thus, in some applications, the reactor can be run without a window attached to or integrated with the light guide assembly.

[0010] In accordance with further exemplary aspects, one or more of the shell and the light guide are cooled. By way of example, the shell and/or the light guide can be water cooled.

[0011] In accordance with yet further exemplary embodiments of the disclosure, a heat storage system includes a shell including an aperture, insulating material within the shell, optionally heaters within the shell (e.g., between a reactor tube and the insulating material or embedded in the insulating material), and a solar light guide assembly mechanically coupled to the shell. The heat storage system can include one or more tubes (similar to the reactor tube), which includes a medium that is heated using the solar light guide. Suitable media for such applications includes phase-change material, such as salt (e.g., sodium chloride and the like).

BRIEF DESCRIPTION OF THE DRAWING FIGURES

[0012] These and other features, aspects, and advantages of the invention disclosed herein are described below with reference to the drawings of certain embodiments, which are intended to illustrate and not to limit the invention.

[0013] FIG. 1 illustrates a hybrid solar reactor/heat storage system in accordance with exemplary embodiments of the disclosure.

[0014] FIG. 2 illustrates the hybrid solar reactor/heat storage system of FIG. 1 during on-sun operation in accordance with exemplary embodiments of the disclosure.

[0015] FIG. 3 illustrates the hybrid solar reactor/heat storage system of FIG. 1 during off-sun operation in accordance with exemplary embodiments of the disclosure.

[0016] FIG. 4 illustrates another view of the hybrid solar reactor/heat storage system of FIG. 1 in accordance with exemplary embodiments of the disclosure.

[0017] FIG. 5 illustrates operation of an exemplary hybrid solar reactor/heat storage system in accordance with exemplary embodiments of the disclosure.

[0018] FIG. 6 illustrates on-sun operation of a hybrid solar reactor/heat storage system in accordance with exemplary embodiments of the disclosure.

[0019] FIG. 7 illustrates a compound parabolic concentrator (CPC) suitable for use as a solar light guide in a hybrid solar reactor/heat storage system in accordance with exemplary embodiments of the disclosure.

[0020] FIG. 8 illustrates an octagonal solar concentrator suitable for use as a solar light guide in a hybrid solar reactor/heat storage system in accordance with exemplary embodiments of the disclosure.

[0021] FIG. 9 illustrates on-sun operation of a hybrid solar reactor/heat storage system using a compound parabolic concentrator in accordance with exemplary embodiments of the disclosure.

[0022] FIG. 10 illustrates another design of a solar concentrator suitable for use in a light guide assembly in accordance with exemplary embodiments of the disclosure.

[0023] FIG. 11 illustrates a portion of a light guide assembly attached to a shell in accordance with exemplary embodiments of the disclosure.

[0024] It will be appreciated that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help improve understanding of illustrated embodiments of the present disclosure.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0025] The description of exemplary embodiments of the present disclosure provided below is merely exemplary and is intended for purposes of illustration only; the following description is not intended to limit the scope of the invention disclosed herein. Moreover, recitation of multiple embodiments having stated features is not intended to exclude other embodiments having additional features or other embodiments incorporating different combinations of the stated features.

[0026] The present disclosure describes exemplary hybrid solar reactors and heat storage systems. The reactors and systems can be used for a variety of applications, including, for example, carbothermal reduction, thermal reduction, cracking, gasification reactions, and thermal storage. Although various embodiments of the disclosure are described below in the context of a hybrid solar reactor, a heat storage system can include the same or similar components, in which a reactor tube of the hybrid solar reactor is replaced with a tube (which may be the same as the reactor tube) that contains a medium, such as phase-change material, that is heated during on-sun operation of the system and that can release stored heat during off-sun operation.

[0027] FIG. 1 illustrates an exemplary hybrid solar reactor/heat storage system 100 in accordance with exemplary embodiments of the disclosure. FIG. 2 illustrates on-sun operation of hybrid solar reactor/heat storage system 100 and FIG. 3 illustrates off-sun operation of hybrid solar reactor/heat storage system 100.

[0028] Exemplary hybrid solar reactor/heat storage system 100 includes a shell 102, insulating material 104-108, and a solar light guide assembly 110, including a solar light guide 112. As discussed in more detail below, solar light guide assembly 110 allows for selective engagement of light guide 112 and an insulator 118. Although not illustrated, hybrid solar reactor 100 can also include temperature control zones that have temperature sensing elements for temperature control and over temperature protection. Air or other gases, such as non-oxidizing gas (e.g., argon, nitrogen, helium, or the like) can be injected into hybrid solar reactor/heat storage system 100--e.g., into a space between an interior surface of shell 102 and a reactor tube/tube 116.

