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(54) APPARATUS WITH IN SITU FUEL REFORMER AND ASSOCIATED METHOD

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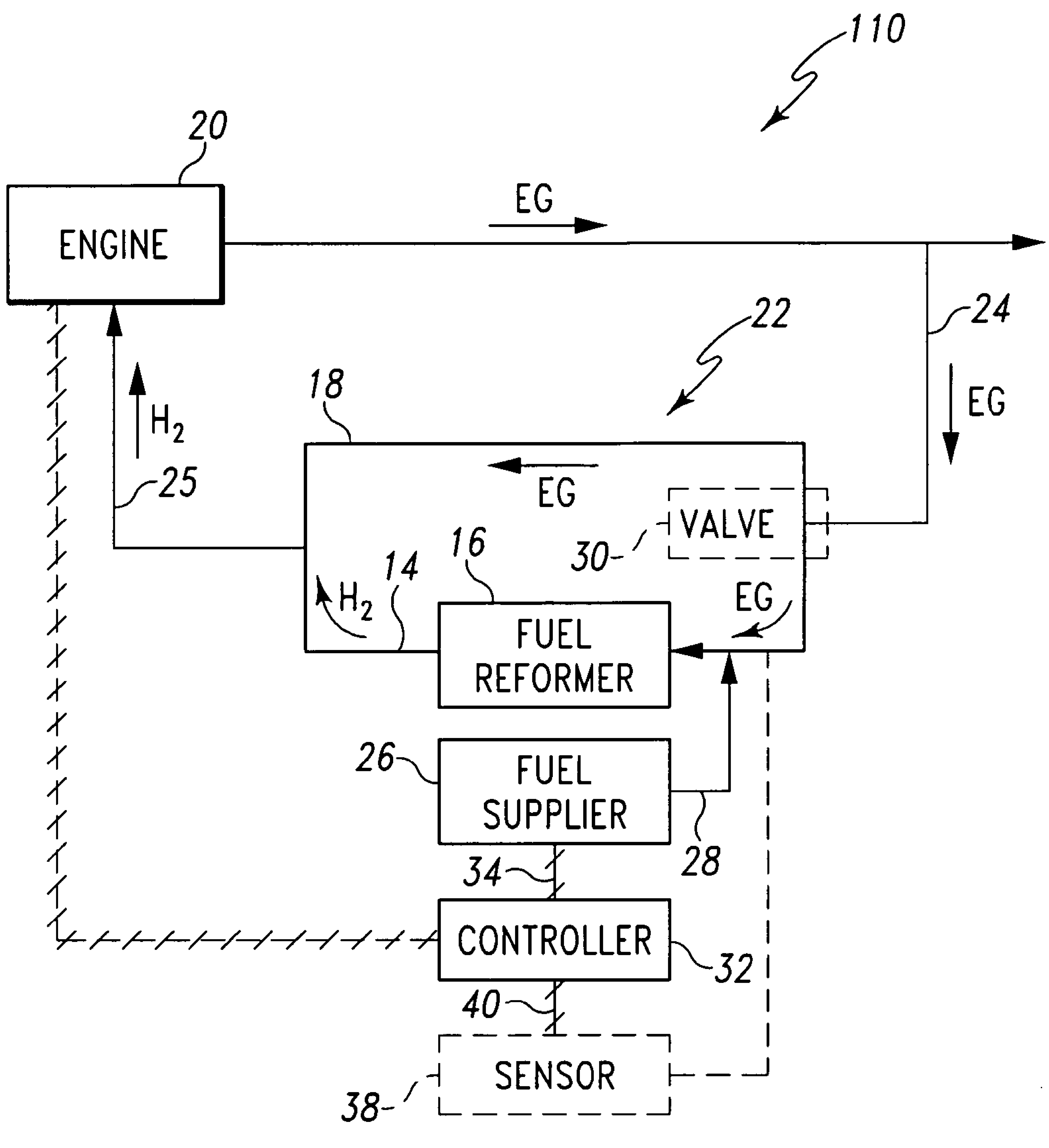
(57) **ABSTRACT**

An apparatus comprises parallel and coaxial first and second exhaust gas passageways, a fuel reformer positioned in the first exhaust gas passageway to generate partial combustion product (e.g., $H_2$ and/or CO), and a component such as an emission abatement device or an internal combustion engine positioned to receive the partial combustion product from the first exhaust gas passageway and exhaust gas from the second exhaust gas passageway. An associated method is disclosed.



