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(54) **ENGINE EXHAUST MANIFOLD ENDOTHERMIC REACTOR AND ASSOCIATED SYSTEMS AND METHODS**

(71) Applicant: **McAlister Technologies, LLC**, Phoenix, AZ (US)

(72) Inventor: **Roy Edward McAlister**, Phoenix, AZ (US)

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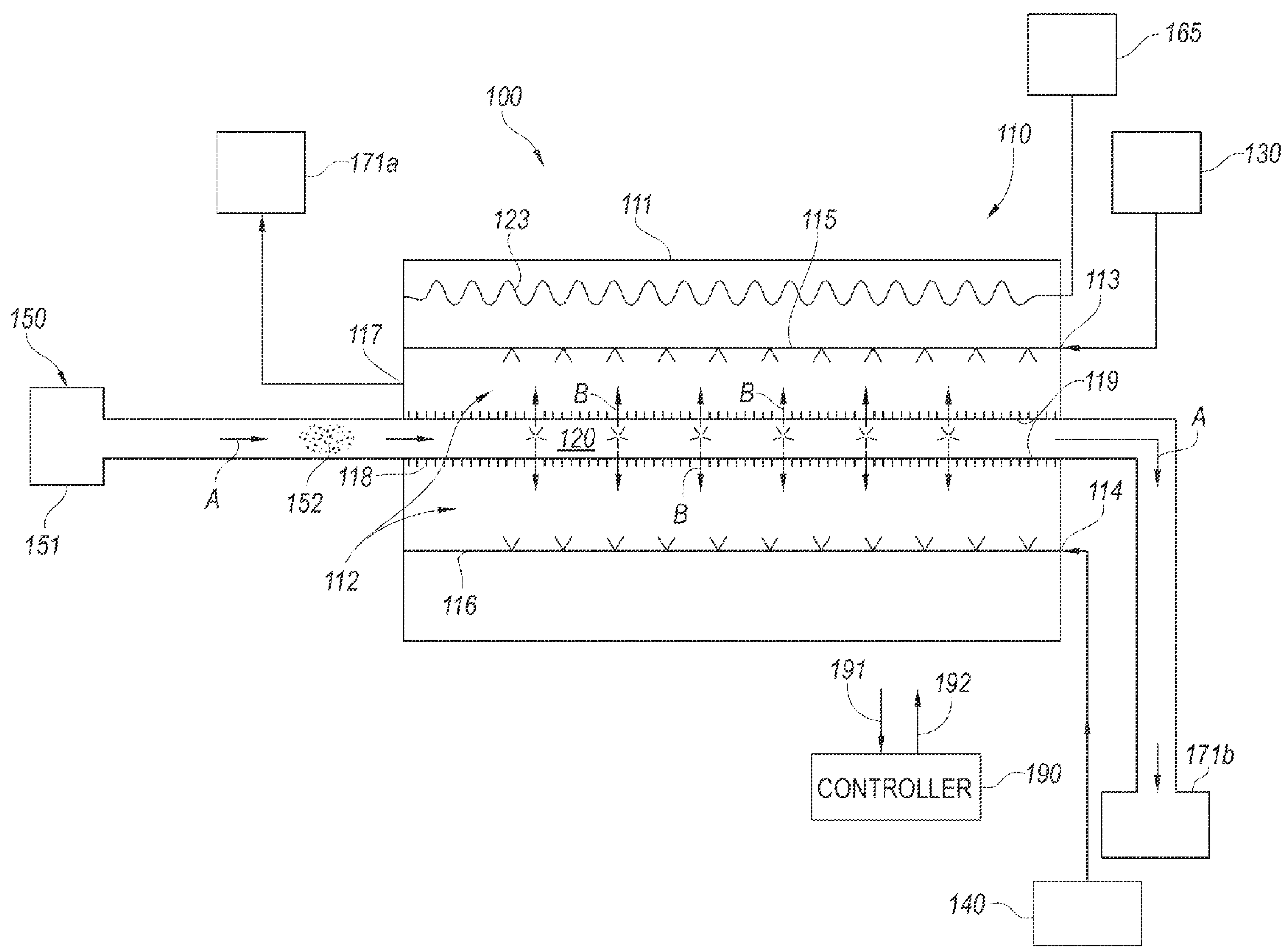
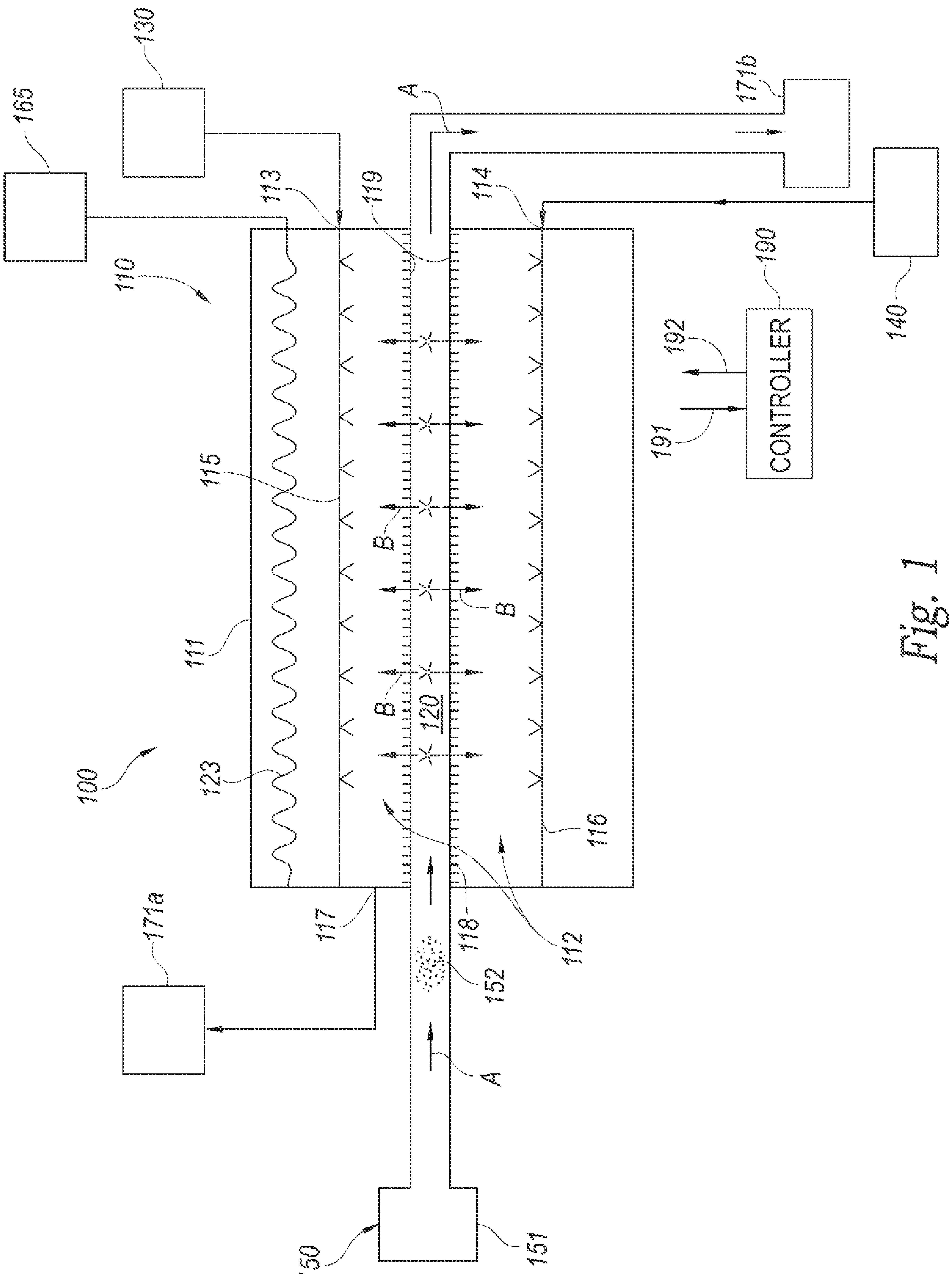
(57) **ABSTRACT**

Engine exhaust manifold endothermic reactors, and associated systems and methods are disclosed herein. A system in accordance with a particular embodiment of the technology includes an engine having a combustion region and an exhaust passage coupled to the engine to receive exhaust products from the combustion region. The exhaust passage can at least partially enclose a passage interior region. The system can further include a reactor having an external heat transfer surface positioned in the passage interior region, and a reaction zone positioned in a region enclosed by the external heat transfer surface. A hydrogen donor source can be coupled in fluid communication with the reaction zone of the reactor vessel via a donor passage, and a product passage can be coupled to the reaction zone to receive a reaction product from the reaction zone.

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CONTROLLER

Fig. 1

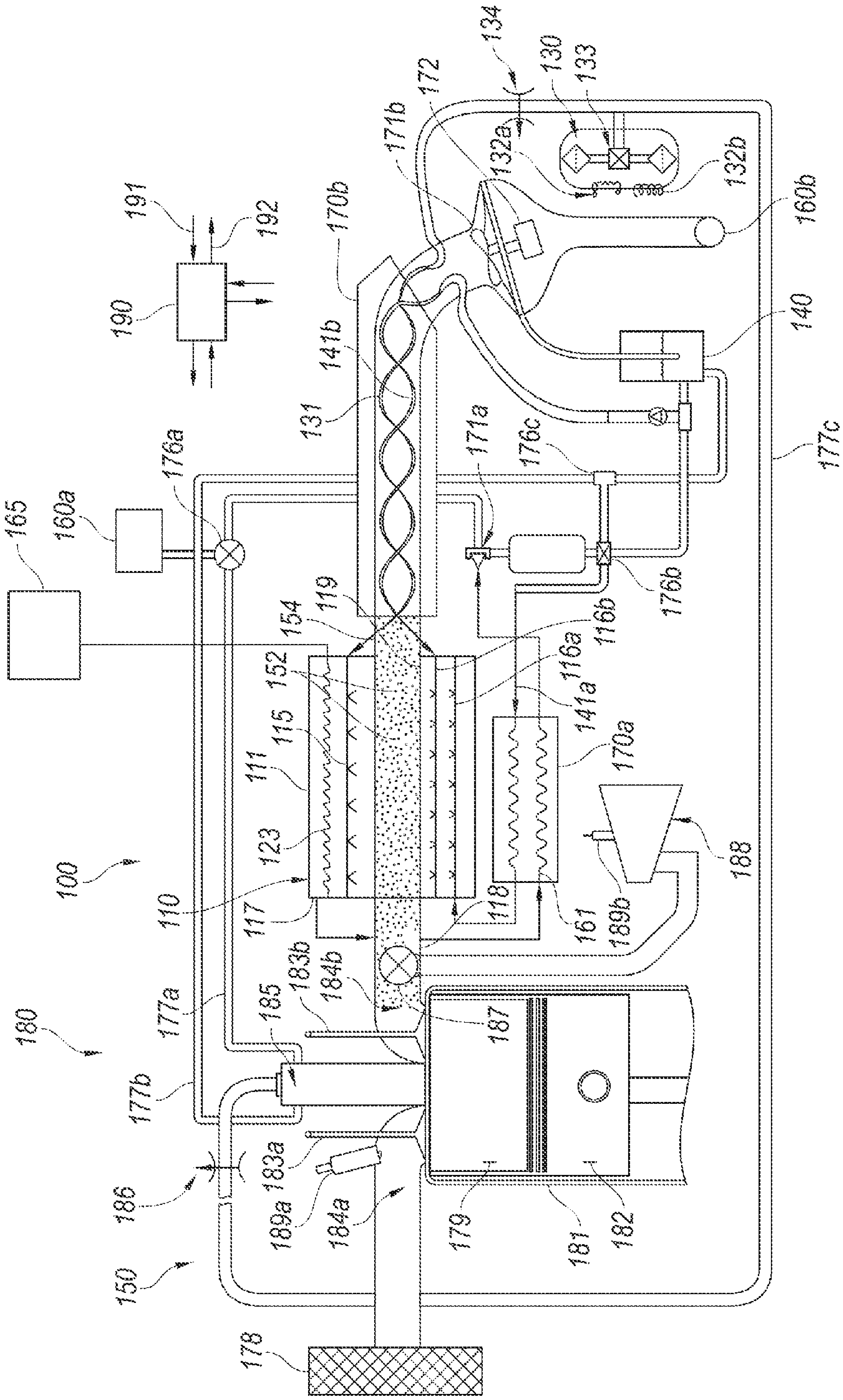
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Fig. 2

