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- (71) **Applicant (for all designated States except US):** VANDYNE SUPERTURBO, INC. [US/US]; Suite A-105, 200 West Mountain Avenue, Fort Collins, Colorado 80521 (US).
- (72) **Inventors; and**
- (75) **Inventors/Applicants (for US only):** VANDYNE, Ed [US/US]; 2604 Farisita Drive, Loveland, Colorado 80538 (US). SCHUMACHER, Volker [DE/DE]; Sandweg 7a, 38524 Sassenberg (DE). BROWN, Jared William [US/US]; 913 Coulter Street, Fort Collins, Colorado 80524 (US). WALDRON, Tom [US/US]; Suite A-105, 200 West Mountain Avenue, Fort Collins, Colorado 80521 (US).
- (74) **Agents:** COCHRAN, William W. et al.; Cochran Freund & Young LLC, 2026 Caribou Drive, Suite 201, Fort Collins, CO 80525 (US).

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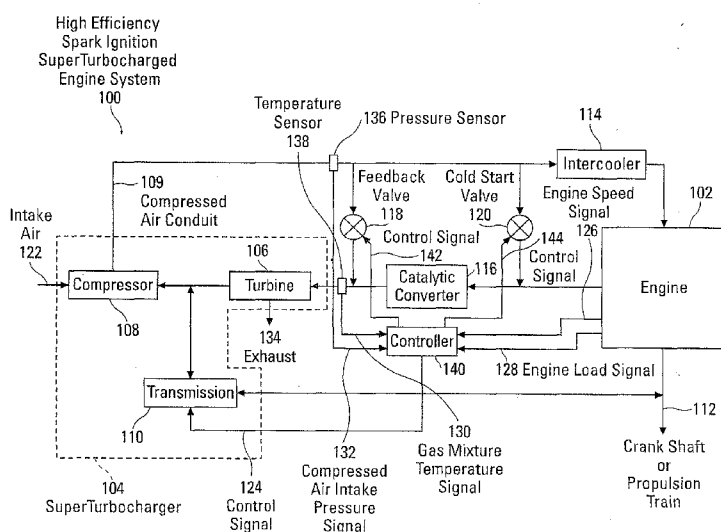
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(54) **Title:** RICH FUEL MIXTURE SUPER-TURBOCHARGED ENGINE SYSTEM

Fig. 1



(57) **Abstract:** Disclosed is a super-turbocharger system (100) that increases power and efficiency of an engine (102). The system uses the exothermic properties of a catalytic converter (116) to extract additional energy from exhaust heat that is used to add power to the engine. Compressed air is supplied and mixed with exhaust gases upstream and/or downstream from a catalytic converter (116) that is connected to an exhaust manifold. The gaseous mixture of exhaust gases and compressed air is sufficiently rich in oxygen to oxidize hydrocarbons and carbon monoxide in the catalytic converter (116), which adds heat to the gaseous mixture. In addition, a sufficient amount of compressed air is supplied to the exhaust gases to maintain the temperature of the gaseous mixture at a substantially optimal temperature level. The gaseous mixture is applied to the turbine (106) of the super-turbocharger, which increases the output of said super-turbocharger, which increases the power and efficiency of said engine (102).

## **RICH FUEL MIXTURE SUPER-TURBOCHARGED ENGINE SYSTEM**

### **BACKGROUND OF THE INVENTION**

[0001] Super-turbochargers are convenient devices for increasing the power and/or efficiency of internal combustion engines. A smaller, more efficient engine that uses a super-turbocharger can produce the same power as a larger, less efficient engine, thereby improving the overall efficiency of the system. Super-turbochargers have at least one compressor and at least one turbine that are connected to a power transmission device that transmits power to and receives power from a propulsion train that is coupled to the engine, or to a crank shaft, vehicle transmission, or other coupling when the engine is used on a vehicle. In this manner, super-turbochargers can increase the performance of a piston engine, whether that engine is used on a vehicle, for power generation, or other function.