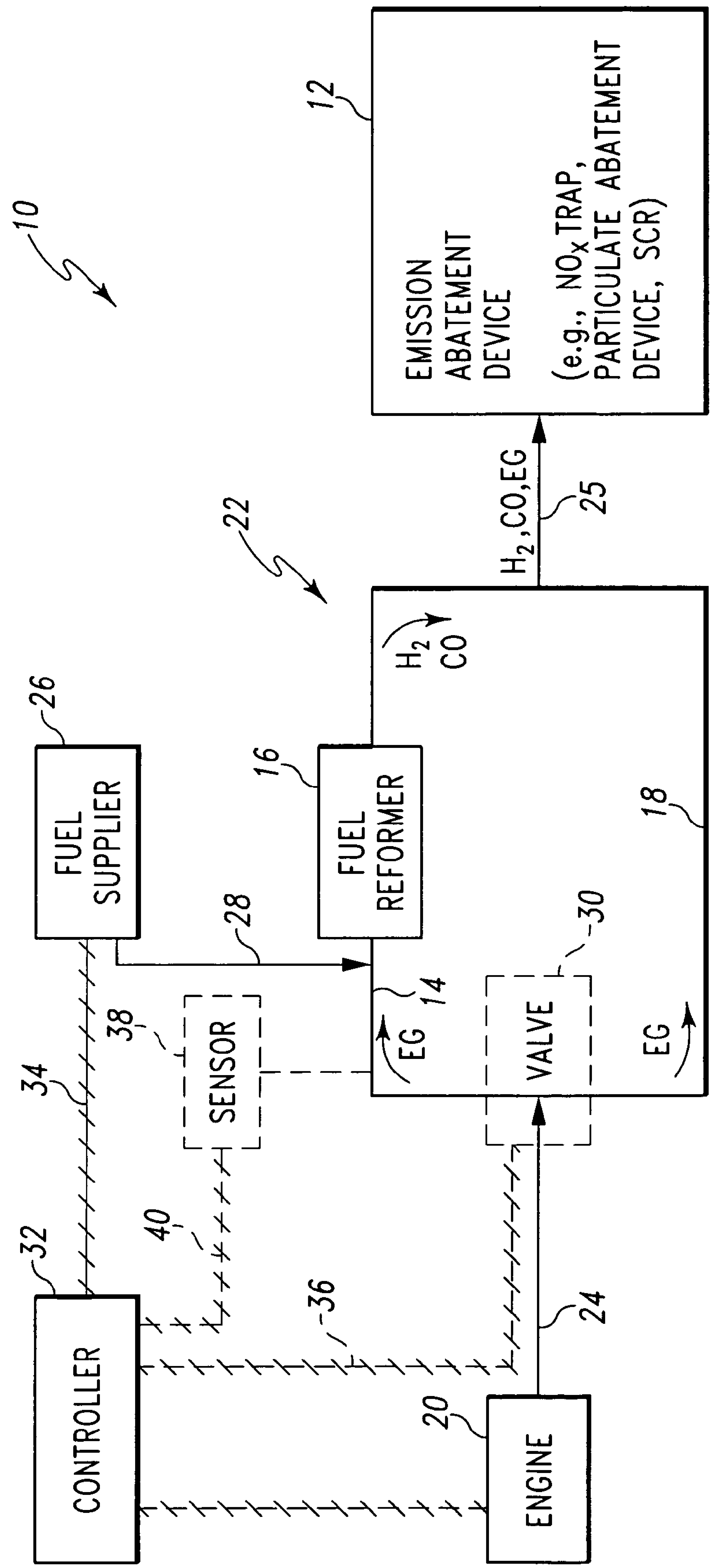

10
12
EMISSION ABATEMENT DEVICE
(e.g., NOx TRAP, PARTICULATE ABATEMENT DEVICE, SCR)
22
H2,CO,EG
25
H2 CO
26
FUEL SUPPLIER
16
FUEL REFORMER
18
28
14
30
VALVE
EG
EG
38
SENSOR
34
32
CONTROLLER
40
36
24
20
ENGINE