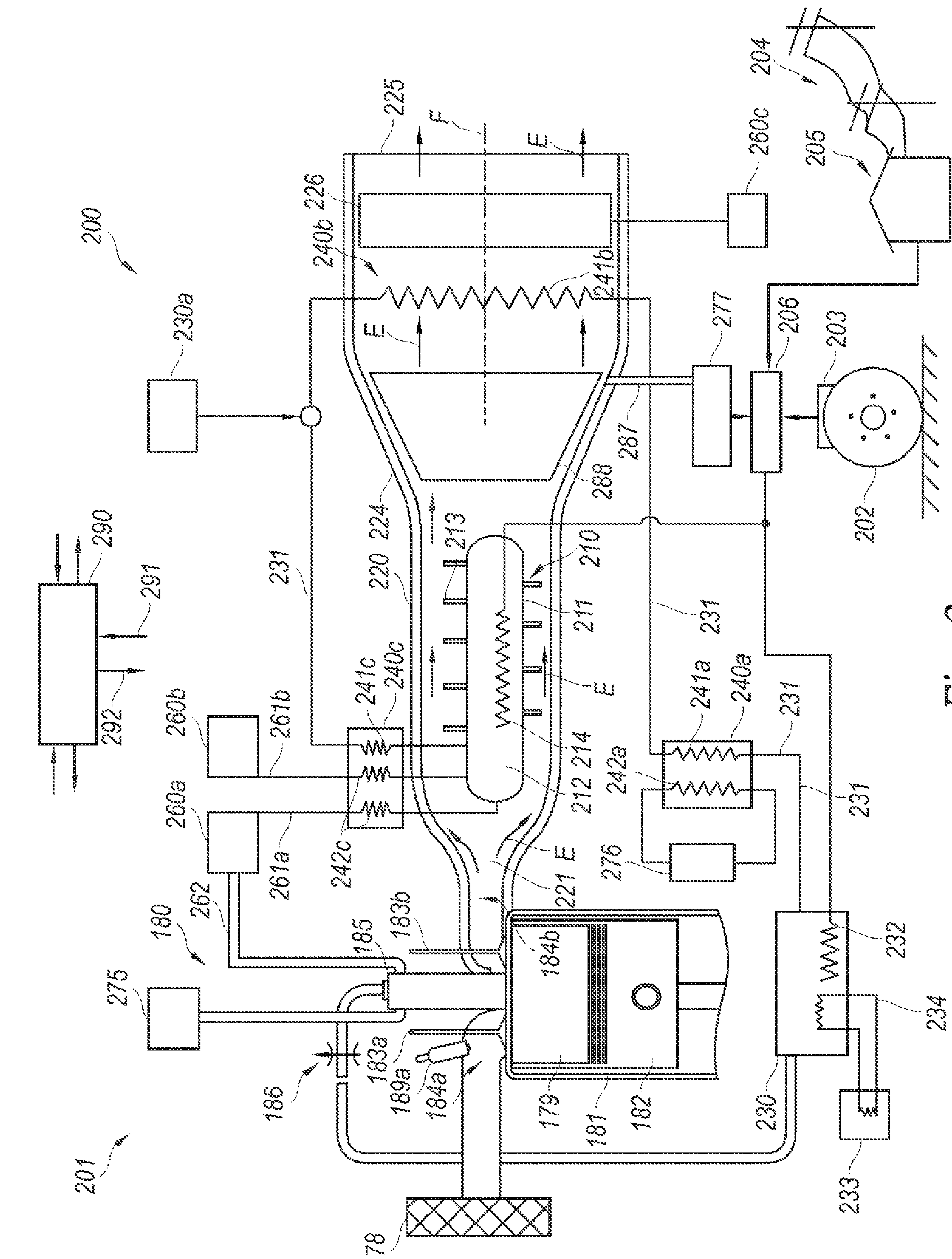
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Fig. 3

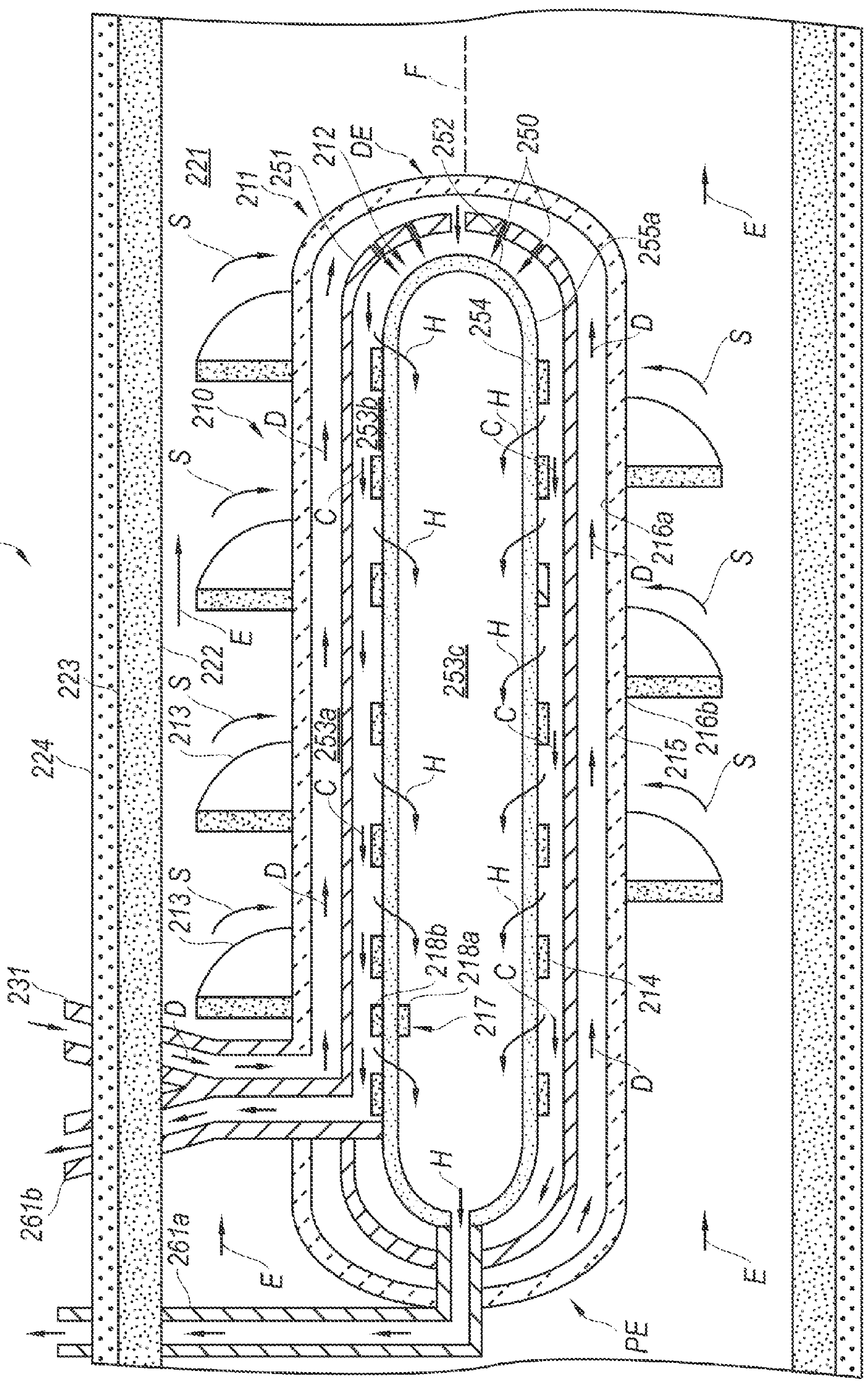

Fig. 4

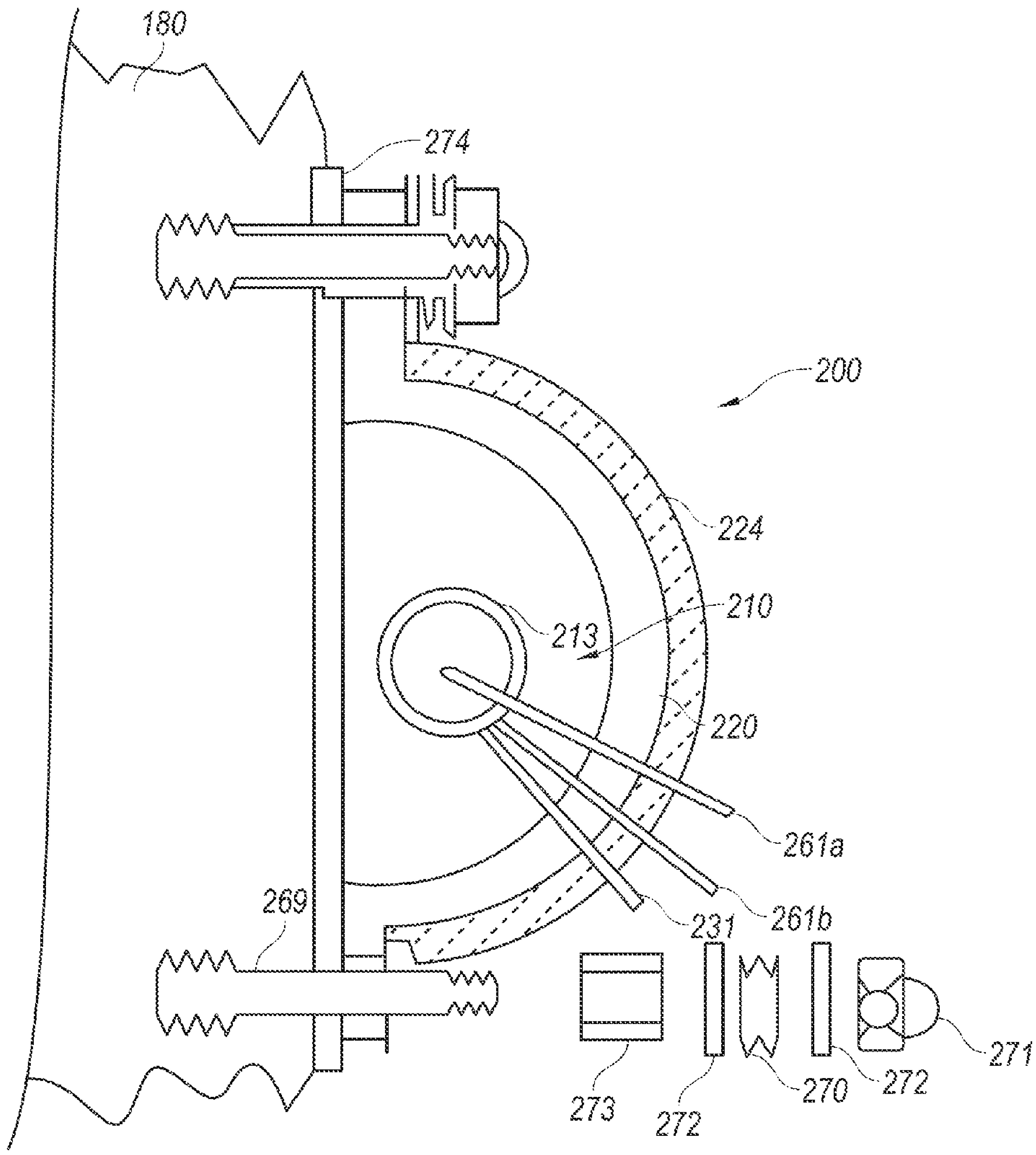
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Fig. 5