[0029] Shell 102 can be formed of, for example, material selected from the group consisting of stainless steel, aluminum, carbon steel, and combinations thereof. As illustrated, shell 102 can include a partial hollow cylinder shape, where a portion of the hollow cylinder is removed to create an opening or aperture 114 within shell 102. By way of example, shell 102 is formed as stainless steel having a thickness of about 1/8" to about 1/2".

[0030] As illustrated in FIG. 4, shell 102 includes flanges 402 and 404. The flanges can be used to receive sealable covers 406, 408 that can be easily attached to and/or removed from shell 102. Using easily removable sealable covers allows easy access to an interior of hybrid solar reactor 100 to, for example, access one or more reactor tubes 116.

[0031] Insulating material 104-108 can comprise the same or different material. By way of examples, one or more of insulating material 104-108 can include one or more of graphite, alumina, zirconia, and silica. Use of graphite may be desirable when hybrid solar reactor 100 is used at higher temperatures (e.g., up to about 2400.degree. C.). However, graphite is susceptible to oxidation, and thus graphite insulating material may desirably be exposed to a non-oxidizing environment. If internal hybrid reactor/heat storage system 100 conditions are oxidizing, insulating material can be formed of one or more of alumina, zirconia, and silica. The insulating material includes an opening or aperture to reduce any obstruction to solar energy received from solar concentrator 112. Insulator 118 can be formed of the same or similar materials. The individual or total thickness for insulating material 104-108 and/or insulator 118 can be between about two inches and six inches, or more. Exemplary insulating material 104-108 and insulator 118 are available from Rath Group, under name ALTRA.RTM. KVS and KVR high-density vacuum-formed boards, and Zircar Zirconia, Inc. Zirconia boards, type FBD. One or more of insulating material 104-108 can include a tapered opening, wherein a dimension of the opening near the light guide is smaller than a dimension) of the opening away from the light guide, as illustrated in FIG. 1. This allows radiation to enter region 208 in a relatively unobstructed manner.

[0032] Reactor/heat storage system 100 can include a region (e.g., an annular space) 208 between insulating material 108 and reactor tube 116. The annular space is designed to provide cross radiation and reflection of solar radiation to facilitate obtaining desired operating temperatures of reactor tube/tube 116.

[0033] As illustrated in FIGS. 2 and 3, hybrid solar reactor/heat storage system 100 can also suitably include one or more heating elements or heaters 202-206. The one or more heaters can be located between insulating material 108 and reactor tube 116 (e.g., annular space 208 between insulating material 108 and reactor tube 116). The one or more heaters can be resistive heaters (e.g., molybdenum disilicide, graphite, and/or silicon carbide resistive heaters). Additionally or alternatively, the one or more heaters can include a burner, such as a natural gas burner (generally suitable for temperatures up to about 1650.degree. C.). The one or more heaters can be located, such that none of the heaters blocks solar energy from light guide (e.g., a solar concentrator) 112.

[0034] Solar light guide assembly 110 is designed to selectively engage solar light guide 112 or insulator 118 with a portion of hybrid solar reactor 100--e.g., with a portion of shell 102. When solar light guide 112 is engaged to direct solar energy toward region 208, an output of solar light guide 112 can be aligned with or adjacent an (e.g., tapered) interior surface of insulating material 108. This configuration facilitates solar heating of region 208 and/or reactor tube 116. Solar light guide 112 can include, for example, a solar concentrator and/or an optical mixer. In such cases, the radiation exiting the light guide has a much more uniform profile than at the inlet of the solar light guide, where the radiation typically is highly focused at, for example, a focal point of a primary solar concentrator, as illustrated in FIG. 5. The uniform profile at the outlet of the solar light guide helps to reduce thermal stresses on the reactor walls and reactor tube/tube that would otherwise result from highly concentrated solar radiation.