Fig. 1

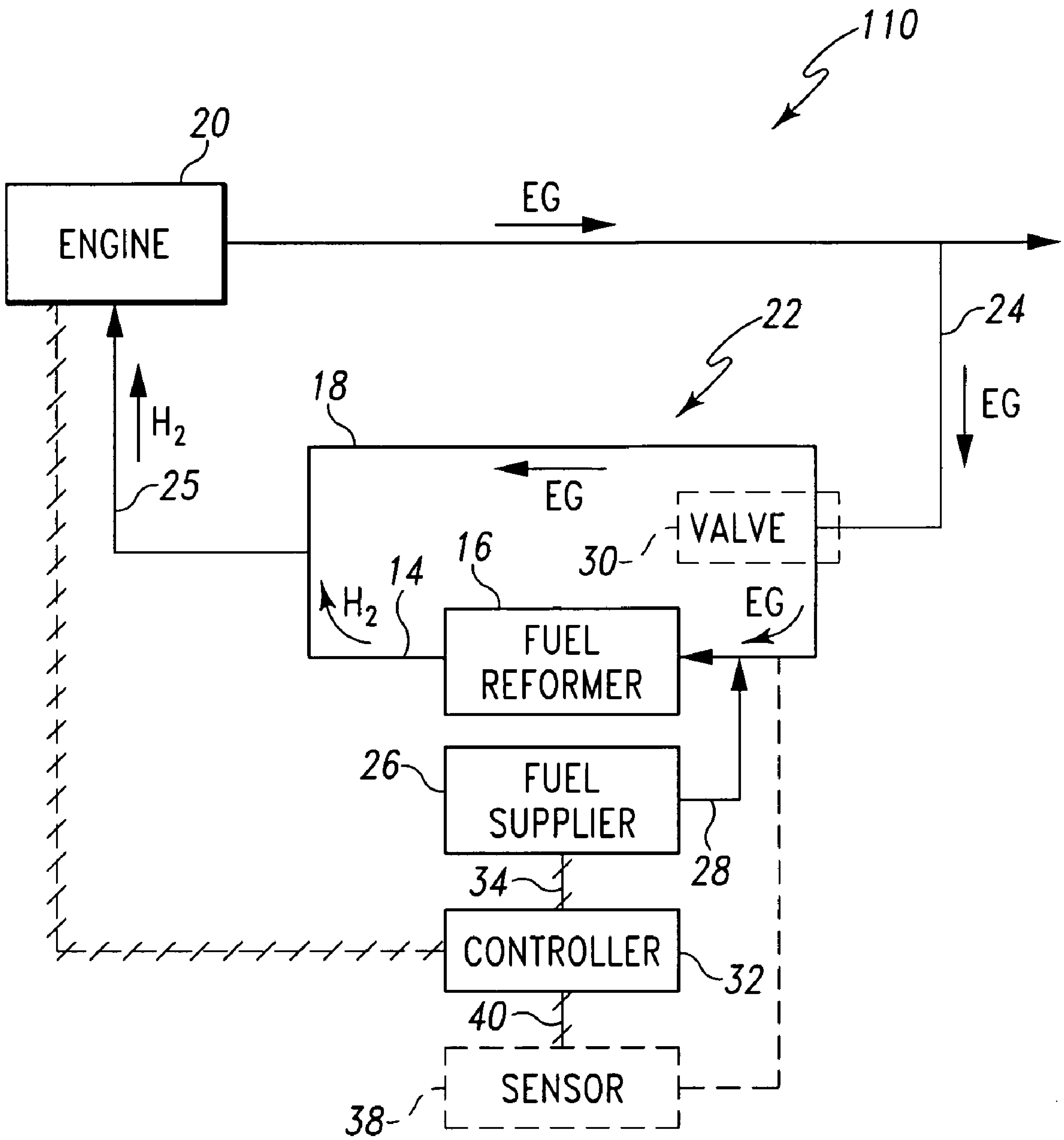

110
20
ENGINE
EG
22
24
EG
18
$H_2$
25
EG
VALVE
30
16
14
$H_2$
EG
FUEL REFORMER
26
FUEL SUPPLIER
28
34
CONTROLLER
32
40
SENSOR
38