### **BRIEF SUMMARY OF THE INVENTION**

[0002] An embodiment of the present invention may therefore comprise a method of improving performance of an engine system having a super turbocharger, the engine system having an engine that operates with a rich fuel mixture comprising: generating an amount of compressed air from a compressor in response to a control signal; mixing the amount of the compressed air with exhaust gases from the engine to produce a gaseous mixture of the exhaust gases and the compressed air; supplying the gaseous mixture to a catalytic converter; detecting oxygen levels of the gaseous mixture that enter the catalytic converter; detecting the temperature levels of the gaseous mixture exiting the catalytic converter; adjusting the amount of compressed air, in response to the oxygen levels, to provide a sufficient amount of the compressed air to substantially oxidize hydrocarbons and carbon monoxide present in the gaseous mixture in the catalytic converter, while maintaining a predetermined substantially optimal temperature level of the gaseous mixture; supplying the gaseous mixture to a turbine of the super-turbocharger to drive the super-turbocharger.

[0003] An embodiment of the present invention may further comprise an engine system that operates with a rich fuel mixture comprising: a super-turbocharger having a turbine and a compressor; an additional compressor that supplies an amount of compressed air in response to a control signal; a mixing chamber that mixes exhaust gases from the engine system with the amount of compressed air to produce a gaseous mixture of the exhaust gases and the compressed air; a catalytic converter coupled to the mixing chamber that

receives the gaseous mixture; an oxygen sensor that senses oxygen levels of the gaseous mixture entering the catalytic converter and generates an oxygen sensor signal; a temperature sensor that senses the temperature levels of the gaseous mixture exiting the catalytic converter and generates a temperature sensor signal; a controller that generates the control signal in response to the oxygen sensor signal and the temperature sensor signal so that the amount of compressed air supplied by the additional compressor to the catalytic converter is sufficient for the catalytic converter to substantially oxidize hydrocarbons and carbon monoxide in the gaseous mixture while maintaining a predetermined substantially optimal temperature level of the gaseous mixture exiting the catalytic converter; supplying the gaseous mixture to the turbine to drive the super-turbocharger.

**[0004]** An embodiment of the present invention may further comprise a method of improving performance of an engine system having a super-turbocharger that is driven by a turbine that is coupled to a compressor comprising: providing a catalytic converter that receives exhaust gases from the engine system and produces an exothermic reaction that adds heat to the exhaust gases to generate converted hot exhaust gases at an output of the catalytic converter; providing compressed air from a compressor; mixing a portion of the compressed air with the converted hot exhaust gases from the catalytic converter to create a gaseous mixture having a temperature that does not exceed a predetermined maximum temperature so as to prevent damage to the turbine of the super-turbocharger; driving the turbine with the gaseous mixture; transferring excess turbine rotational mechanical energy from the turbine to a propulsion train that would otherwise cause the turbine to rotate at a speed which would cause damage to the compressor.

**[0005]** An embodiment of the present invention may further comprise a method of improving performance of a super-turbocharged engine system comprising: providing an engine; providing a catalytic converter that is connected to an exhaust outlet proximate to the engine that receives engine exhaust gases from the engine that activate an exothermic reaction in the catalytic converter which adds additional energy to the engine exhaust gases and produces catalytic converter exhaust gases at an output of the catalytic converter that are hotter than the engine exhaust gases; providing a flow of compressed air to an intake of the engine; providing a flow of additional compressed air; mixing the additional compressed air with the catalytic converter exhaust gases downstream from the catalytic converter to produce a gaseous mixture of the catalytic converter exhaust gases and the additional compressed air; generating a control signal to regulate the flow of the additional compressed air into the mixing chamber to maintain the gaseous mixture below a maximum temperature; supplying the gaseous mixture to a turbine that produces turbine rotational mechanical energy in response to flow of the gaseous mixture; transmitting the turbine

rotational mechanical energy from the turbine to the compressor that uses the turbine rotational mechanical energy to compress a source of air to produce the compressed air when the flow of the gas mixture through the turbine is sufficient to drive the compressor; extracting at least a portion of the turbine rotational mechanical energy from the turbine and applying the portion of the turbine rotational mechanical energy to a propulsion train when the portion of the turbine rotational mechanical energy from the turbine is not needed to run the compressor; providing propulsion train rotational mechanical energy from the propulsion train to the compressor to prevent turbo-lag when the flow of the gaseous mixture through the turbine is not sufficient to drive the compressor.