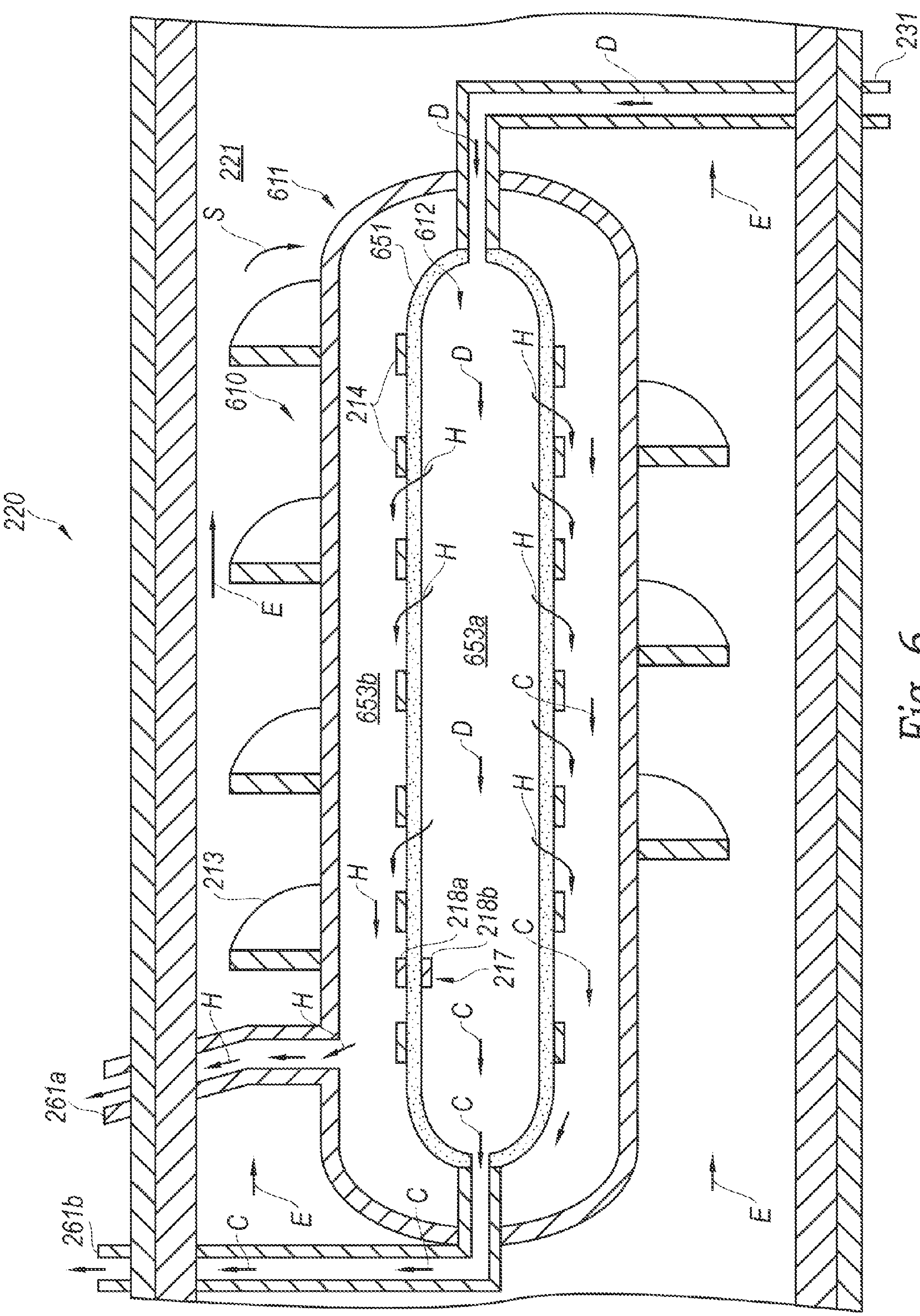
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Fig. 6

ENGINE EXHAUST MANIFOLD ENDOTHERMIC REACTOR AND ASSOCIATED SYSTEMS AND METHODS

TECHNICAL FIELD

[0001] The present technology is directed generally to engine exhaust manifold endothermic reactors, and associated systems and methods. Such systems and methods can include endothermic reactors positioned within an exhaust manifold to receive heat for conducting endothermic reactions.

BACKGROUND

[0002] Renewable energy sources such as solar, wind, wave, falling water, and biomass-based sources have tremendous potential as significant energy sources, but currently suffer from a variety of problems that prohibit widespread adoption. For example, using renewable energy sources in the production of electricity is dependent on the availability of the sources, which can be intermittent. Solar energy is limited by the sun's availability (i.e., daytime only), wind energy is limited by the variability of wind, falling water energy is limited by droughts, and biomass energy is limited by seasonal variances, among other things. As a result of these and other factors, much of the energy from renewable sources, captured or not captured, tends to be wasted.

[0003] The foregoing inefficiencies associated with capturing and saving energy limit the growth of renewable energy sources into viable energy providers for many regions of the world, because they often lead to high costs of producing energy. Thus, the world continues to rely on oil and other fossil fuels as major energy sources because, at least in part, government subsidies and other programs supporting technology developments associated with fossil fuels make it deceptively convenient and seemingly inexpensive to use such fuels. At the same time, the replacement cost for the expended resources, and the costs of environment degradation, health impacts, and other by-products of fossil fuel use are not included in the purchase price of the energy resulting from these fuels.

[0004] In light of the foregoing and other drawbacks currently associated with sustainably producing renewable resources, there remains a need for improving the efficiencies and commercial viabilities of producing products and fuels with such resources.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. **1** is a partially schematic, partially cross-sectional illustration of a reactor system that receives energy from a combustion engine in accordance with an embodiment of the presently disclosed technology.

[0006] FIG. **2** is a partially schematic, partially cross-sectional illustration of a reactor system that receives energy from a combustion engine and returns reaction products to the engine in accordance with an embodiment of the presently disclosed technology.

[0007] FIG. **3** is a partially schematic, partially cross-sectional illustration of a reactor system that includes a reactor vessel positioned within an exhaust manifold in accordance with another embodiment of the presently disclosed technology.

[0008] FIG. **4** is a partially schematic, cross-sectional illustration of a representative reactor vessel suitable for positioning within an exhaust manifold in the manner shown in FIG. **3**.

[0009] FIG. **5** is a partially schematic, cross-sectional illustration of a representative reactor vessel of the type shown in FIGS. **1** and **2**.

[0010] FIG. **6** is a partially schematic, cross-sectional illustration of a representative reactor vessel configured in accordance with another embodiment of the present technology.

DETAILED DESCRIPTION

Overview

[0011] Several examples of devices, systems and methods for efficiently producing hydrogen fuels and structural materials are described below. The efficiencies can result from using waste heat produced by a combustion engine to heat the reactor, and by returning at least some reaction products to the engine for combustion or other purposes. The overall process can result in clean-burning fuel and re-purposed carbon and/or other constituents for use in durable goods, including polymers and carbon composites. Although the following description provides many specific details of the following examples in a manner sufficient to enable a person skilled in the relevant art to practice, make and use them, several of the details and advantages described below may not be necessary to practice certain examples of the technology. Additionally, the technology may include other examples that are within the scope of the claims but are not described here in detail.

[0012] References throughout this specification to "one example," "an example," "one embodiment" or "an embodiment" mean that a particular feature, structure, process or characteristic described in connection with the example is included in at least one example of the present technology. Thus, the occurrences of the phrases "in one example," "in an example," "one embodiment" or "an embodiment" in various places throughout this specification are not necessarily all referring to the same example. Furthermore, the particular features, structures, routines, steps or characteristics may be combined in any suitable manner in one or more examples of the technology. The headings provided herein are for convenience only and are not intended to limit or interpret the scope or meaning of the claimed technology.

[0013] Certain embodiments of the technology described below may take the form of computer-executable instructions, including routines executed by a programmable computer or controller. Those skilled in the relevant art will appreciate that the technology can be practiced on computer or controller systems other than those shown and described below. The technology can be embodied in a special-purpose computer, controller, or data processor that is specifically programmed, configured or constructed to perform one or more of the computer-executable instructions described below. Accordingly, the terms "computer" and "controller" as generally used herein refer to any data processor and can include internet appliances, hand-held devices, multi-processor systems, programmable consumer electronics, network computers, mini-computers, and the like. The technology can also be practiced in distributed environments where tasks or modules are performed by remote processing devices that are linked through a communications network. Aspects of the technology described below may be stored or distributed on computer-readable media, including magnetic or optically readable or removable computer discs as well as media distributed electronically over networks. In particular embodiments, data structures and transmissions of data particular to aspects of the technology are also encompassed within the scope of the present technology. The present technology encompasses both methods of programming computer-readable media to perform particular steps, as well as executing the steps.

[0014] A system in accordance with a particular embodiment of the technology includes an engine having a combustion region and an exhaust passage coupled to the engine to receive exhaust products from the combustion region. The exhaust passage can at least partially enclose a passage interior region. The system can further include a reactor having an external heat transfer surface positioned in the passage interior region, and a reaction zone positioned in a region enclosed by the external heat transfer surface. A hydrogen donor source can be coupled in fluid communication with the reaction zone of the reactor vessel via a donor passage, and a product passage can be coupled to the reaction zone to receive a reaction product from the reaction zone.

[0015] A system in accordance with another embodiment of the disclosed technology includes an engine having a combustion region, and an exhaust manifold coupled to the engine to receive exhaust products from the combustion region. The exhaust manifold can have a manifold external surface and a manifold internal surface at least partially enclosing an interior region, with insulation positioned around the external surface. The system can further include a reactor having a shell positioned in the interior region of the exhaust manifold, the shell having a shell external heat transfer surface, and a shell internal surface positioned around a reaction zone. A spiral heat transfer element is carried by the shell and projects into the passage interior region. A first wall is positioned annularly inwardly from the shell internal surface and is spaced radially apart from the shell internal surface to define a first annular passage. A second wall is positioned annularly inwardly from the first wall and spaced radially apart from the first wall to define a second annular passage positioned between the first and second walls, and a third passage positioned inwardly from the second wall. The second wall can include a porous medium that is transmissive to hydrogen but not transmissive to carbon compounds.