Fig. 2

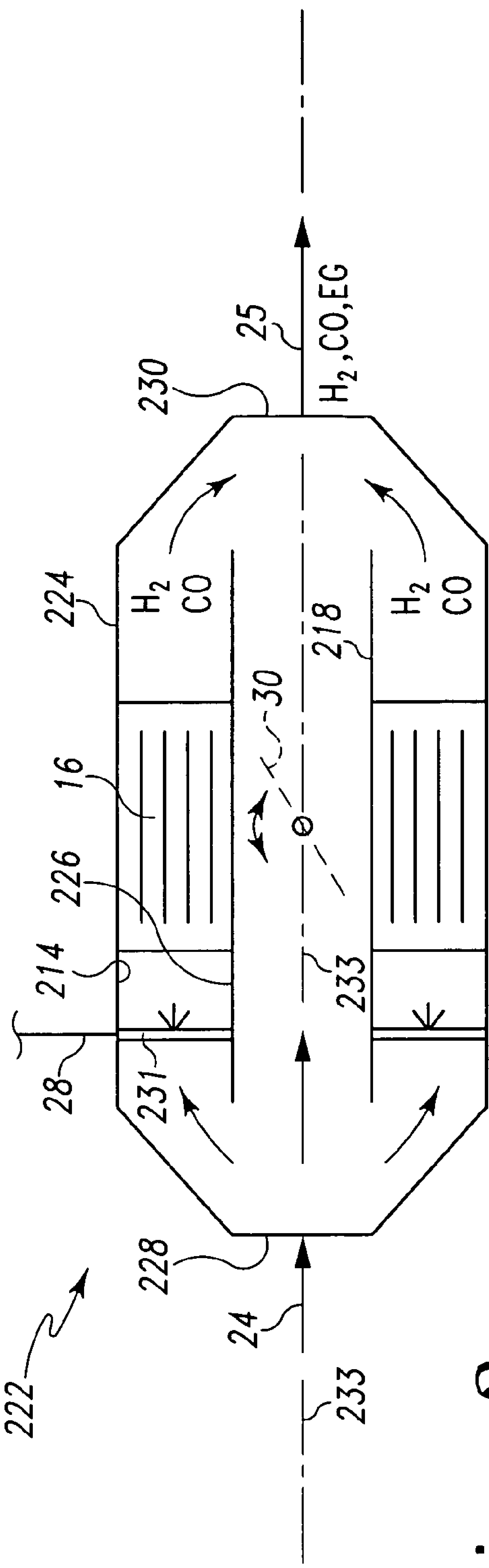

222
224
226
214
16
30
218
228
230
231
233
24
25
28
$H_2$
CO
$H_2$,CO,EG

Fig. 3

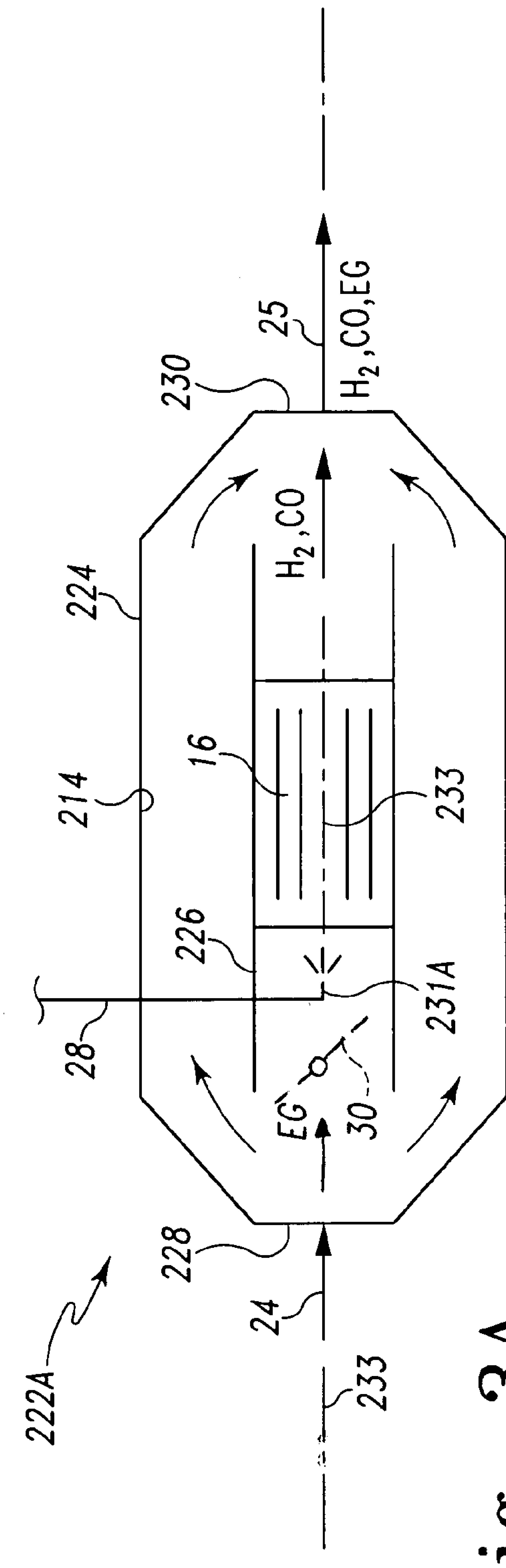

222A
224
226
214
16
233
231A
228
230
24
25
28
30
EG
$H_2$,CO
$H_2$,CO,EG

Fig. 3A

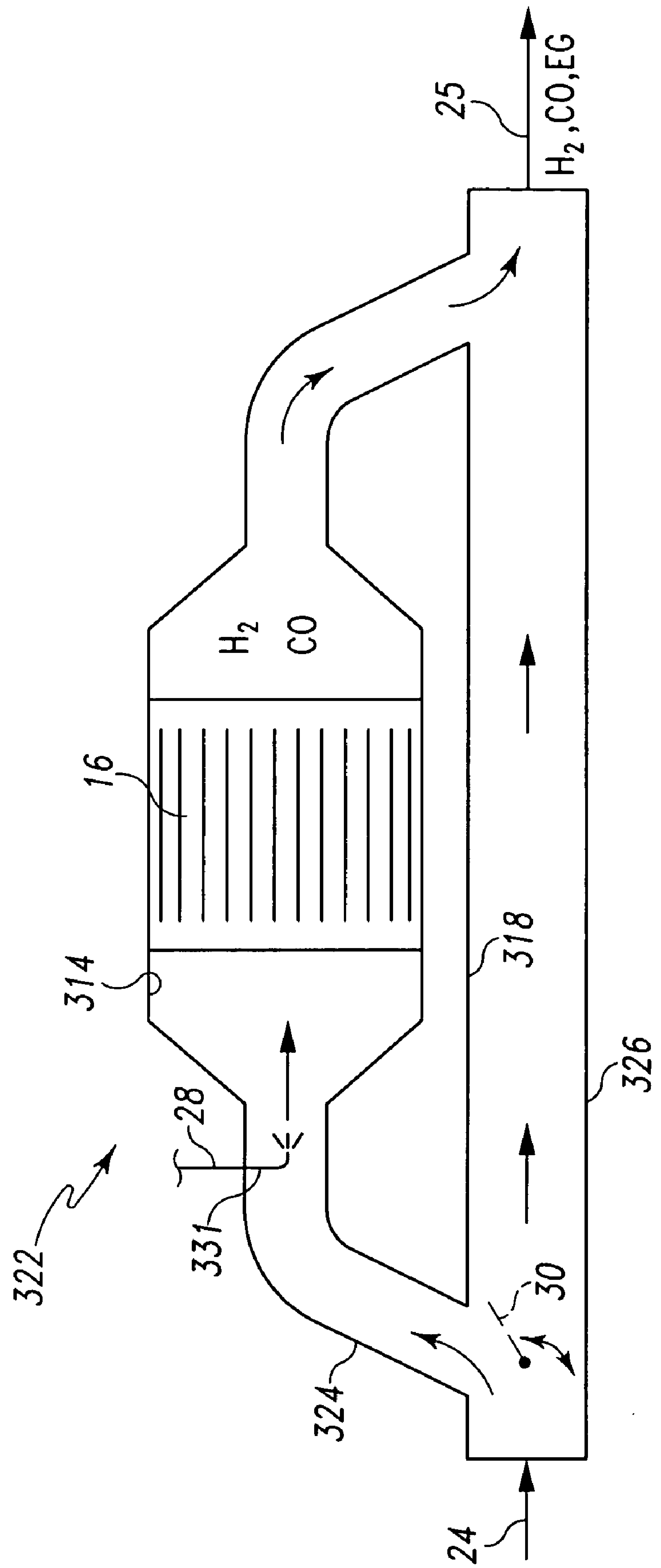



Fig. 4

# APPARATUS WITH IN SITU FUEL REFORMER AND ASSOCIATED METHOD

## FIELD OF THE DISCLOSURE

[0001] The present disclosure relates generally to exhaust systems and fuel reformers.

## BACKGROUND OF THE DISCLOSURE

[0002] Fuel reformers may be used for a variety of purposes. In some cases, for example, fuel reformers are used in the process of regenerating emission abatement devices such as NOx traps and particulate traps. In other cases, fuel reformers are used to provide hydrogen ($H_2$) to an internal combustion engine to enhance the fuel combustion process.

## SUMMARY OF THE DISCLOSURE

[0003] According to a first aspect of the present disclosure, there is provided an apparatus having parallel and coaxial first and second exhaust gas passageways. A fuel reformer is positioned in the first exhaust gas passageway and configured to partially combust fuel supplied to the first exhaust gas passageway with oxygen from exhaust gas present in the first exhaust gas passageway to generate partial combustion product. Placement of the fuel reformer in the first exhaust gas passageway facilitates control of the air-to-fuel ratio of the flow delivered to the fuel reformer and thus facilitates generation of the partial combustion product.

[0004] A component is fluidly coupled to the first and second exhaust gas passageways to receive the partial combustion product from the first exhaust gas passageway and exhaust gas from the second exhaust gas passageway. The component may be, for example, an emission abatement device (e.g., a NOx trap, a particulate abatement device, a selective catalytic reduction device, or any combination thereof) or an internal combustion engine.

[0005] According to a second aspect of the disclosure, the fuel reformer is a catalyst. The catalyst is activated by the heat of the exhaust gas in the first exhaust gas passageway and catalyzes a chemical reaction to partially combust the fuel into hydrogen ($H_2$) and carbon monoxide (CO) which are useful in the regeneration of NOx traps and particulate abatement devices and may also be useful with selective catalytic reduction devices. The hydrogen ($H_2$) is also useful for enhancement of combustion of an internal engine.