[0035] FIG. 10 illustrates another light guide 1000 in accordance with various embodiments of the disclosure. Light guide 1000 includes a first section 1002 and a second section 1004. First section 1002 can be designed to protect an insulator 1016 from radiation spillage. Second section 1004 can be used to guide and/or concentrate radiation as described herein. In the illustrated example, first section 1002 is frusto-conical shaped, and second section 1003 is compound parabolic shaped. Light guide 1000 includes a conduit 1006 for a cooling medium, such as water. Cooling medium can be supplied to conduit 1006 via a supply tube 1010. Light guide 1000 can also include a tapered end 1008 to reduce a surface area of light guide 1000 that is exposed to high temperatures. As illustrated, insulator 1016 includes a first section 1012 formed of a first material and a second section 1014 formed of a second material. The first material can be selected to be readily machinable and to retain its shape, such a machinable zirconia. The second insulating material can be any suitable insulating material, such as the insulating materials described elsewhere herein. As shown, first section 1012 includes a tapered section 1018, which comes to a point 1020. Tapered section 1018 may be desirable to protect tapered end 1008 of light guide 1000, while minimizing blockage of light between the light guide and a region within a reactor or system, such as region 208.

[0036] FIG. 11 illustrates a light guide assembly 1102 attached to a shell 1104. In this example, light guide assembly includes a reflective surface 1106 and an insulator 1108 that includes a first section 1110 and a second section 1112. First section 1110 and second section 1112 can be formed of the same materials as first section 1012 and second section 1014. As illustrated in FIG. 11, a tapered end 1114 of first section 1110 extends to cover an end 1116 of a light guide 1108, while mitigating blockage of radiation entering shell 1104. Although not separately illustrate, light guide assembly 1102 can include a conduit, cooling medium, and supply tube, as described above in connection with FIG. 10.

[0037] Referring again to FIG. 1, solar light guide assembly 110 and other light guide assemblies described herein can optionally include or have attached thereto a solar-radiation transparent window 120. Use of window 120 allows use of inert or non-oxidizing gases within shell 102, which in turn, allows insulating material 104-108 and/or reactor tube 116 to be formed of material that might oxidize in, for example, air. Hybrid solar reactor 100 can additionally or alternatively include a window at an output end of solar concentrator 112. As noted above, use of non-oxidizing/inert gas allows for reactor tube 116 and/or insulating material 104-108 to be formed of, for example, graphite.

[0038] Insulator 118 of solar light guide assembly 110 can be selectively engaged with the portion of hybrid solar reactor/system 100 when, for example, light guide 112 and/or hybrid solar reactor/system 100 are off-sun, as illustrated in FIG. 3. Insulator 118 can be used to retain heat within shell 102, and reduce unwanted thermal leakage.

[0039] Reactor tube/tube 116 can be formed of a variety of materials, including one or more of graphite, silicon carbide, alumina, mullite, zirconia, and quartz. As noted above, graphite may be desirable when reactor tube/tube 116 is run at higher temperatures--e.g., up to 2400.degree. C. Silicon carbide can be used in an oxidizing environment (e.g., air), and is relatively non-porous compared to graphite, so (reactor) tubes formed of silicon carbide can be run under vacuum conditions (or under pressure); running the reactor at lower pressure in turn can allow the reactor to run at lower temperatures. However, a silicon carbide reactor can typically only be operated at temperatures up to about 1650.degree. C. Alumina and zirconia are similarly non-porous, and can generally be run at temperatures up to 1800.degree. C. and 2000.degree. C. respectively. Quartz can also be used, but quartz may be sensitive to particles, which can melt the glass. In addition to its chemical susceptibility to damage, "quartz", actually fused silica, is limited to temperatures and stresses at which its deformation will be tolerated.

[0040] FIG. 5 illustrates a hybrid solar reactor/system 500 that includes a solar concentrator 502 as a light guide. In the illustrated example, solar concentrator 502 receives radiation from one or more primary or first solar concentrators 506, and the focal point of the radiation from the one or more primary/first solar concentrators 506 is located at an inlet (e.g., a plane of the inlet) of solar concentrator 502. The radiation can enter an interior region 510 of hybrid solar reactor/system 500. In some cases, the radiation can heat insulation 512, which then radiates the heat toward a reactor tube/tube 520 Similar to hybrid solar reactor/system 100, hybrid solar reactor/system 500 includes insulating material 512 (which can be the same or similar to insulating materials 104-108) heaters 514-518 (which can be the same or similar to heaters 202-206, and which may be optional in the case of heat storage systems), and reactor tube 520 (which can be the same or similar to reactor tube/tube

116).

[0041] FIG. 6 and FIG. 9 illustrate another hybrid solar reactor/heat storage system 600 in accordance with additional exemplary embodiments of the disclosure. Hybrid solar reactor/heat storage system 600 includes a compound parabolic concentrator 602, which is illustrated in more detail in FIG. 7. Similar to hybrid solar reactor/system 100, hybrid solar reactor 600 includes insulating material 612 (which can be the same or similar to insulating materials 104-108) heaters 614-618 (which can be the same or similar to heaters 202-206), and a reactor tube/tube 620 (which can be the same or similar to reactor tube 116). Hybrid solar reactor/system 600 receives radiation from one or more primary/first concentrators 604-608.