[0016] In still further embodiments, a representative system further includes an electrically-powered heater positioned in the second annular passage, and a galvanic circuit coupled across the second wall to pressurize the third passage. A hydrogen donor source is coupled to the first annular passage via a donor passage to direct a hydrogen donor to the reaction zone. A first product passage is coupled to the third passage to receive hydrogen, and a second product passage is coupled to the second annular passage to receive a carbon-bearing product. A liquid cooling system can be coupled to the engine to cool the engine, and can include a working fluid passage. A first heat exchanger can be coupled between the donor passage and the working fluid passage to transfer heat from the working fluid passage to the donor passage. The system can further include a second heat exchanger coupled between the donor passage and the exhaust manifold downstream of the reactor to transfer heat from the exhaust manifold to the donor passage. A third heat exchanger can be coupled between the donor passage and at least one of the first and second product passages to transfer heat from the at least one product passage to the donor passage. A turbine can be positioned downstream of the reactor and the spiral heat transfer element to extract energy from the flow that has passed around the reactor.

[0017] A method for operating an engine and a chemical reactor in accordance with a particular embodiment of the disclosed technology includes combusting a fuel in an engine to produce power and combustion products, directing the combustion products through an exhaust passage and around a reactor positioned within the exhaust passage, and transferring heat from the combustion products to a reaction zone within the reactor, via an external surface of the reactor. The method can further include directing a hydrogen donor into the reaction zone of the reactor, and dissociating the hydrogen donor into dissociation products in the reaction zone. The products can include a hydrogen-bearing constituent, and a non-hydrogen bearing constituent.

Representative Reactor Systems

[0018] FIGS. **1** and **2** illustrate representative reactor systems for producing hydrogen-based fuels and structural building blocks or architectural constructs in accordance with several embodiments of the technology. FIG. **1** illustrates the general arrangement of a reactor that uses waste heat from a combustion process. FIG. **2** illustrates further details of the reactor system, and illustrates mechanisms and arrangements by which the combustion engine and reactor can be coupled in a closed-loop fashion. FIGS. **3-6** illustrate further embodiments in which the reactor is positioned within an exhaust manifold.

[0019] FIG. **1** is a partially schematic illustration of a representative system **100** that includes a reactor **110**. The reactor **110** further includes a reactor vessel **111** that encloses or partially encloses a reaction zone **112**. In at least some instances, the reactor vessel **111** has one or more transmissive surfaces positioned to facilitate the chemical reaction taking place within the reaction zone **112**. Suitable transmissive surfaces are disclosed in co-pending U.S. application Ser. No. 13/026,996, titled "REACTOR VESSELS WITH TRANSMISSIVE SURFACES FOR PRODUCING HYDROGEN-BASED FUELS AND STRUCTURAL ELEMENTS, AND ASSOCIATED SYSTEMS AND METHODS" (Attorney Docket No. 69545.8602US), filed on Feb. 14, 2011, and incorporated herein by reference. To the extent of the foregoing reference and/or any other references incorporated herein by reference conflict with the present disclosure, the present disclosure controls. In a representative example, the reactor vessel **111** receives a hydrogen donor provided by a donor source **130** to a donor entry port **113**. For example, the hydrogen donor can include methane or another hydrocarbon. A donor distributor or manifold **115** within the reactor vessel **111** disperses or distributes the hydrogen donor into the reaction zone **112**. The reactor vessel **111** also receives steam from a steam/water source **140** via a steam entry port **114**. A steam distributor **116** in the reactor vessel **111** distributes the steam into the reaction zone **112**. The reactor vessel **111** can further include a heater **123** that supplies heat to the reaction zone **112** to facilitate endothermic reactions. The power for the heater (e.g., electrical power) can be provided by a renewable energy source **165**. The renewable energy source **165** can include a solar, wind, water and/or other suitable sustainable sources. The reactions performed at the reaction zone **112** can include dissociating methane or another hydrocarbon into hydrogen or a hydrogen compound, and carbon or a carbon compound. In other embodiments, the reactor **110** can dissociate other hydrogen donors, e.g. nitrogenous hydrogen donors. Representative reactions are further described in co-pending U.S. application Ser. No. 13/027,208 (referred to herein as the '208 Application) titled "CHEMICAL PROCESSES AND REACTORS FOR EFFICIENTLY PRODUCING HYDROGEN FUELS AND STRUCTURAL MATERIALS, AND ASSOCIATED SYSTEMS AND METHODS" (Attorney Docket No. 69545.8601US), filed on Feb. 14, 2011 and incorporated herein by reference. The products of the reaction exit the reactor vessel **111** via an exit port **117** and are collected at a reaction product collector **171***a*.

[0020] The system **100** can further include a source **150** of radiant energy (e.g., waste heat) and/or additional reactants, which provides constituents to a passage **118** within the reactor vessel **111**. For example, the heat/reactant source **150** can include a combustion chamber **151** that provides hot combustion/exhaust products **152** to the passage **118**, as indicated by arrow A. The combustion products **152** and associated waste heat are produced by a process separate from the dissociation process (e.g., a power generation process). A combustion products collector **171***b* collects combustion products exiting the reactor vessel **111** for further recycling and/or other uses. In a particular embodiment, the combustion products **152** can include hot carbon monoxide, water vapor, and/or other constituents. One or more transmissive surfaces **119** are positioned between the reaction zone **112** (which can be disposed annularly around the passage **118**) and an interior region **120** of the passage **118**. The transmissive surface **119** can accordingly allow radiant energy and/or a chemical constituent to pass radially outwardly from the passage **118** into the reaction zone **112**, as indicated by arrows B. By delivering the radiant energy (e.g., heat) and/or chemical constituent(s) provided by the flow of combustion products **152**, the system **100** can enhance the reaction taking place in the reaction zone **112**, for example, by increasing the reaction zone temperature and/or pressure, and therefore the reaction rate, and/or the thermodynamic efficiency of the reaction. The foregoing process can accordingly recycle or reuse energy and/or constituents that would otherwise be wasted, in addition to facilitating the reaction at the reaction zone **112**.

[0021] The composition and structure of the transmissive surface **119** can be selected to allow radiant energy to readily pass from the interior region **120** of the passage **118** to the reaction zone **112**. Accordingly, the transmissive surface **119** can include glass, graphene, or a re-radiative component. Suitable re-radiative components are described further in co-pending U.S. application Ser. No. 13/027,015, titled "CHEMICAL REACTORS WITH RE-RADIATING SURFACES AND ASSOCIATED SYSTEMS AND METHODS" (Attorney Docket No. 69545.8603US), filed on Feb. 14, 2011 and incorporated herein by reference.

[0022] As noted above, the combustion products **152** can include steam and/or other constituents that may serve as reactants in the reaction zone **112**. Accordingly, the transmissive surface **119** can be manufactured to selectively allow such constituents into the reaction zone **112**, in addition to or in lieu of admitting radiant energy into the reaction zone **112**. In a particular embodiment, the transmissive surface **119** can be formed from a carbon crystal structure, for example, a layered graphene structure. The carbon-based crystal structure can include spacings (e.g., between parallel layers oriented transverse to the flow direction A) that are deliberately selected to allow water molecules to pass through. At the same time, the spacings can be selected to prevent useful reaction products produced in the reaction zone **112** from passing out of the reaction zone. In particular embodiments, the transmissive surface **119** can be formed by using the same type of architectural constructs produced or facilitated by the reactor **110**.

[0023] The system **100** can further include a controller **190** that receives input signals **191** (e.g., from sensors) and provides output signals **192** (e.g., control instructions) based at least in part on the inputs **191**. Accordingly, the controller **190** can include suitable processor, memory and I/O capabilities. The controller **190** can receive signals corresponding to measured or sensed pressures, temperatures, flow rates, chemical concentrations and/or other suitable parameters, and can issue instructions controlling reactant delivery rates, pressures and temperatures, heater activation, valve settings and/or other suitable actively controllable parameters. An operator can provide additional inputs to modify, adjust and/or override the instructions carried out autonomously by the controller **190**.

[0024] FIG. **2** is a partially schematic illustration of system **100** that includes a reactor **110** in combination with a radiant energy/reactant source **150** in accordance with another embodiment of the technology. In this embodiment, the radiant energy/reactant source **150** includes an engine **180**, e.g., an internal combustion engine having a piston **182** that reciprocates within a cylinder **181**. In other embodiments, the engine **180** can have other configurations, for example, an external combustion configuration. In an embodiment shown in FIG. **2**, the engine **180** includes an intake port **184***a* that is opened and closed by an intake valve **183***a* to control air entering the cylinder **181** through an air filter **178**. The air flow can be unthrottled in an embodiment shown in FIG. **2**, and can be throttled in other embodiments. A fuel injector **185** directs fuel into the combustion zone **179** where it mixes with the air and ignites to produce the combustion products **152**. Additional fuel can be introduced by an injection valve **189***a*. The combustion products **152** exit the cylinder **181** via an exhaust port **184***b* controlled by an exhaust valve **183***b*. Further details of representative engines and ignition systems are disclosed in co-pending U.S. application Ser. No. 12/653,085 (Attorney Docket No. 69545.8304US) filed on Dec. 7, 2010, and incorporated herein by reference.

[0025] The engine **180** can include features specifically designed to integrate the operation of the engine with the operation of the reactor **110**. For example, the engine **180** and the reactor **110** can share fuel from a common fuel source **130** which is described in further detail below. The fuel is provided to the fuel injector **185** via a regulator **186**. The engine **180** can also receive end products from the reactor **110** via a first conduit or passage **177***a*, and water (e.g., liquid or steam) from the reactor **110** via a second conduit or passage **177***b*. Further aspects of these features are described in greater detail below, following a description of the other features of the overall system **100**.

[0026] The system **100** shown in FIG. **2** also includes heat exchangers and separators configured to transfer heat and segregate reaction products in accordance with the disclosed technology. In a particular aspect of this embodiment, the system **100** includes a steam/water source **140** that provides steam to the reactor vessel **111** to facilitate product formation. Steam from the steam/water source **140** can be provided to the reactor **110** via at least two channels. The first channel includes a first water path **141***a* that passes through a first heat exchanger **170***a* and into the reactor vessel **111** via a first steam distributor **116***a*. Products removed from the reactor vessel **111** pass through a reactor product exit port **117** and along a products path **161**. The products path **161** passes through the first heat exchanger **170***a* in a counter-flow or counter-current manner to cool the products and heat the steam entering the reactor vessel **111**. The products continue to a reaction product separator **171***a* that segregates useful end products (e.g., hydrogen and carbon or carbon compounds). At least some of the products are then directed back to the engine **180**, and other products are then collected at a products collector **160***a*. A first valve **176***a* regulates the product flow. Water remaining in the products path **161** can be separated at the reaction product separator **171***a* and returned to the steam/water source **140**.

[0027] The second channel via which the steam/water source **140** provides steam to the reactor **110** includes a second water path **141***b* that passes through a second heat exchanger **170***b*. Water proceeding along the second water path **141***b* enters the reactor **110** in the form of steam via a second stream distributor **116***b*. This water is heated by combustion products that have exited the combustion zone **179** and passed through the transfer passage **118** (which can include a transmissive surface **119**) along a combustion products path **154**. The spent combustion products **152** are collected at a combustion products collector **160***b* and can include nitrogen compounds, phosphates, re-used illuminant additives (e.g., sources of sodium, magnesium and/or potassium), and/or other compositions that may be recycled or used for other purposes (e.g., agricultural purposes). The illuminant additives can be added to the combustion products **152** (and/or the fuel used by the engine **180**) upstream of the reactor **110** to increase the amount of radiant energy available for transmission into the reaction zone **112**.