[0006] An embodiment of the present invention may further comprise a super-turbocharged engine comprising: an engine; a catalytic converter connected to an exhaust conduit proximate to an exhaust outlet of the engine such that hot exhaust gases from the engine activate an exothermic reaction in the catalytic converter that adds energy to the hot exhaust gases and produces converted exhaust gases; a compressor connected to a source of air that provides compressed air that is applied to an intake of the engine; an additional compressor that provides an amount of additional compressed air that has a pressure that is greater than a pressure level of the exhaust gases; a conduit that supplies the additional compressed air to the converted exhaust gases so that the additional compressed air is mixed with the converted exhaust gases to produce a gaseous mixture; a turbine that is mechanically coupled to the compressor and generates turbine rotational mechanical energy from the gaseous mixture; a controller that generates a control signal that regulates the amount of the additional compressed air to maintain the gaseous mixture below a maximum temperature; a transmission that provides propulsion train rotational mechanical energy from a propulsion train to the compressor to reduce turbo-lag when the flow of the exhaust through the turbine is not sufficient to drive the compressor to a desired boost level, and extracts excess turbine rotational mechanical energy from the turbine to maintain rotational speeds of the compressor below a predetermined maximum rotational speed at which damage would occur to the compressor.

[0007] An embodiment of the present invention may further comprise a method of increasing the performance of a piston engine system having a super turbocharger: applying exhaust gases from the piston engine system to an NO<sub>x</sub> converter, which converts the exhaust gases to produce NO<sub>x</sub> converted gases; generating an amount of compressed air from a compressor in response to a control signal; mixing the amount of the compressed air with the NO<sub>x</sub> converted gases to produce a gaseous mixture of the NO<sub>x</sub> converted gases and the compressed air; supplying the gaseous mixture to a hydrocarbon/carbon monoxide converter to produce hydrocarbon/carbon monoxide converted gases; detecting the

temperature level of the hydrocarbon/carbon monoxide converted gases; adjusting the amount of compressed air to adjust the temperature level of the hydrocarbon/carbon monoxide converted gases to a desired temperature level.

**[0008]** An embodiment of the present invention may further comprise a method of increasing the performance of a piston engine system having a super turbocharger: applying exhaust gases from the piston engine system to an NO<sub>x</sub> converter, which converts the exhaust gases to produce NO<sub>x</sub> converted gases; generating a first amount of compressed air; mixing the first amount of the compressed air with the NO<sub>x</sub> converted gases to produce a first gaseous mixture of the NO<sub>x</sub> converted gases and the compressed air; supplying the first gaseous mixture to a hydrocarbon/carbon monoxide converter to produce hydrocarbon/carbon monoxide converted gases; generating a second amount of compressed air; mixing the second amount of compressed air with the hydrocarbon/carbon monoxide converted gases to cool the hydrocarbon/carbon monoxide converted gases to a desired temperature to produce cooled hydrocarbon/carbon monoxide converted gases; driving a turbine of the superturbocharger with the cooled hydrocarbon/carbon monoxide converted gases.

**[0009]** An embodiment of the present invention may further comprise a super-turbocharged engine system comprising: a piston engine that generates exhaust gases; a NO<sub>x</sub> converter coupled to receive the exhaust gases and produce NO<sub>x</sub> converted gases; a compressor connected to a source of air that provides compressed air that is applied to an intake of the engine; a feedback valve that supplies a portion of the compressed air that is mixed with the NO<sub>x</sub> converted gases to produce a gaseous mixture; a hydrocarbon/carbon monoxide converter connected to receive the gaseous mixture and oxidize hydrocarbons and carbon monoxide in the gaseous mixture to produce a hydrocarbon/carbon monoxide converted gaseous mixture; a turbine that is coupled to receive the hydrocarbon/carbon monoxide gaseous mixture and generate turbine rotational mechanical energy from the hydrocarbon/carbon monoxide converted gaseous mixture.

**[0010]** An embodiment of the present invention may further comprise a super-turbocharged engine system comprising: a piston engine that generates exhaust gases; a NO<sub>x</sub> converter coupled to receive the exhaust gases and produce NO<sub>x</sub> converted gases; a compressor that generates a source of compressed air; a conduit that supplies the compressed air to the NO<sub>x</sub> converted gases so that said NO<sub>x</sub> converted gases are mixed with the compressed air to produce a gaseous mixture; a hydrocarbon/carbon monoxide converter coupled to receive the gaseous mixture and oxidize hydrocarbons and carbon monoxide present in the gaseous mixture to produce a hydrocarbon/carbon monoxide

converted gaseous mixture; a turbine that is coupled to receive the hydrocarbon/carbon monoxide gaseous mixture and generate turbine rotational mechanical energy from the hydrocarbon/carbon monoxide converted gaseous mixture.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0011] Figure 1 is a simplified single line system diagram of one embodiment of a super-turbocharged engine in accordance with the teachings of the present invention.