[0042] FIG. 8 illustrates an octagonal solar concentrator 802 that can be used as, for example, solar concentrator 112. Octagonal solar concentrator 802 can be formed of eight surfaces 804-818 that reflect radiation into a hybrid solar reactor, such as one or more of the hybrid solar reactors described herein.

[0043] Various examples of the disclosure include: [0044] The heating elements are arranged in such a way that they do not block incoming radiation and such that overheating of the elements is prevented. In accordance with some examples, no heating elements are placed in front of the reactor aperture. During hybrid operation, i.e., simultaneous heating by solar radiation and electrical power heating, elements close to the aperture and susceptible to overheating can be individually turned off such that they are heated by solar radiation only. [0045] A water-cooled light guide/secondary concentrator (e.g., solar concentrator 112) with highly reflecting surfaces (e.g., greater than ninety percent reflective) is incorporated/integrated with a movable insulation slab (e.g., solar concentrator assembly 110). During on-sun operation, the light guide/secondary concentrator is placed in front of the reactor aperture to guide incoming concentrated radiation (e.g., radiation 504, 622) across the insulation. In the case of a secondary concentrator, which has an exit area smaller than the inlet area of the incoming radiation, solar energy from, e.g., a primary/first solar concentrator (e.g., first solar concentrator 506, 604-608), is further concentrated towards the exit of the secondary concentrator (inlet of the reactor) to minimize the aperture area and hence the radiation losses. This may be especially important at high temperature operations (>1000.degree. C.). During off-sun operation, the insulation slab with secondary concentrator is moved such that insulation is (e.g., insulation 118) fully covering the reactor/system aperture. In such a way, thermal losses by radiation, convection and conduction are minimized, while window and light guide/secondary concentrator are kept free from contamination. [0046] Switching from on- to off-sun operation can be performed whenever the losses through the reactor/system aperture by radiation, convection and conduction during on-sun operation exceed the power supplied by incoming radiation. [0047] Typically, concentrated radiation exiting a secondary concentrator has a half-opening angle of about 90.degree.. Therefore the exit of the light guide/secondary concentrator is located at the reactor aperture such that concentrated radiation enters the heating chamber (e.g., region 208) without being blocked by insulation. The heat flux close to the aperture can be very high. Accordingly, it is desirable to cover the reactor-facing surfaces of the light guide. This is achieved using a high temperature, robust, machinable insulation. Such a material can hold the complex shape required to perform the service. In an oxidizing atmosphere, a suitable material is Zircar FBD available from Zirconia, Inc. at 90 lbs per cubic foot density. [0048] When used, a window (e.g., window 120) can be placed stationary in front of the light guide/secondary concentrator and away from the hot heating chamber to protect it from overheating and potential contaminations. [0049] The overall dimensions of the window can be larger than the inlet dimensions of the light guide/secondary concentrator such that the window frame and window sealing keeping the window in position do not block the incoming radiation. In such a way, the window sealing and frame are protected from overheating and radiation losses due to the blocking of the window frame/sealing being minimized. [0050] The focal point of the source of concentrated radiation is located at the inlet plane of the light guide/secondary concentrator to maximize incoming radiation while minimizing the reactor aperture diameter and associated losses by thermal radiation.

[0051] Specific examples of the disclosure include the following. [0052] 1. A hybrid solar reactor/heat storage system comprising:

[0053] a shell comprising an aperture;

[0054] insulating material within the shell, the insulating material comprising an interior surface;