[0028] In addition to heating water along the second water path **141***b* and cooling the combustion products along the combustion products path **154**, the second heat exchanger **170***b* can heat the hydrogen donor passing along a donor path **131** to a donor distributor **115** located within the reactor vessel **111**. The donor vessel **130** houses a hydrogen donor, e.g., a hydrocarbon such as methane, or a nitrogenous donor such as ammonia. The donor vessel **130** can include one or more heaters **132** (shown as first heater **132***a* and a second heater **132***b*) to vaporize and/or pressurize the hydrogen donor within. A three-way valve **133** and a regulator **134** control the amount of fluid and/or vapor that exits the donor vessel **130** and passes along the donor path **131** through the second heat exchanger **170***b* and into the reactor vessel **111**. As discussed above, the hydrogen donor can also serve as a fuel for the engine **180**, in at least some embodiments, and can be delivered to the engine **180** via a third conduit or passage **177***c*.

[0029] In the reactor vessel **111**, the combustion products **152** pass through the combustion products passage **118** while delivering radiant energy and/or reactants through the transmissive surface **119** into the reaction zone **112**. After passing through the second heat exchanger **170***b*, the combustion products **152** can enter a combustion products separator **171***b* that separates water from the combustion products. The water returns to the steam/water source **140** and the remaining combustion products are collected at the combustion products collector **160***b*. In a particular embodiment, the separator **171***b* can include a centrifugal separator that is driven by the kinetic energy of the combustion product stream. If the kinetic energy of the combustion product stream is insufficient to separate the water by centrifugal force, a motor/generator **172** can add energy to the separator **171***b* to provide the necessary centrifugal force. If the kinetic energy of the combustion product stream is greater than is necessary to separate water, the motor/generator **172** can produce energy, e.g., to be used by other components of the system **100**. The controller **190** receives inputs from the various elements of the system **100** and controls flow rates, pressures, temperatures, and/or other parameters.

[0030] The controller **190** can also control the return of reactor products to the engine **180**. For example, the controller can direct reaction products and/or recaptured water back to the engine **180** via a series of valves. In a particular embodiment, the controller **190** can direct the operation of the first valve **176***a* which directs hydrogen and carbon monoxide obtained from the first separator **171***a* to the engine **180** via the first conduit **177***a*. These constituents can be burned in the combustion zone **179** to provide additional power from the engine **180**. In some instances, it may be desirable to cool the combustion zone **179** and/or other elements of the engine **180** as shown. In such instances, the controller **190** can control a flow of water or steam to the engine **180** via second and third valves **176***b*, **176***c* and the corresponding second conduit **177***b*.

[0031] In some instances, it may be desirable to balance the energy provided to the reactor **110** with energy extracted from the engine **180** used for other proposes. Accordingly, the system **100** can included a proportioning valve **187** in the combustion products stream that can direct some combustion products **152** to a power extraction device **188**, for example, a turbo-alternator, turbocharger or a supercharger. When the power extraction device **188** includes a supercharger, it operates to compress air entering the engine cylinder **181** via the intake port **184***a*. When the extraction device **188** includes a turbocharger, it can include an additional fuel injection valve **189***b* that directs fuel into the mixture of combustion products for further combustion to produce additional power. This power can supplement the power provided by the engine **180**, or it can be provided separately, e.g., via a separate electrical generator.

[0032] As is evident from the forgoing discussion, one feature of the system **100** is that it is specifically configured to conserve and reuse energy from the combustion products **152**. Accordingly, the system **100** can include additional features that are designed to reduce energy losses from the combustion products **152**. Such features can include insulation positioned around the cylinder **181**, at the head of the piston **182**, and/or at the ends of the valves **183***a*, **183***b*. Accordingly, the insulation prevents or at least restricts heat from being conveyed away from the engine **180** via any thermal channel other than the passage **118**.

[0033] One feature of at least some of the foregoing embodiments is that the reactor system can include a reactor and an engine linked in an interdependent manner. In particular, the engine can provide waste heat that facilitates a dissociation process conducted at the reactor to produce a hydrogen-based fuel and a non-hydrogen based structural building block. The building block can include a molecule containing carbon, boron, nitrogen, silicon and/or sulfur, and can be used to form an architectural construct. Representative examples of architectural constructs, in addition to the polymers and composites described above are described in further detail in co-pending U.S. Application No. 13/027,214, titled "ARCHI-

TECTURAL CONSTRUCT HAVING FOR EXAMPLE A PLURALITY OF ARCHITECTURAL CRYSTALS" (Attorney Docket No. 69545.8701) filed on Feb. 14, 2011 and incorporated herein by reference. An advantage of this arrangement is that it can provide a synergy between the engine and the reactor. For example, the energy inputs normally required by the reactor to conduct the dissociation processes described above can be reduced by virtue of the additional energy provided by the combustion product. The efficiency of the engine can be improved by adding clean-burning hydrogen to the combustion chamber, and/or by providing water (e.g., in steam or liquid form) for cooling the engine. Although both the steam and the hydrogen-based fuel are produced by the reactor, they can be delivered to the engine at different rates and/or can vary in accordance with different schedules and/or otherwise in different manners.

[0034] FIG. **3** is a partially schematic, cross-sectional illustration of a system **200** that includes a reactor **210** having a reactor vessel **211** positioned in an engine exhaust manifold or passage **220**. The exhaust manifold **220** can be coupled to an engine **180** having a reciprocating internal combustion configuration generally similar to that described above with reference to FIG. **2**. In other embodiments, the engine **180** can have other configurations, for example, a gas turbine configuration. In any of these embodiments, exhaust products from the engine **180** pass into the exhaust manifold **220** and around the reactor vessel **211** to provide heat to a reaction zone **212** located within the reactor vessel **211**. Further details of a representative manner in which the reactor **210** is integrated with other features of the system **200** are described below with continued reference to FIG. **3**. Further details of the reactor itself are described later with reference to FIGS. **4-6**.

[0035] As shown in FIG. **3**, the exhaust manifold **220** can have an interior region **221** through which exhaust gases from the exhaust port **184***b* pass. The exhaust gases pass around the reactor vessel **211** as indicated by arrows E, and as they pass the reactor vessel **211**, transfer heat into the reactor vessel **211**. One or more heat transfer elements **213** can project into the interior region **221** of the exhaust manifold **220** to facilitate this heat transfer process. In particular embodiments, the reactor vessel **211** can also include an internal heater **214** that can, on an intermittent or continuous basis, supplement the heat provided to the reaction zone **212** by the exhaust gases passing through the manifold **220**.

[0036] In a further aspect of an embodiment shown in FIG. **3**, the externally projecting heat transfer elements **213** can be arranged to impart a spiral or radial flow component to the exhaust gases. Accordingly, when the exhaust gases pass downstream to a turbine **288** or other energy extraction device, the turbine **288** can extract the rotational kinetic energy. The turbine **288** can be coupled to an electric generator **277** via a shaft **287**. The generator **277** can in turn provide the electrical energy to an energy storage medium **206** e.g. a battery, a bank of capacitors and/or another suitable medium. The electrical energy can be retrieved from the energy storage medium **206** to power the reactor heater **214** and/or other components of the system **200**.

[0037] Exhaust gases exiting the turbine **288** can proceed downstream along a flow axis F past a heat exchanger **240***b* which will be described later, and to an exhaust product separator **226**. The exhaust product separator **226** can separate one or more constituents from the exhaust gas stream, and provide the constituents to an exhaust product collector **260***c*. Separated exhaust products can then be directed to any of a number of suitable uses, for example, sulfur applications, fertilizer applications, and/or others, depending upon the composition of the exhaust gas products. Any remaining exhaust gas exits the exhaust manifold or passage **220** at an exit **225**.

[0038] At least some portions, and in particular embodiments, all portions, of the exhaust manifold or passage **220** can include insulation **224** that prevents or at least restricts heat from escaping the manifold **220**. Instead, this heat is directed to the reaction zone **212**. This is unlike most conventional exhaust gas manifolds, which typically facilitate heat transfer to the external environment for purposes of cooling.

[0039] The system **200** can include one or more reactant vessels **230** (e.g. donor sources) that supply one or more reactants (e.g., hydrogen donors) to the reaction zone **212**. The reactant is gaseous in several embodiments, and can be liquid and/or solid, or any suitable combination of phases in others. In particular embodiments, the donor includes a hydrogen donor, e.g., methane or another hydrocarbon. Suitable hydrocarbons include ethane, propane or butane, along with cetane and/or octane rated compounds. In still further embodiments, the reactant can include a lower grade constituent, e.g., off-grade cetane or octane rated hydrocarbons, or wet alcohol. In at least some embodiments, the donor substance can include compounds other than hydrocarbon fuels (e.g., carbohydrates, fats, alcohols, esters, cellulose and/or others). In yet further embodiments, the hydrogen donor can include hydrogen atoms in combination with constituents other than carbon. For example, nitrogenous compounds (e.g., ammonia and/or urea) can serve a similar hydrogen donor function. Examples of other suitable hydrogen donors are described in the '208 Application, previously incorporated herein by reference.

[0040] In yet further embodiments, the donor substance can donate constituents other than hydrogen. For example, the reactor **210** can dissociate oxygen from CO2 and/or another oxygen donor, or the reactor **210** can dissociate a halogen donor. In other embodiments, the donor can have other compositions and/or donate other constituents. In any of these embodiments, the donor is dissociated in the reaction zone **212** to produce two or more products. Accordingly, the system **200** can include multiple product collectors that collect the resulting products. In a particular embodiment shown in FIG. **3**, the product collectors include a first product collector **260***a* and a second product collector **260***b*. In particular embodiments, as was discussed above with reference to FIGS. **1** and **2**, the reactant vessel **230** can supply a hydrocarbon to the reaction zone **212**. In the reaction zone **212**, the hydrocarbon can be dissociated into hydrogen or a hydrogen-bearing compound (directed to the first product collector **260***a*) and a carbon or carbon-bearing compound directed to the second product collector **260***b*. The hydrogen can be stored and/or delivered to the combustion zone **179** of the engine **180** via a product delivery passage **262** and the fuel injector **185**. The hydrogen alone or in combination with other constituents can accordingly form a hydrogen-characterized fuel. An optional water source **275** can deliver water to the combustion zone **179**. The system **200** can include a number of heat exchangers (e.g., counter-current or counter-flow heat exchangers) and/or other features that increase the overall efficiency of the reactor **210**, as will be described in further detail below.

[0041] As shown in FIG. **3**, the reactant vessel **230** can perform multiple purposes. For example, in addition to supplying a reactant to the reaction zone **212**, the reactant vessel **230** can supply fuel to the engine **180**. In particular, in a manner generally similar to that described above with reference to FIG. **2**, the reactant **230** can provide fuel (e.g. a hydrocarbon fuel) to the engine **180** via the fuel injector **185**, under the control of the regulator **186**. The reactant vessel **230** can include features for preheating the fuel/reactant/donor prior to delivering the reactant to the fuel injector **185** and/or the reaction zone **212**. For example, the reactant vessel **230** can include an internal heater **232**. In a particular aspect of this embodiment, the internal heater **232** can be a resistive heater, which receives electrical current from the energy storage medium **206** described above. The reactant vessel **230** can receive heat from other sources, in addition to or in lieu of the heater **232**. Such sources can include a burner **233** that burns a portion of the reactant contained within the reactant vessel **230** (and/or another suitable fuel) and provides the resultant heat to the reactant vessel **230** via a heat pipe **234** or other suitable thermal transfer device. The heat provided to the reactant vessel **230** can vaporize and/or pressurize the reactant therein. As described above, suitable reactants can include methane or methanol, optionally with water, which can operate as an oxidant.