[0012] Figure 2 is a schematic illustration of another embodiment of a high efficiency super-turbocharged engine system.

[0013] Figure 3 is a schematic illustration of another embodiment of a high efficiency super-turbocharged engine system.

[0014] Figure 4 is another embodiment of a high efficiency super-turbocharged engine system.

[0015] Figure 5 is another embodiment of a high efficiency super-turbocharged engine system.

[0016] Figure 6 is another embodiment of a high efficiency super-turbocharged engine system.

[0017] Figure 7 is a graph of the operational temperatures of a catalytic converter.

[0018] Figure 8 is another embodiment of a high efficiency super-turbocharged engine system.

[0019] Figure 9 is another embodiment of a high efficiency super-turbocharged engine system.

[0020] Figure 10 is another embodiment of a high efficiency super-turbocharged engine system.

[0021] Figure 11 is another embodiment of a high efficiency super-turbocharged engine system.

[0022] Figure 12 is another embodiment of a high efficiency super-turbocharged engine system.

[0023] Figure 13 is another embodiment of a high efficiency super-turbocharged engine system.

[0024] Figure 14 is another embodiment of a high efficiency super-turbocharged engine system.

[0025] Figure 15 is another embodiment of a high efficiency super-turbocharged engine system.

[0026] Figure 16 is another embodiment of a high efficiency super-turbocharged engine system.

[0027] Figure 17 is another embodiment of a high efficiency super-turbocharged engine system.

[0028] Figure 18 is schematic illustration of another embodiment of a catalytic converter.

### **DETAILED DESCRIPTION OF THE EMBODIMENTS**

[0029] Figure 1 is simplified illustration of one embodiment of a high efficiency, super-turbocharged engine system 100 constructed in accordance with the teachings of the present invention. As will become apparent to those skilled in the art from the following description, such a super-turbocharged engine system 100 finds particular applicability in spark ignited, gasoline engines that are used in passenger and commercial vehicles, and therefore the illustrative examples discussed herein utilize such an environment to aid in the understanding of the invention. However, recognizing that embodiments of system 100 of the present invention have applicability to other operating environments such as, for example, land based, power generation engines, and other land based engines, such examples should be taken by way of illustration and not by way of limitation.

[0030] As may be seen from FIG. 1, the system 100 includes an engine 102 that utilizes a super-turbocharger 104 to increase the performance of the engine 102. In general, a super-turbocharger comprises a compressor and a turbine that are coupled together with a turbo shaft. Other ways to couple the compressor and turbine together have been used. Further, the super-turbocharger includes a transmission which transmits power between the turbo shaft and the power train or drive train (propulsion train) of the vehicle. For example, the transmission may be mechanically coupled to the crank shaft of an engine, to the vehicle's transmission, or other portions of the drive train or power train. These are collectively referred to as the propulsion train. The transmission can be a mechanical transmission that uses gearing, a hydraulic transmission, pneumatic transmission, a traction

drive transmission or an electrical transmission. An electric motor/generator can be coupled to the turbo shaft and used to either drive the turbo shaft or be driven by the turbo shaft and generate electrical energy. The electrical energy generated by the motor/generator can be used to simply produce electricity, charge batteries, drive motor/generators that are used to propel a vehicle, or assist in powering a hybrid vehicle. In that regard, the super-turbocharged engine system 100 may be sized and used for the purposes of generating electricity in an electric car system, or may be employed to both generate energy and assist in powering the vehicle with mechanical energy, such as in a hybrid vehicle system.

**[0031]** As shown in Figure 1, the super-turbocharger 104 includes a turbine 106, a compressor 108, and a transmission 110 that is coupled to the crank shaft 112 of the engine 102 or other portions of the propulsion train. While not required in all embodiments, the illustrated embodiment of FIG. 1 also includes an intercooler 114 to increase the density of the air supplied to the engine 102 from the compressor 108 to further increase the power available from the engine 102.