[0006] The above and other features of the present disclosure will become apparent from the following description and the attached drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. **1** is a simplified block diagram showing a first apparatus with an “in situ” fuel reformer positioned in an exhaust gas passageway to generate partial combustion product (e.g., $H_2$ and CO) for use in conjunction with an emission abatement device;

[0008] FIG. **2** is a simplified block diagram showing a second apparatus with the “in situ” fuel reformer configured to generate partial combustion product provided to an internal combustion engine to enhance the combustion process in the engine;

[0009] FIG. **3** is a diagrammatic view showing a first coaxial parallel flow arrangement for use with the first and second apparatus;

[0010] FIG. **3***a* is a diagrammatic view showing a second coaxial parallel flow arrangement for use with the first and second apparatus; and

[0011] FIG. **4** is a diagrammatic view showing a non-coaxial parallel flow arrangement for use with the first and second apparatus.

## DETAILED DESCRIPTION OF THE DRAWINGS

[0012] While the concepts of the present disclosure are susceptible to various modifications and alternative forms, specific exemplary embodiments thereof have been shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit the disclosure to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives following within the spirit and scope of the invention as defined by the appended claims.

[0013] Referring to FIG. **1**, there is shown an apparatus **10** configured to generate partial combustion product such as hydrogen ($H_2$) and/or carbon monoxide (CO) for use in conjunction with a downstream component such as an emission abatement device **12**. It does so by diverting a portion of a stream of exhaust gas (“EG” in the drawings) to flow into a first exhaust gas passageway **14** containing an “in situ” fuel reformer **16** configured, for example, as a catalyst. The fuel reformer **16** partially combusts a hydrocarbon fuel (e.g., diesel fuel) supplied to the passageway **14** with oxygen from exhaust gas present in the passageway **14** to produce the partial combustion product for delivery to the emission abatement device **12**. The remainder of the exhaust gas passes through an exhaust gas passageway **18** parallel to the passageway **14**.

[0014] Such an arrangement facilitates control of the air-to-fuel ratio of the flow delivered to the fuel reformer **16** and thus facilitates generation of the partial combustion product. Further, since oxygen of the exhaust gas is used, it avoids the need for a supplemental source of oxygen. In addition, an ignition source is not needed because the heat of the exhaust gas is sufficient for the partial combustion reaction.