[0042] The reactant or donor (both terms are used herein to refer to the compound delivered to the reactor **210**) exits the reactant vessel **230** via a reactant passage **231**, which directs the reactant to the reaction zone **212** via one or more additional heat transfer arrangements that can further preheat the reactant before it arrives at the reaction zone **212**. For example, the system **200** can include a first heat exchanger **240***a* having a first heat exchange passage **241***a* and a second heat exchange passage **242***a* that are positioned in a counterflow arrangement relative to each other. The reactant can pass through the first heat exchanger passage **241***a* so as to receive heat from the second heat exchanger passage **242***a*. The second heat exchanger passage **242***a* can be coupled to an engine coolant circuit **276**. The engine coolant circuit **276** can include antifreeze or another heat transfer working fluid that receives heat from the engine **180**. In most conventional arrangements, this heat is rejected to the environment via a radiator. In the present embodiment, this heat is instead transferred to the reactant passing through the first heat exchanger passage **241***a*. In a representative embodiment, the fluid in the second heat exchanger passage **242***a* can have a temperature of up to about 105° C., and in other embodiments, the temperature can have other suitable values.

[0043] The reactant passage **231** can further be coupled to a second heat exchanger **240***b* positioned at the exhaust manifold **220**. The second heat exchanger **240***b* can include a heat exchange passage **241***b* that is in direct thermal communication with the exhaust flow passing through the exhaust manifold **220**, to further preheat the reactant in the reactant passage **231**. The temperature of the exhaust gas at this location (e.g., downstream of the turbine **288**) can be up to about 600° C. in a representative embodiment.

[0044] The system **200** can further include a third heat exchanger **240***c* that directs heat from products exiting the reactor **210** to the reactants entering the reactor **210**. Accordingly, the third heat exchanger **240***c* can include a first heat exchanger passage **241***c* having a counter-flow arrangement relative to one or more second heat exchanger passages **242***c*. In a particular embodiment shown in FIG. **2**, the third heat exchanger **240***c* includes two second heat exchanger passages **242***c*, one coupled between the reactor **210** and the first product collector **260***a* via a first product passage **261***a*, and the other coupled between the reactor **210** and the second product collector **260***b* via a second product passage **261***b*. Accordingly, both products exiting the reactor **210** can preheat the reactant. In other embodiments (e.g., for which more than two products are separated) the third heat exchanger **240***c* can include additional second heat exchanger passages **242***c*.

[0045] In at least some instances, the system **200** can further include a supplemental reactant vessel **230***a* coupled to the donor passage **231**. Accordingly, the system **200** can supply an additional reactant (in addition to the reactant provided by the reactant vessel **230**) into the reaction zone **212**. Suitable constituents carried by the supplemental reactor **230***a* can include but are not limited to methanol.

[0046] In a typical embodiment, the system **200** includes a vehicle **201** (e.g., a truck, a locomotive or another transportation medium) that carries the engine **180**, the exhaust manifold **220** and the reactor **210**. Accordingly, the system **200** includes one or more wheels **202**, one of which is shown schematically in FIG. **3**. The wheel or wheels **202** can be coupled to a regenerative brake **203** that converts kinetic energy from the wheel to electrical energy during a braking operation, and directs the electrical energy to the energy storage medium **206**. The energy storage medium **206** can in turn direct the electrical energy to the reactant vessel heater **232**, the reactor heater **214** and/or other electrically powered subsystems to increase the overall efficiency of the vehicle-based system **200**. Further embodiments of regenerative brakes and other vehicle-based energy capture techniques are disclosed in U.S. application Ser. No. 13/584,786 (Attorney Docket No. 69545.8615US3) filed Feb. 11, 2013 and incorporated herein by reference.

[0047] When the vehicle **201** in not in use (or if the system **200** is fixed in place), the energy source **206** can be coupled to an electrical grid **204** via a power outlet **205** or other suitable arrangement. Accordingly, the energy source **206** can be recharged, e.g., during non-operational periods, so as to provide energy on an as-needed basis during operational periods. Power management tasks and other coordination tasks used to direct the operation of the reactor **210** and associated subsystems can be controlled by a controller **290** that receives inputs **291** and provides appropriate outputs **292**. The controller **290** can accordingly include one or more computer-readable media programmed with instruction that, when executed, carry out one or more of the tasks and operations described herein. Further details of the structure and operation of the reactor **210** are described below with reference to FIGS. **4** and **5**.

[0048] FIG. **4** is a partially schematic, side cross-sectional illustration of an embodiment of the reactor **210** positioned within the exhaust manifold or passage **220**. The manifold **220** can have a manifold internal surface **222** facing toward the reactor **210**, and a manifold external surface **223** facing outwardly away from the reactor **210**. As discussed above, the manifold **220** can be surrounded or at least partially surrounded with insulation **224** (e.g., a ceramic or other suitable material) that prevents or at least restricts heat from escaping via the manifold external surface **223**. Instead, such heat is available for transfer by convection, conduction, and/or radiation to the manifold interior region **221** and the reactor **210**.

[0049] The reactor **210** can include a shell **215** having a shell internal surface **216***a* and a shell external surface **216***b*. The external surface **216***b* can include a highly thermally conductive, heat-resistant and oxidation-resistant material (e.g. a super alloy that includes nickel and/or cobalt, or another high temperature furnace alloy) to facilitate transferring heat from the exhaust gas to the reaction zone **212** within the reactor **210**. Unlike the arrangement described above with reference to FIG. **2**, the shell **215** can prevent constituent transfers into the reactor **220** from the adjacent exhaust flow, while permitting heat transfer from the exhaust flow. As discussed above, the reactor **210** can further include one or more heat transfer elements **213** that project from the shell **215** into the interior region **221** of the manifold **220** to extract additional thermal energy from the exhaust gas and conduct that energy to the reaction zone **212** via the shell **215**. In a particular embodiment, the heat transfer element **213** can have a generally spiral shape that, in addition to extracting heat from the passing exhaust flow, imparts a rotational motion to the exhaust flow, which can be extracted by the turbine **288** described above with reference to FIG. **3**. In one embodiment, the heat transfer element **213** can include a single screw-shaped annular element. In other embodiments, the heat transfer element **213** can have multiple components, e.g., multiple vanes, fins, or other surfaces that are at least partially inclined relative to the axial gas flow direction indicated by arrows E. Accordingly, any of these arrangements can generate the spiral flow pattern indicated by arrows S. The heat transfer elements can generally have a high surface area-to-volume ratio so as to increase the efficiency with which they collect and transmit heat.

[0050] The reactor **210** can have one or more annularly-positioned flow passages, defined by one or more corresponding walls. For example, the reactor vessel **211** can include a first wall **251** (e.g., in the form of a capped tube) positioned inwardly from the shell **215** to define, at least in part, a first passage **253***a*. The vessel **211** can further include a second wall **252** (e.g., in the form of a capped tube) positioned radially inwardly from the first wall **251**. Accordingly, the second wall **252** can define, at least in part, a second passage **253***b* positioned between the first wall **251** and the second wall **252**, and a third passage **253***c* positioned inwardly from the second wall **252**. The first wall **251** can be generally solid and thermally insulated or non-transmissive, so as to restrict or prevent the loss of heat generated by the reaction heater **214**. Accordingly, a reactant flow provided by the reactant passage **231** can receive heat from the shell **215** as it travels axially along the annular first passage **253***a*, as indicated by arrows D. The first wall **251** can include openings or perforations **250** toward a distal end DE of the first passage **253***a*, allowing the reactant to pass inwardly into the second passage **253***b*. The reactant then travels back in a proximal direction through the second passage **253***b* toward a proximal end PE of the reactor **210**.

[0051] As the reactant receives heat in both the first and second passages **253***a*, **253***b*, it begins to oxidize, partially oxidize, reform, and/or dissociate in a non-combustion, endothermic reaction process, forming one or more first products and one or more second products. These processes can be conducted in accordance with the parameters described in the '208 Application previously incorporated herein by reference. Representative reactions include:

$$Heat+CH4+H2O \rightarrow CO+3H2 \qquad \text{Equation 1}$$

$$Heat+CH4 \rightarrow C+2H2 \qquad \text{Equation 2}$$

$$Heat+CH3OH \rightarrow CO+2H2 \qquad \text{Equation 3}$$

$$Heat+CH3OH+H2O \rightarrow CO2+3H2 \qquad \text{Equation 4}$$

$$Heat+CH3IH+\text{"C"}+H2O \rightarrow 2CO+3H2 \qquad \text{Equation 5}$$

$$Heat+CxHy+xH2O \rightarrow xCO+(0.5y+x)H2 \qquad \text{Equation 6}$$

$$Heat+2NH3 \rightarrow N2+3H2 \qquad \text{Equation 7}$$

$$Heat+CO(NH2)2 \rightarrow CO+2H2+N2 \qquad \text{Equation 8}$$

$$Heat+CO(NH2)2+H2O \rightarrow CO2+3H2+N2 \qquad \text{Equation 9}$$

$$CH4+0.5O2 \rightarrow CO+3H2+Heat \qquad \text{Equation 10}$$

$$HxCy+y/2O2 \rightarrow yCO+x/2H2 \qquad \text{Equation 11}$$

$$HxCy=yH2O \rightarrow yCO=(y+x/2)H2 \qquad \text{Equation 12}$$

[0052] In at least some cases, various carbon donors (identified as "C" in Equation 5) can contribute further carbon to the foregoing reactions. Suitable carbon donors can include coal, grain dust, food and/or farm wastes. In addition to or in lieu of such sources, optional surfactants can be added to improve emulsion stability, including surfactants that may also contribute carbon in the endothermic reaction. In at least some embodiments (e.g., as indicated by Equations 10-12), exothermic and/or partial oxidation reactions can contribute heat to the foregoing endothermic reactions.

[0053] In particular embodiments, the first products include hydrogen or hydrogen compounds, and the second products include carbon or carbon compounds. The second wall **252** can be constructed to separate these two products and direct each to a respective one of the first product collector **260***a* or the second product collector **260***b* described above with reference to FIG. **3**. In a particular embodiment, the second wall **252** can include a porous medium **254** having porous surfaces **255** and being selectively transmissive to hydrogen or selected hydrogen compounds, but is not transmissive to carbon or carbon compounds. Accordingly, hydrogen can pass into the third passage **253***c* as indicated by arrows H, and carbon or carbon compounds can remain in the second passage **253***b*, as indicated by arrows C. The hydrogen is then collected at the first product passage **261***a*, and the carbon or carbon compounds are collected at the second product passage **261***b*.

[0054] In one embodiment, the second wall **252** can be manufactured by winding selected filaments on a temporary forming mandrel sized to match or approximately match the inner diameter of this tube-shaped element. The fibers can be wound in a pattern that is selected or optimized for reinforcing a pressure-containing vessel. Filaments suitable for such purposes include polyacrylonitrile (PAN) including co-polymers and solutions with other compounds, pitch fiber, along with carbon fiber, silicon carbide and/or other suitable filament selections. The resulting matrix can then be heat treated and/or subjected to other furnace operations to convert the PAN to carbon. Additional carbon can be added to (e.g., deposited on) the matrix by one or more steps similar to the reaction identified above in Equation 2. The resulting structure can accordingly include a porous network that favors hydrogen (e.g., separates hydrogen) from feedstocks such as natural gas liquids and other reactants listed in Equations 1-9, as well as from other products listed in Equations 1-9 above.