[0055] one or more heaters within the shell; and

[0056] a solar light guide assembly mechanically coupled to the shell, the solar light guide assembly comprising a solar light guide that directs solar energy from outside the shell to the interior surface. [0057] 2. The hybrid solar reactor/heat storage system of example 1, further comprising one or more reactor tubes within the shell. [0058] 3. The hybrid solar reactor/heat storage system of any of examples 1-2, wherein the light guide assembly comprises insulation. [0059] 4. The hybrid solar reactor/heat storage system of example 3, wherein the light guide and the insulation are selectably engaged with a portion of the reactor. [0060] 5. The hybrid solar reactor/heat storage system of any of examples 1-4, wherein the shell comprises a partial cylinder. [0061] 6. The hybrid solar reactor/heat storage system of any of examples 1-5, wherein the insulating material comprises a partial cylinder. [0062] 7. The hybrid solar reactor/heat storage system of any of examples 1-6, wherein light guide assembly further comprises a window. [0063] 8. The hybrid solar reactor/heat storage system of example 7, wherein the window is sealably coupled to the solar light guide assembly. [0064] 9. The hybrid solar reactor/heat storage system of any of examples 1-8, wherein the solar light guide is cooled. [0065] 10. The hybrid solar reactor/heat storage system of any of examples 1-9, wherein the solar light guide is water cooled. [0066] 11. The hybrid solar reactor/heat storage system of any of examples 1-10, wherein the one or more heaters comprise a resistive heater. [0067] 12. The hybrid solar reactor/heat storage system of any of examples 1-11, wherein the one or more heaters comprise a combustion heater. [0068] 13. The hybrid solar reactor/heat storage system of any of examples 1-12, wherein the shell comprises material selected from the group consisting of stainless steel, aluminum, carbon steel, and combinations thereof. [0069] 14. The hybrid solar reactor/heat storage system of any of examples 1-13, wherein the insulating material comprises one or more of alumina, zirconia, silica, and graphite. [0070] 15. The hybrid solar reactor/heat storage system of any of examples 1-14, wherein the insulating material comprises porous foam. [0071] 16. The hybrid solar reactor/heat storage system of any of examples 1-14, wherein the reactor runs under vacuum conditions, and wherein the reactor material is not graphite. [0072] 17. The hybrid solar reactor/heat storage system of any of examples 1-16, wherein an operating pressure of the reactor ranges from about 1 mbar to about 10 bar or about 1 mbar to about 1 bar absolute pressure. [0073] 18. The hybrid solar reactor/heat storage system of any of examples 1-15, wherein the reactor runs at ambient pressure. [0074] 19. The hybrid solar reactor/heat storage system of any of examples 1-15 and 18, wherein the reactor tube comprises graphite. [0075] 20. The hybrid solar reactor/heat storage system of any of examples 1-18, wherein the reactor tube comprises material selected from the group consisting of silicon carbide, alumina, zirconia, quartz, and combinations thereof. [0076] 21. The hybrid solar reactor/heat storage system of any of examples 1-20, wherein sunlight exits the solar light guide proximate a junction between the solar light guide and the interior surface. [0077] 22. The hybrid solar reactor/heat storage system of any of examples 1-14, wherein one or more of the insulation and the reactor tube comprise graphite. [0078] 23. The hybrid solar reactor/heat storage system of any of examples 1-22, wherein the reactor is heated using the one or more heaters, concentrated solar energy, or both. [0079] 24. The hybrid solar reactor/heat storage system of any of examples 1-23, wherein one or more of the reactor tube and the insulation comprise one or more of alumina, zirconia, and silica. [0080] 25. The hybrid solar reactor/heat storage system of any of examples 1-18, 20, 21, 23 and 24, wherein the insulating material comprises an oxide and the aperture is selectively exposed to an ambient environment. [0081] 26. The hybrid solar reactor/heat storage system of any of examples 1-14, wherein one or more of the reactor tube and the insulating material comprise graphite and the reactor comprises a window sealably coupled to the solar light guide assembly. [0082] 27. The hybrid solar reactor/heat storage system of any of examples 1-26, wherein the one or more heaters are not disposed between the solar light guide and the reactor tube. [0083] 28. The hybrid solar reactor/heat storage system of any of examples 1-27, wherein the solar light guide comprises an optical mixer. [0084] 29. The hybrid solar reactor/heat storage system of any of examples 1-28, wherein the solar light guide comprises a compound parabolic concentrator. [0085] 30. The hybrid solar reactor/heat storage system of any of examples 1-27, wherein the solar light guide comprises a polygonal concentrator. [0086] 31. The hybrid solar reactor/heat storage system of any of examples 1-27 and [0087] 30, wherein the solar light guide comprises an octagonal solar concentrator. [0088] 32. A system comprising one or more hybrid solar reactor/heat storage system of any of claims 1-31 and one or more primary concentrators.

[0089] Although exemplary embodiments of the present disclosure are set forth herein, it should be appreciated that the disclosure is not so limited. For example, although the methods and reactor systems are described in connection with various specific configurations, the disclosure is not necessarily limited to these examples. Various modifications, variations, and enhancements of the exemplary systems and methods set forth herein may be made without departing from the spirit and scope of the present disclosure.

[0090] The subject matter of the present disclosure includes all novel and nonobvious combinations and subcombinations of the various systems, components, and configurations, and other features, functions, acts, and/or properties disclosed herein, as well as any and all equivalents thereof.

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