[0015] The system **10** includes an internal combustion engine **20** (e.g., a diesel engine), a parallel flow arrangement **22**, and the emission abatement device **12**. The engine **20** produces the exhaust gas which flows through an exhaust gas supply passageway **24**. The parallel flow arrangement **22** then divides the exhaust gas stream to flow into the parallel passageways **14**, **18**. A portion of the exhaust gas flows into the passageway **14** containing the fuel reformer **16**. The other portion of the exhaust gas flows into the passageway **18**. The passageways **14**, **18** recombine downstream from the fuel reformer **16** into a downstream exhaust gas passageway **25** which delivers the $H_2$ and/or CO produced by the fuel reformer **16** and the exhaust gas from the passageway **18** to the emission abatement device **12**.

[0016] The emission abatement device **12** may be, for example, a NOx trap, a selective catalytic reduction (SCR) device, or a particulate abatement device. A NOx trap is used to remove NOx from the exhaust gas. It does so by trapping

NOx present in the exhaust gas under lean conditions (as is normally the case in diesel exhaust) and reducing the trapped NOx to nitrogen under rich conditions when the fuel reformer **16** is operated to produce the partial combustion product. The partial combustion product (e.g., H2, CO) is thus useful as a NOx-reducing agent. If the fuel reformer **16** is operated to produce the partial combustion product for a longer time, the partial combustion product can be used to desulphate the NOx trap **16**.

[**0017**] An SCR device operates in conjunction with the partial combustion product to convert NOx into nitrogen without the need to first trap the NOx and then release and reduce the NOx. The SCR device is "selective" in the sense that it catalyzes a reaction between the partial combustion product (e.g., $H_2$, CO) generated by the fuel reformer **16** and NOx present in the exhaust gas. The NOx is thereby removed from the exhaust gas.

[**0018**] A particulate abatement device is used to remove particulates from the exhaust gas. It may take the form of a particulate trap (catalyzed or uncatalyzed) alone or in combination with an upstream oxidation catalyst (e.g., diesel oxidation catalyst). The partial combustion product (e.g., $H_2$, CO) may be oxidized in the presence of the catalyst of a catalyzed particulate trap or in the presence of an upstream oxidation catalyst to generate heat useful for burning off particulate matter trapped by the particulate trap so as to regenerate the particulate trap.

[**0019**] It is within the scope of this disclosure for the emission abatement device **12** to include any combination of a NOx trap, an SCR device, and a particulate abatement device. One such combination example is an SCR device and a particulate trap.

[**0020**] Fuel is supplied to the passageway **14** by a fuel supplier **26**. A fuel line **28** of the fuel supplier **26** is coupled to the passageway **14** to supply fuel to passageway **14** upstream from the fuel reformer **16**. The fuel may be, for example, diesel fuel in liquid form or as a vapor. The fuel supplier **26** is not coupled to the passageway **18**.

[**0021**] The system **10** may be used with or without an exhaust gas valve **30** to control flow of the exhaust gas between passageways **14**, **18**. In the case in which the system **10** has the valve **30**, the valve **30** may be located in either passageway **14**, **18** or at the upstream junction of the two passageways **14**, **18**.

[**0022**] A controller **32** is electrically coupled to the fuel supplier **26** via an electrical line **34** and, when the valve **30** is included, it is electrically coupled to the valve **30** via an electrical line **36** to control operation of the fuel supplier **26** and the valve **30**. The controller **32** is thus able to vary the injection rate of fuel into passageway **14** and/or vary admission of exhaust gas and thus oxygen into passageway **14**. In so doing, the controller **32** is able to control the air-to-fuel ratio of the flow delivered to the fuel reformer **16** to facilitate generation of the partial combustion product by the fuel reformer **16**. Exemplarily, in the case where the emission abatement device **12** is a NOx trap, the controller **32** may cycle operation of the fuel supplier **26** so as to provide fuel to the passageway **14** for a predetermined period of time (e.g., three seconds) followed by a predetermined period of time (e.g., 60 seconds) in which fuel is not supplied to passageway **14**.

[**0023**] To further facilitate the control of the air-to-fuel ratio, the system **10** may employ a sensor **38** and/or engine mapping to provide input(s) to the controller **32** for control of the fuel supplier **26** and/or the valve **30**. The sensor **38** may be, for example, a lambda sensor coupled to the passageway **14** upstream from the fuel reformer **16** for sensing the air-to-fuel ratio of the flow in the passageway **14**. In such a case, the sensor **38** is electrically coupled to the controller **32** via an electrical line **40** to provide its sensor output to controller **32**. The controller **32** may also have stored therein engine mapping information for control of the fuel supplier **26** and/or the valve **30** based on operational parameters associated with the engine **20** (e.g., engine rpm, temperature, throttle position).

[**0024**] The fuel reformer **16** is configured, for example, as a catalyst in the form of a catalyzed substrate. The catalyst is, for example, a metallic catalyst. In the case where the fuel reformer **16** is a catalyst, the temperature of the catalyst is elevated to its activation temperature by the heat of the exhaust gas. Moreover, use of a catalyst obviates the need for an ignition source with its own power supply to ignite the combustible mixture in the passageway **14**.