[0055] In another embodiment, the tube forming the second wall **252** can be formed by compacting graphene, carbon, and/or other powders with one or more suitable organic polymers and/or binders, followed by heat treating to convert the organics and/or binders and densification to the degree desired for separation of hydrogen and/or carbon monoxide from other gases such as the reactants of Equations 1-9. In particular, densifiying the matrix can include producing nanomaterials such as nanotubes, fibers, and whiskers by the technologies disclosed in U.S. Application Publication No. 2009/0186214, U.S. Pat. No. 8,158,217 and/or U.S. Pat. No. 8,168,291. Accordingly, the products formed at the reactor **210** can be used to form new structures for additional reactors. In particular, the carbon extracted from a hydrocarbon in one process can be used to form the porous medium that is used to separate additional carbon and hydrogen in a subsequent process.

[0056] In still further embodiments, the tube forming the second wall **252** can be repaired or repurposed after use in the reactor **210**. For example, the initial use of the tube as a component of an exhaust manifold provides a highly purified, sterilized, and refined micro-porous electrode or filter matrix. After such use, the tube can have deposited on it a carbon fuzz so that the tube can function as a high value electrode for electro-dialysis or as a filter for fluids such as air, water, beer, whiskey, wine or pharmaceutical products.

[0057] The temperature of the reaction zone **212** may vary depending upon the operational state of the engine **180** (FIG. **3**). For example, during cold engine startup, the exhaust gases will have a relatively low temperature e.g., 120° C. As the engine warms up, the exhaust gas temperature will increase e.g., to 300° C. for idle, coasting or lightly loaded operation. At maximum load conditions, the exhaust gas temperature can increase to 700° C. In any of these embodiments, the reactor heater **214** can supplement the energy provided to the reaction zone **212**. The heater **214** can be an electrical resistance heater or induction heater that, under the control of the controller **290** (FIG. **3**) provides the requisite amount of heat. In some embodiments, the heater **214** is activated only during engine operational phases that result in relatively low exhaust gas temperatures. In other embodiments, the heater **214** is active at all times, but provides more heat during some operational phases than others. For example, a typical temperature for hydrogen dissociation is at least 650° C., and in several embodiments, it is desirable to conduct the reaction at higher temperatures (e.g., at least 700° C. and in particular, from about 750° C. to about 1600° C.). Such elevated temperatures can produce product pressures high enough to support injecting the products (e.g., hydrogen) into a high compression ratio engine. In at least some instances, the heat transferred to the reactant via the engine coolant, the exhaust downstream of the turbine **288**, and the exhaust upstream of the turbine **288** may be insufficient to elevate the reaction zone **212** to these temperatures. In such instances, the reactor heater **214** may operate at all times when the reactor **210** operates, but, as described above, its energy output can vary depending on the engine operational state and by extension reaction zone temperature. Temperature sensors, pressure sensors, and/or other feedback devices are used to determine the operational states and/or parameters of the system **200** to provide suitable information to the controller **290**.

[0058] In another aspect of an embodiment shown in FIG. **4**, the reaction vessel **211** can include one or more galvanic circuits **217**, each of which can include one or more cathodes **218***a* and one or more anodes **218***b*. The galvanic circuit **217** can be coupled to the energy storage medium **206** (FIG. **3**) to provide a voltage across the second wall **252**. When activated, the galvanic circuit can pressurize the hydrogen collected in the third passage **253***c*, which can in turn facilitate the dissociation process conducted in the reaction zone **212** by reducing the hydrogen partial pressure in the reaction **212**. In addition, hydrogen at elevated pressures within the third passage **253***c* can be used to facilitate high-pressure fuel injection at the injector **185** (FIG. **3**). Representative pressures include 200 Bar (gage) or higher.

[0059] Galvanic separation can facilitate the foregoing hydrogen separation and pressurization processes, e.g., by proton conduction. Composites and ceramics such as perovskite (SrCeO3) oxide can provide suitable media for such processes, and can be used in addition to the porous medium described above. In particular, gas volumes at elevated temperatures, that include hydrogen, can be separated at increased rates by doped perovskite-type oxides. Such enhanced proton conductivity is provided with membranes such as doped SrCeO3, CaZrO3, BaCeO3 and/or SrZrO3. Suitable dopants include yttrium, ytterbium, europium, samarium, neodymium, and gadolinium.

[0060] Hydrogen separation by such oxide ceramics can be further enhanced by an increased pressure gradient and/or via a DC bias. In embodiments that apply a DC bias or galvanic drive in the hydrogen separation process, the hydrogen can permeate from a lower hydrogen pressure on one side of the membrane to a higher hydrogen partial pressure on the other side of the membrane, or vice versa. By contrast, in a non-galvanic hydrogen separation process in which a pressure difference exists across a separation membrane, transport is only from the high hydrogen partial pressure side to the low hydrogen partial pressure side of the membrane.

[0061] Catalysts may be utilized at a reaction surface to influence surface exchange reactions such as various steps or the processes of Equations 1, 2, and/or 7 above, and the hydrogen permeation can be enhanced by coating the membrane with a surface catalyst to reduce the activation energy for the surface exchange reactions. In particular embodiments, the selected anode material is also a favorable catalyst. Representative anodes for galvanic hydrogen pumps include porous films of Ni, Ag, Pt, and Ni/BCY porous layer. In such hydrogen pumping processes, the gas mixture in the anode and cathode zones compartments can include steam or be humidified with water vapor to improve the proton conductivity of the electrolyte and suppress its electronic conductivity.

[0062] The hydrogen separation rate increases as the applied current is increased in accordance with Faraday's law. Depending upon factors such as reactant pressure and temperature, dopant selection, membrane thickness, and humidity, the applied galvanic voltage gradients can have values in a representative range of from about 0.2 VDC to about 20 VDC, which are sufficient to produce substantially higher pressure hydrogen. Such net galvanic voltage gradients may be produced by much higher voltage AC or DC electricity delivered to the reactor heater **214**.

[0063] Thus various mixtures of reactants and products such as H2 along with C**0**, CO2, H2O, and/or N2 in the anode zone can be separated to provide pressurized H2 at the cathode zone. Such hydrogen pressurization driven by an applied external voltage can move hydrogen from a suitably pressurized gas mixture including reactants and products to higher pressure for delivery for denser storage and injection purposes. In particular embodiments, reactants are delivered to the anode **218***b* at 61 Bar (900PSI) and are reacted to produce hydrogen that is removed to improve the reaction yield and delivered by galvanic separation at voltage gradients of 0.2 to 20VD to the cathode **218***a*, at 122 Bar (1800PSI).

[0064] As shown in FIG. **4**, embodiments of the present technology include a coaxial flow circuit that heats the reactants in the first passage **253***a* via exhaust gases, and then directs the gases into the second passage **253***b* wherein the foregoing galvanic process facilitates hydrogen separation and pressurization. Accordingly, the exhaust gases can provide an initial quantity of heat alone or in combination with the heat received from heat transfer processes described above with reference to FIG. **4**. Additional heat, e.g., obtained from a regenerative braking process, can be provided at higher and adaptively controlled temperatures to produce hydrogen at the desired rate and/or pressure needed to optimize or at least improve operation of the engine **180** (FIG. **3**).

[0065] Reactants delivered to the anode within the tube bore at 61 Bar (900PSI) can be reacted to produce hydrogen that is removed to improve the reaction yield and delivered by galvanic separation at voltage gradients of 0.2 to 20VD to the cathode at the outside zone of the separator tube at 122 Bar (1800PSI). The pressurized hydrogen can be directly injected into the engine **180** (FIG. **3**).

[0066] FIG. **5** is an end cross-sectional illustration of a portion of the system **200** described above with reference to FIGS. **3** and **4**. FIG. **5** illustrates the manifold **220** attached to the engine **180** with an arrangement that, in addition to or in lieu of the insulation **224** reduces or prevents heat loss, so as to preserve the available heat for heating the reactor **210**. For example, the system **200** can include a thermally insulating gasket **274** between the manifold **220** and the engine **180**. The manifold **220** can be fastened to the engine **180** with thermally isolating or insulating elements. Such elements can include a thermally non-conductive bolt **269** and nut **271**, thermally insulating washers **272**, a compression disk spring **270**, and/or a fastener isolator tube **273**, all of which reduce thermal losses. As a result, the efficiency with which the reaction carried out in the reactor **210** is conducted can be improved relative to the systems that do not include such insulating features.

[0067] FIG. **6** is a partially schematic, cross-sectional illustration of a reactor **610** configured in accordance with another embodiment of the present technology, and disposed in the exhaust manifold **220** in a manner generally similar to that described above with reference to FIGS. **3**-**5**. Accordingly, aspects of the reactor **610** shown in FIG. **6** that are similar or generally similar to corresponding aspects of the reactor **220** described above are not described in detail below.

[0068] In a particular aspect of an embodiment shown in FIG. **6**, the reactor **610** includes a reactor vessel **611** that encloses an inwardly disposed, first wall **651** having a construction generally similar to the construction of the second wall **252** described above with reference to FIG. **4**. Accordingly, the first wall **651** can include a hydrogen-selective porous medium. The first wall **651** can enclose a first passage **653***a* through which the hydrogen donor passes, as indicated by arrows D. Heat is provided to the first passage **653***a* via heat transfer from the exhaust gas flow (indicated by arrows E), supplemented in at least some operational phases with heat provided by the reactor heater **214**. Accordingly, the first passage **653***a* forms a reaction zone **612**. As the carbon donor dissociates in the reaction zone **612**, the hydrogen passes outwardly through the first wall **651** into a second passage **653***b* as indicated by arrows H. The hydrogen passes out of the second passage **653***b* via a first product passage **261***a*, and the remaining carbon and/or carbon compounds pass outwardly from the reactor **610** via a second product passage **261***b*, as indicated by arrows C. The galvanic circuit **217** can include one or more cathodes **218***a* positioned in the second flow passage **653***b*, and one or more anodes **218***b* positioned in the first passage **253***a*. Accordingly, the pressure in the second passage **653***b* can be higher than the pressure in the first passage **653***a*, which can place a compressive force on the first wall **651**. As a result, the first wall **651** can be sized to withstand a radially compressive force, rather than a radially expansive force, which can reduce the thickness of the first wall **651** and/or increase the material options available for the first wall **651**.

[0069] In addition to producing hydrogen for fuel or other purposes, the reactor **210** can produce carbon and/or carbon compounds, which can have still further uses. For example representative carbon-based products from the reactor **210** include carbon, silicon carbide, halogenated hydrocarbons, graphite, and graphene. These products can be further processed, e.g., to form carbon films, ceramics, semiconductor devices, polymers and/or other structures. For example, the products can include carbon pipes, sheets, the second wall described above, and/or other suitable structures. Accordingly, the products of the reaction conducted in the reactor **210** can be architectural constructs or structural building blocks that can be used as is or after further processing. Other suitable products are described in the '208 Application.

[0070] One feature of several of the embodiments described with reference to FIGS. **3**-**6** is that the systems can include insulated exhaust manifolds, in combination with reactor surfaces that are highly thermally conductive. This combination can result in low thermal mass, low thermal inertia, and high thermal shock resistance. As a result, the efficiency of the dissociation reaction carried out at the reactor can be significantly greater than for systems that do not include these features.