**[0032]** Super-turbochargers have certain advantages over turbochargers. A turbocharger utilizes a turbine that is driven by the exhaust of the engine. This turbine is coupled to a compressor which compresses the intake air that is fed into the cylinders of the engine. The turbine in a turbocharger is driven by the exhaust from the engine. As such, the engine experiences a lag in boost when first accelerated until there is enough hot exhaust to spin up the turbine to power a compressor, which is mechanically coupled to the turbine, to generate sufficient boost. To minimize lag, smaller and/or lighter turbochargers are typically utilized. The lower inertia of the lightweight turbochargers allows them to spin up very quickly, thereby minimizing the lag in performance.

**[0033]** Unfortunately, such smaller and/or lighter weight turbochargers may be over-spun during high engine speed operation when a great deal of exhaust flow and temperature is produced. To prevent such over-speed occurrences, typical turbochargers include a waste gate valve that is installed in the exhaust pipe upstream from the turbine. The waste gate valve is a pressure operated valve that diverts some of the exhaust gas around the turbine when the output pressure of the compressor exceeds a predetermined limit. This limit is set at a pressure which is less than the pressure which would cause the turbocharger to be over-spun. Unfortunately, this results in a portion of the energy available from the exhaust gases of the engine being wasted.

[0034] Recognizing that conventional turbochargers sacrifice low end performance for high end power, devices known as super-turbochargers were developed. One such super-turbocharger is described in US Patent No. 7,490,594 entitled "Super-Turbocharger," issued February 17, 2009, and assigned to the assignee of the instant application. This application is specifically incorporated herein by reference for all that it discloses and teaches.

[0035] As discussed in the above-referenced application, in a super-turbocharger the compressor is driven by the engine crank shaft via a transmission that is coupled to the engine during low engine speed operation when sufficiently heated engine exhaust gas is not available to drive the turbine. The mechanical energy supplied by the engine to the compressor reduces the turbo lag problem suffered by conventional turbochargers, and allows for a larger or more efficient turbine and compressor to be used.

[0036] The super-turbocharger 104, illustrated in Figure 1, operates to supply compressed air from the compressor 108 to the engine 102 without suffering from the turbo-lag problem of a conventional turbocharger at the low end and without wasting energy available from the engine exhaust gas heat supplied to the turbine 106 at the high end. These advantages are provided by inclusion of the transmission 110 that can both extract power from, and supply power to, the engine crank shaft 112 to both drive the compressor 108 and load the turbine 106, respectfully, during various modes of operation of the engine 102.

[0037] During start up, when conventional turbochargers suffer a lag due to the lack of sufficient power from the engine exhaust heat to drive the turbine, the super-turbocharger 104 provides a supercharging action whereby power is taken from the crank shaft 112 via the transmission 110 to drive the compressor 108 to provide sufficient boost to the engine 102. As the engine comes up to speed and the amount of power available from the engine exhaust gas heat is sufficient to drive the turbine 106, the amount of power taken from the crank shaft 112 by the transmission 110 is reduced. Thereafter, the turbine 106 continues to supply power to the compressor 108 to compress the intake air for use by the engine 102.

[0038] As the engine speed increases, the amount of power available from the engine exhaust gas heat increases to the point where the turbine 106 would over-speed in a conventional turbocharger. However, in super-turbocharger 104, the excess energy provided by the engine exhaust gas heat to the turbine 106 is channeled through the transmission 110 to the engine crank shaft 112 while maintaining the compressor 108 at the

proper speed to supply the ideal boost to the engine 102. As more output power is available from the exhaust gas heat of the engine 102, more power is generated by the turbine 106, which is channeled through the transmission 110 to the crank shaft 112, while boost available from the compressor 108 is maintained. Loading of the turbine 106 by the transmission 110 prevents the turbine 106 from over-speeding and maximizes the efficiency of the power extracted from the engines exhaust gases. As such, a conventional waste gate is not required and energy is not lost through a waste gate.

[0039] While the amount of power available to drive the turbine 106 in a conventional super-turbocharged application is limited strictly to the amount of power available from the engine exhaust, the turbine 106 is capable of generating significantly more power if the thermal energy and mass flow supplied to the turbine blades can be fully utilized and/or can be increased. However, the turbine 106 cannot operate above a certain temperature without damage, and the mass flow is conventionally limited to the exhaust gases coming out of the engine 102.