[**0025**] The apparatus **10** is thus able to generate partial combustion product through the use of relatively "fine" control of the air-to-fuel ratio of the flow delivered to the fuel reformer **16**. Moreover, it does so by use of the oxygen and heat content of the exhaust gas so that there is no need for supplemental oxygen or an ignition source. It is within the scope of this disclosure, however, to include such supplemental oxygen and an ignition source.

[**0026**] Referring to FIG. **2**, there is shown a second apparatus **110** employing many of the components of the apparatus **10** for use in combustion enhancement of the engine **20**. In particular, the "in situ" fuel reformer **16** of the parallel flow arrangement **22** is used to generate partial combustion product such as $H_2$ which is advanced to the engine **20** to enhance the combustion of fuel (e.g., gasoline) in the engine **20**. The system **110** is otherwise similar in structure and function to the system **10** so that identical reference numbers refer to similar components.

[**0027**] Referring to FIG. **3**, there is shown a coaxial parallel flow arrangement **222** for use as the parallel flow arrangement **22** in the systems **10**, **110**. The arrangement **222** has a housing **224** and an inner tube **226** mounted in the housing **224**. The housing **224** has an inlet port **228** that receives exhaust gas from the exhaust gas supply passageway **24** and an outlet port **230** that discharges exhaust gas and partial combustion product to the downstream exhaust gas passageway **25**.

[**0028**] An annular outer exhaust gas passageway **214** corresponding to the first exhaust gas passageway **14** of the systems **10**, **110** is defined between the housing **224** and the inner tube **226**. The passageway **214** contains the fuel reformer **16** which has an annular shape to fit in the passageway **214** around the inner tube **226** and an inner exhaust gas passageway **218** defined therein. A fuel dispenser ring **231** is secured to the housing **224** to dispense fuel received from the fuel line **28** into the passageway **214**.

[**0029**] The inner tube **226** defines the inner exhaust gas passageway **218** which corresponds to the second exhaust gas passageway **18** of the systems **10**, **110** to conduct exhaust gas so as to bypass the fuel reformer **16**. The passageways **214**, **218** are parallel and have a common axis **233** such that the passageways **214**, **218** are coaxial. The optional valve **30** may be configured, for example, as a butterfly valve positioned in the inner exhaust gas passageway **218**.

**[0030]** Referring to FIG. **3***a*, there is shown another coaxial parallel flow arrangement **222***a* for use as the parallel flow arrangement **22** in the systems **10**, **110**. The arrangement **222***a* is configured in a manner similar to the arrangement **222** except that the fuel reformer **16** is non-annular and is mounted in the inner tube **226** so as to be positioned in the passageway **218** rather than the passageway **214**. A fuel dispenser **231***a* receives fuel from the fuel line **28** and is mounted to dispense fuel supplied thereby into the passageway **218**. The valve **30** may also be used with the arrangement **222***a* to control flow of exhaust gas into the passageway **218**.

**[0031]** Referring to both FIGS. **3** and **3***a*, the coaxial feature of the passageways **214**, **218** of the arrangements **222**, **222***a* provides a number of benefits. For example, the coaxial feature provides that each of the arrangements **222**, **222***a* is relatively compact, which may be especially useful in environments where space economy is a factor (e.g., on board vehicles).

**[0032]** In addition, the coaxial feature promotes transfer of exhaust gas heat to the reformer **16** to facilitate operation of the reformer **16**. More specifically, in the arrangement **222**, heat of exhaust gas in the passageway **218** may be transferred to the surrounding reformer **16** and, in the arrangement **222***a*, heat of exhaust gas in the passageway **214** may be transferred to the reformer **16** surrounded by the passageway **214**. Indeed, more heat may be transferred to the reformer **16** in the arrangement **222***a* than in the arrangement **222** since, in the arrangement **222***a*, the reformer **16** is spaced apart from the housing **224** which may be exposed to atmosphere. Such heat transfer to the reformer **16** may be especially useful when the reformer **16** is a catalyst having an activation temperature at which the catalyst becomes operational. Production of the partial combustion product is thus enhanced.

**[0033]** Referring to FIG. **4**, there is shown a non-coaxial parallel flow arrangement **322** for use as the parallel flow arrangement **22** in the systems **10**, **110**. The arrangement **322** has a first conduit **324** and a second conduit **326**. The conduits **324**, **326** are secured to one another at upstream and downstream junctions and extend between such junctions outside of one another.

**[0034]** Exhaust gas is divided at the upstream junction to flow into a first exhaust gas passageway **314** corresponding to the passageway **14** of the systems **10**, **110** and a second exhaust gas passageway **318** corresponding to the passageway **18** of the systems **10**, **110**. The passageways **314**, **318** are parallel but not co-axial. A fuel dispenser **331** is secured to the first conduit **324** to dispense fuel from the fuel line **28** into the passageway **314**. The reformer **16** is configured, for example, as a catalyst positioned in the first exhaust gas passageway **314** to partially combust the fuel with oxygen from the exhaust gas present in the passageway **314** into $H_2$ and/or CO. The passageways **314**, **318** recombine at the downstream junction between the conduits **324**, **326** for delivery of the $H_2$ and/or CO to the downstream exhaust gas passageway **25**.