[0071] Other features of the foregoing embodiments include the ability to use significantly less expensive fuels, including methane produced from sewage, garbage, farm wastes, and/or forest slash, in addition to or in lieu of natural gas, with considerably higher efficiencies than are available with conventional diesel engines. In addition to being less expensive, such fuels are generally more easily and quickly renewed than are conventional fuels. Engines converted to use such fuels can last longer than conventional engines, produce higher peak power, and/or reduce objectionable emissions. One feature that contributes to reduced emissions is not throttling the engine **180**. The efficiency with which such fuels are generated is increased by using engine heat that is otherwise wasted. Excess energy can be readily stored at the energy storage medium **206**.

[0072] Still further features include capturing heat and energy from the engine exhaust system, which has lower pressures and kinetic energy levels than other portions of the engine, and is therefore safer. In addition, the insulation provided around the exhaust manifold can provide a containment shell that further increases engine safety. Still further, the system is configured to absorb very large amounts of braking energy, via regenerative brakes, without generating unsafe heat levels.

[0073] In particular embodiments, the arrangement selected for a given reactor can depend on the power of the engine **180** to which it is coupled. For example, the arrangement shown in FIG. **2** may be more suitable for larger engines (e.g., greater than 700 HP) for which high fuel use rates correspond to high radiant energy rates. The reactor shown in FIG. **2** is configured at least in part to make use of these elevated radiant energy levels. By contrast, the arrangement shown in FIGS. **3-6** may be more suitable for smaller engines (e.g., less than 700 HP) which do not generate as much radiant energy and which tend to be cheaper. In particular, many of the components used in the arrangements shown in FIGS. **3-6** can be formed from 310 stainless steel or other more reasonably priced materials.

[0074] From the foregoing, it will appreciated that specific embodiments of the technology have been described herein for purposes of illustration, but that various modifications may be made without deviating from the technology. For example, certain embodiments of the processes described above were described in the context of methane. In other embodiments, other hydrocarbon fuels or non-carbon-containing hydrogen donors can undergo similar processes to form hydrogen-based fuels and architectural constructs. The waste heat provided by the engine can be supplemented by other waste heat sources, e.g., waste heat from regenerative braking.

[0075] Certain aspects of the technology described in the context of particular embodiments may be combined or eliminated in other embodiments. For example, in some embodiments, selected heat exchangers can be eliminated or combined. Further while advantages associated with certain embodiments of the technology have been described in the context of those embodiments, other embodiments may also exhibit such advantages, and not all embodiments need necessarily exhibit such advantages to fall within the scope of the present disclosure. Accordingly, the present disclosure and associated technology can encompass other embodiments not expressly shown or described herein.

I claim:

1. A chemical reactor system, comprising:
- an engine having a combustion region;
- an exhaust passage coupled to the engine to receive exhaust products from the combustion region, the exhaust passage at least partially enclosing a passage interior region;
- a reactor having an external heat transfer surface positioned in the passage interior region, the reactor further having a reaction zone positioned in a region enclosed by the external heat transfer surface;
- a hydrogen donor source;
- a donor passage coupled in fluid communication with the hydrogen donor source and the reaction zone of the reactor vessel; and
- a product passage coupled to the reaction zone to receive a reaction product from the reaction zone.

2. The system of claim **1** wherein the product passage is a first product passage positioned to receive hydrogen from the reaction zone, and wherein the system further comprises a second product passage positioned to receive a carbon-bearing product from the reaction zone.

3. The system of claim **2**, further comprising a porous medium positioned between the first product passage and the second product passage, the porous medium being selective for hydrogen.

4. The system of claim **2**, further comprising a galvanic circuit coupled between the first and second product passages to pressurize hydrogen in the first product passage.

5. The system of claim **1**, further comprising at least one heat transfer element carried by the external heat transfer surface and projecting into the passage interior region.

6. The system of claim **5** wherein the exhaust passage is elongated along a flow axis, and wherein the at least one heat transfer element is arranged in an at least partially spiral manner relative to the flow axis.

7. The system of claim **6**, further comprising a turbine coupled to the exhaust passage downstream of the reactor.

8. The system of claim **1** wherein the reaction zone is bounded in part by a porous surface, the porous surface being transmissive to hydrogen and not transmissive to carbon compounds.

9. The system of claim **1**, further comprising an electrically powered heater positioned in thermal communication with the reaction zone.

10. The system of claim **9** wherein the electrically powered heater includes at least one of an inductive heater and a resistive heater.

11. The system of claim **1** wherein the electrically powered heater is positioned within the reaction zone.

12. The system of claim **1** wherein the engine and reactor are carried by a vehicle, and wherein the vehicle includes a regenerative brake coupled to an electricity storage medium.

13. The system of claim **1**, further comprising a heat exchanger coupled in thermal communication with the donor passage to transfer heat to a flow volume in the donor passage.

14. The system of claim **13**, further comprising a liquid cooling system coupled to the engine to cool the engine, the liquid cooling system including working fluid passage, and wherein the heat exchanger includes:
- a first heat exchanger passage coupled to the donor passage; and
- a second heat exchanger passage coupled to the working fluid passage and in thermal communication with the first heat exchanger passage at the heat exchanger.

15. The system of claim **13** wherein the heat exchanger includes:
- a first heat exchanger passage coupled to the donor passage; and
- a second heat exchanger passage coupled to the products passage and in thermal communication with the first heat exchanger passage at the heat exchanger.

16. The system of claim **13** wherein the heat exchanger includes:
- a heat exchanger passage coupled to the products passage and in thermal communication with the exhaust passage, downstream of the reactor.

17. The system of claim **1**, further comprising insulation positioned around the exhaust passage.

18. The system of claim **1** wherein the reactor includes:
- a first annular passage positioned inwardly from the heat transfer surface;
- a second annular passage positioned inwardly from the first annular passage; and
- a third passage positioned inwardly from the second annular passage.

19. The system of claim **18** wherein:
- the product passage is a first product passage positioned to receive hydrogen from the reaction zone, and wherein the system further comprises a second product passage positioned to receive a carbon-bearing product from the reaction zone;
- the first annular passage is coupled to the donor passage;

the second annular passage is coupled to the second product passage; and
the third passage is coupled to the first product passage.

20. The system of claim **1**, further comprising a fuel passage coupled between the product passage and the combustion region of the engine to direct the reaction product to the combustion region.

21. A chemical reactor system, comprising:
an engine having a combustion region;
an exhaust manifold coupled to the engine to receive exhaust products from the combustion region, the exhaust manifold having a manifold external surface the exhaust manifold further having a manifold internal surface at least partially enclosing an interior region;
insulation positioned around the external surface of the exhaust manifold;
a reactor, comprising
a shell positioned in the interior region of the exhaust manifold, the shell having a shell external heat transfer surface, the shell further having a shell internal surface positioned around a reaction zone, and;
a spiral heat transfer element carried by the shell and projecting into the passage interior region;
a first wall positioned annularly inwardly from the shell internal surface and spaced radially apart from the shell internal surface to define a first annular passage;
a second wall positioned annularly inwardly from the first wall and spaced radially apart from the first wall to define a second annular passage positioned between the first and second walls, and a third passage positioned inwardly from the second wall, the second wall including a porous medium transmissive to hydrogen but not transmissive to carbon compounds;
an electrically-powered heater positioned in the second annular passage; and
a galvanic circuit coupled across the second wall to pressurize the third passage;
a hydrogen donor source;
a donor passage coupled between the hydrogen donor source and the first annular passage to direct a hydrogen donor to the reaction zone
a first product passage coupled to the third passage to receive hydrogen
a second product passage coupled to the second annular passage to receive a carbon-bearing product;
a liquid cooling system coupled to the engine to cool the engine, the liquid cooling system including working fluid passage;
a first heat exchanger coupled between the donor passage and the working fluid passage to transfer heat from the working fluid passage to the donor passage;
a second heat exchanger coupled between the donor passage and the exhaust manifold downstream of the reactor to transfer heat from the exhaust manifold to the donor passage;
a third heat exchanger coupled between the donor passage and at least one of the first and second product passages to transfer heat from the at least one product passage to the donor passage; and
a turbine positioned downstream of the reactor and the spiral heat transfer element.

22. A method for operating an engine and a chemical reactor, comprising:
combusting a fuel in an engine to produce power and combustion products;
directing the combustion products through an exhaust passage and around a reactor positioned within the exhaust passage;
transferring heat from the combustion products to a reaction zone within the reactor, via an external surface of the reactor;
directing a hydrogen donor into the reaction zone of the reactor;
dissociating the hydrogen donor into dissociation products in the reaction zone;
from the dissociation products, providing:
(a) a hydrogen-bearing constituent; and
(b) a non-hydrogen bearing constituent.

23. The method of claim of claim **22** wherein transferring heat from the combustion zone to the reaction zone includes:
transferring heat from the combustion products to at least one heat transfer element carried by the reactor and projecting into the passage interior region; and
transferring heat from the at least one heat transfer element to the reaction zone.

24. The method of claim **23** wherein the at least one heat transfer element has a spiral shape, and wherein transferring heat from the combustion products to at least one heat transfer element includes directing the exhaust products along the heat transfer element to impart a rotational flow component to the exhaust products.

25. The method of claim **24**, further comprising extracting kinetic energy from the exhaust products by directing the exhaust products through a turbine downstream of the at least one heat transfer element.

26. The method of claim **22**, further comprising providing heat to the reaction zone via an electrically-powered heater.

27. The method of claim **22**, wherein the engine and reactor are carried by a vehicle, and wherein the method further comprises:
braking the vehicle with a regenerative brake; and
directing electrical power obtained from the regenerative brake to the reactor.

28. The method of claim **22**, further comprising:
cooling the engine with a coolant fluid; and
directing heat from the coolant fluid to the hydrogen donor before the hydrogen donor enters the reaction zone.

29. The method of claim **22**, further comprising directing heat from the dissociation products to the hydrogen donor before the hydrogen donor enters the reaction zone.

30. The method of claim **22**, further comprising directing heat from the combustion products to the hydrogen donor before the hydrogen donor enters the reaction zone.

31. The system of claim **22**, further comprising at least restricting heat loss from the exhaust passage with insulation positioned around the exhaust passage.

32. The method of claim **22** wherein the reactor includes:
an outwardly facing heat transfer surface positioned in the flow of exhaust products;
a first annular passage positioned inwardly from the heat transfer surface;
a second annular passage positioned inwardly from the first annular passage; and
a third passage positioned inwardly from the second annular passage; and wherein the method further comprises:
directing the hydrogen donor axially through the first passage in a first direction to heat the hydrogen donor;

directing the hydrogen donor axially through the second passage in a second direction opposite the first direction; and

directing dissociated hydrogen into the third passage.

33. The method of claim **22** wherein directing the dissociated hydrogen includes directing the dissociated hydrogen through a porous medium separating the second and third passages.

34. The method of claim **22**, further comprising combusting at least a portion of the hydrogen-bearing constituent in the combustion chamber.

35. The method of claim **22**, further comprising separating hydrogen from carbon-bearing constituents of the dissociation products by exposing the dissociation products to a porous medium that is transmissive to hydrogen but not transmissive to carbon compounds.

36. The method of claim **35** wherein the porous medium is a first porous medium, and wherein the method further comprises forming a second porous medium from the carbon-bearing constituents.

37. The method of claim **35**, further comprising:

removing the porous medium from the reactor; and

using the porous medium to purify at least one of air or water.

38. The method of claim **35**, further comprising pressurizing the hydrogen by applying a galvanic current across the porous medium.

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