[0040] Recognizing this, the embodiment of the system 100 is capable of extracting additional energy from the exhaust gases while protecting the turbine 106 from high temperature transients. In one embodiment, the catalytic converter 116 is placed upstream from the turbine near the exhaust manifold which enables exothermic reactions that result in an increase in exhaust gas temperature during sustained high speed or high load operation of the engine. To cool the exhaust gas, prior to reaching the turbine, a portion of the compressed air generated by the compressor 108 is fed directly into the exhaust upstream from the turbine via a controllable feedback valve 118 and added to the engine exhaust gases leaving the catalytic converter 116. The cooler intake air 122 expands and cools the exhaust gas and adds additional mass to the exhaust gas flow, which adds additional power to the turbine of the super-turbocharger, as described in more detail below. As more cooler air is provided to the hot exhaust gases to maintain the temperature of the combined flow to the turbine at the optimum temperature, the energy and the mass flow that is delivered to the turbine blades also increases. This increases the power supplied by the turbine to drive the engine crank shaft.

[0041] So as to not interfere with the stoichiometric reaction within the catalytic converter, the compressor feedback air is added downstream of the catalytic converter. In such an embodiment, the engine exhaust gas is passed through the catalytic converter and

temperature of the exhaust gas is increased by the exothermic reaction. The compressor feedback air is then added and expands so that the total mass flow supplied to the turbine is increased. Embodiments of the present invention control the amount of compressed feedback air supplied to cool the exhaust and to drive the turbine to ensure that the combination of the cooler compressor feedback air and the engine exhaust gases are delivered to the turbine at an optimum temperature for turbine blade operation.

[0042] Since the catalytic converter 116, illustrated in Figure 1, has a large thermal mass, catalytic converter 116 operates as a thermal damper initially, which prevents high temperature thermal spikes from reaching the turbine 106. However, since the reactions in the catalytic converter 116 are exothermic in nature, the temperature of the exhaust gases leaving the catalytic converter 116 will eventually be higher than that of the exhaust gas entering the catalytic converter 116. So long as the temperature of the exhaust gas entering the turbine remains below the maximum operating temperature of the turbine 106, the turbine will not be damaged.

[0043] However, during sustained high speed and high load operation of the engine 102, the exit temperatures of the converted exhaust gas from catalytic converter 116 can exceed the maximum operating temperature of turbine 106. As set forth above, the temperature of the exhaust gases exiting the catalytic converter 116 are reduced by supplying a portion of the compressed air from the compressor 108 via a feedback valve 118, and mixed with the exhaust gas exiting the catalytic converter 116. Significantly improved fuel economy is achieved by not using fuel as a coolant during such conditions, as is done in conventional systems. Additionally, the operation of the transmission is controlled to allow the compressor 108 to supply a sufficient amount of compressed air to provide optimum boost to the engine 102 and the compressed feedback air to the turbine 106 via the feedback valve 118. The excess power generated by the turbine 106 resulting from the increased mass flow of the compressed air through the turbine is channeled via the transmission 110 to the crank shaft 112, yet further increasing fuel efficiency.

[0044] The output temperature of the compressed air from the compressor 108 is typically between about 200°C to 300°C. A conventional turbine can operate optimally to extract power from gases at approximately 950°C, but not significantly higher, without distortion or possible failure. Because of the material limits of the turbine blades, the optimal power is achieved at approximately 950°C. Since the materials limit the exhaust

gas temperatures to about 950°C, supplying more air to increase the mass flow across the turbine at the temperature limit, e.g., 950°C, increases the performance of the turbine.

[0045] While such a flow of compressed feedback air at 200°C to 300°C is helpful in reducing the temperature of the exhaust gas coming out of the catalytic converter 116, it is recognized that maximum power from the turbine 106 can be supplied when the temperature and the mass flow is maximized within the thermal limits of the turbine 106. As such, in one embodiment, the amount of feedback air is controlled so that the combination of exhaust gas and feedback air is maintained at or near the turbine's maximum operating temperature so that the amount of power delivered to the turbine is maximized or significantly increased. Since all of this excess power is normally not required by the compressor 108 to supply the optimum boost to engine 102 and to supply the compressor feedback air via feedback valve 118, the excess power may be transferred by the transmission 110 to the crank shaft 112 of the engine 102, or to the propulsion train of a vehicle, to thereby increase the overall efficiency or power of the engine 102.