**[0035]** The optional valve **30** may be configured, for example, as a butterfly valve positioned in either passageway **314**, **318** to control flow of exhaust into passageways **314**, **318**. Illustratively, the valve **30** is located in the passageway **318**.

**[0036]** While the concepts of the present disclosure have been illustrated and described in detail in the drawings and foregoing description, such an illustration and description is to be considered as exemplary and not restrictive in character, it being understood that only the illustrative embodiments have been shown and described and that all changes and modifications that come within the spirit of the disclosure are desired to be protected.

**[0037]** There are a plurality of advantages of the concepts of the present disclosure arising from the various features of the systems described herein. It will be noted that alternative embodiments of each of the systems of the present disclosure may not include all of the features described yet still benefit from at least some of the advantages of such features. Those of ordinary skill in the art may readily devise their own implementations of a system that incorporate one or more of the features of the present disclosure and fall within the spirit and scope of the invention as defined by the appended claims.

**1**. A method, comprising the steps of:

dividing a stream of exhaust gas to flow into parallel and coaxial first and second exhaust gas passageways upstream from a component,

introducing fuel into the first exhaust gas passageway,

partially combusting the fuel introduced into the first exhaust gas passageway with oxygen from the exhaust gas present in the first exhaust gas passageway so as to generate partial combustion product, and

advancing the partial combustion product to the component.

**2**. The method of claim 1, wherein the dividing step comprises advancing a first exhaust gas stream in the first exhaust gas passageway and a second exhaust gas stream in the second exhaust gas passageway such that the first exhaust gas stream either surrounds the second exhaust gas stream or is surrounded by the second exhaust gas stream.

**3**. The method of claim 1, wherein the dividing step comprises operating an exhaust gas valve to direct a portion of the exhaust gas stream into the first exhaust gas passageway and a portion of the exhaust gas stream into the second exhaust gas passageway.

**4**. The method of claim 1, wherein the combusting step comprises operating a fuel reformer positioned in the first exhaust gas passageway.

**5**. The method of claim 4, wherein:

the fuel reformer is a catalyst, and

the operating step comprises partially combusting the fuel into hydrogen ($H_2$) and carbon monoxide (CO) with the catalyst.

**6**. The method of claim 4, wherein the operating step comprises the fuel reformer generating at least one of hydrogen ($H_2$) and carbon monoxide (CO) by use of the oxygen and heat content of the exhaust gas present in the first exhaust gas passageway without the assistance of additional oxygen from a supplemental oxygen source and without the assistance of heat from an ignition source.

**7**. The method of claim 1, further comprising varying introduction of at least one of fuel and exhaust gas into the first exhaust gas passageway so as to control the air-to-fuel ratio of the flow supplied to the fuel reformer.

**8**. The method of claim 1, wherein:

the component comprises at least one of an emission abatement device and an internal combustion engine, and

the advancing step comprises advancing the partial combustion product from the first exhaust gas passageway to at least one of the emission abatement devices and the internal combustion engine.

**9**. An apparatus, comprising:

parallel and coaxial first and second exhaust gas passageways,

a fuel reformer positioned in the first exhaust gas passageway and configured to partially combust fuel supplied to the first exhaust gas passageway with oxygen from exhaust gas present in the first exhaust gas passageway to generate partial combustion product, and

a component fluidly coupled to the first and second exhaust gas passageways to receive the partial combustion product from the first exhaust gas passageway and exhaust gas from the second exhaust gas passageway.

**10**. The apparatus of claim 9, wherein the first exhaust gas passageway surrounds the second exhaust gas passageway.

**11**. The apparatus of claim 10, wherein:

the first exhaust gas passageway is annular, and

the fuel reformer is an annular catalyst positioned in the annular first exhaust gas passageway so as to surround the second exhaust gas passageway.

**12**. The apparatus of claim 9, wherein the second exhaust gas passageway surrounds the first exhaust gas passageway.

**13**. The apparatus of claim 9, wherein the first exhaust gas passageway or the second exhaust gas passageway is annular.

**14**. The apparatus of claim 9, wherein the fuel reformer is a catalyst configured to partially combust the fuel into at least one of hydrogen ($H_2$) and carbon monoxide (CO).

**15**. The apparatus of claim 9, further comprising a fuel supplier that is fluidly coupled to the first exhaust gas passageway, but not fluidly coupled to the second exhaust gas passageway, to supply fuel to the fuel reformer.

**16**. The apparatus of claim 15, further comprising (i) an exhaust gas valve positioned to direct exhaust gas between the first and second exhaust gas passageways and (ii) a controller coupled to the fuel supplier and the valve to control operation thereof.

**17**. The apparatus of claim 9, wherein the component is a NOx trap.

**18**. The apparatus of claim 9, wherein the component is a particulate abatement device.

**19**. The apparatus of claim 9, wherein the component is a selective catalytic reduction device.

**20**. The apparatus of claim 9, wherein the component is an internal combustion engine.

* * * * *