[0046] As discussed above, in one embodiment, the connection of the compressor feedback air via feedback valve 118 employs a catalytic converter 116 as the thermal buffer between the engine 102 and turbine 106. As such, the supply of air from the compressor is provided downstream of the catalytic converter 116 so as to not disrupt the stoichiometric reaction within the catalytic converter 116. That is, in embodiments that utilize a catalytic converter 116, supplying the compressor feedback air upstream of the catalytic converter 116 would result in excess oxygen being supplied to the catalytic converter 116, thereby preventing the catalytic converter 116 from generating a stoichiometric reaction that is required for proper operation, as described in more detail below.

[0047] Since increased efficiency of power generation by the turbine 106 is achieved when the temperature of the gas mixture of the compressor feedback air and exhaust gas on the turbine blades is nearly maximized (within the material limits of the turbine itself), the amount of compressor feedback air admitted by the feedback valve 118 is limited so as to not reduce the temperature significantly below such an optimized temperature. As the catalytic converter 116 produces more thermal energy via an exothermic reaction and the temperature of the converted exhaust gases from the catalytic converter 116 increases to near the maximum operating temperature of the turbine 106, more compressor feedback air may be supplied via feedback valve 118, which increases the mass flow and energy supplied

to the turbine 106. As the amount of thermal energy generated by catalytic converter 116 is reduced, the amount of compressor feedback air supplied by feedback valve 118 can also be reduced so as to avoid supplying more air than necessary, which results in the maintenance of the temperature of the gas mixture at nearly the optimum operating condition.

[0048] In another embodiment, the system utilizes the feedback valve 118 for feeding back the cooler compressor air into the exhaust ahead of the turbine at low speed, high load operating conditions to avoid surging the compressor. Compressor surge occurs when the compressor pressure gets high but the mass flow allowed into the engine is low as a result of the engine from turning at a slow rpm and not requiring much intake air flow. Surging (or aerodynamic stalling) of the compressor resulting from low airflow across the compressor blades causes the efficiency of the compressor to fall very rapidly. In the case of a normal turbocharger, enough surge can stop the turbine from spinning. In the case of a super-turbocharger it is possible to use power from the engine crank shaft to push the compressor into surge. Opening the feedback valve 118 allows a portion of the compressed air to feedback around the engine. This feedback flow brings the compressor out of surge and allows higher boost pressure to reach the engine 102, thereby allowing the engine 102 to generate more power than would normally be possible at low engine speeds. Injecting the compressed air into the exhaust ahead of the turbine conserves the total mass flow through the compressor so that all the flow reaches the turbine which minimizes the power needed from the engine to supercharge to a high boost pressure level.

[0049] In another embodiment, an additional cold start control valve 120 may be included for operation during rich engine cold starts. During such an engine cold start, the exhaust gases from the engine 102 typically include excess un-burnt fuel. Since this rich mixture is not stoichiometric, the catalytic converter 116 is unable to fully oxidize the un-burnt hydrocarbons (UHC) in the exhaust gas. During such times, the cold start control valve 120 may be opened to provide compressor feedback air to the input of the catalytic converter 116 to supply the extra oxygen necessary to bring the rich mixture down to stoichiometric levels. This allows the catalytic converter 116 to light off faster and more efficiently reduce the emissions during the cold start event. If the engine is idling, a normal turbocharger would have no boost pressure to be able to supply the feedback air. However, the transmission ratio of transmission 110 can be adjusted to give enough speed to the compressor to generate the pressure needed for the air to flow through valve 120. In that

regard, control signal 124 can be used to adjust the ratio of transmission 110 so that sufficient rotational speed can be provided from the engine drive shaft 112 to the compressor 108 during idling, especially during a cold start, to compress enough air to flow through the cold start valve 120 and ignite catalytic converter 116 with a sufficient amount of oxygen.

[0050] The requirement for the additional oxygen is typically limited in a cold start event, and often lasts only for 30 to 40 seconds. Many vehicles currently include a separate air pump to supply this oxygen during the cold start event, at significant cost and weight compared to the limited amount of time that such an air pump is required to operate. By replacing the separate air pump with the simple cold start control valve 120, significant costs, weight and complexity savings are realized. Because the super-turbocharger 104 can control the speed of the compressor 108 via the transmission 110, the cold start control valve 120 may comprise a simple on-off valve. The amount of air supplied during the cold start event can then be controlled by controlling the speed of the compressor 108 via transmission 110 under operation of the control signal 124.

[0051] The cold start control valve 120 may also be used during periods of extremely high temperature operation if fuel is used as a coolant within the engine and/or for the catalytic converter 116, despite the negative effect on fuel efficiency. As explained in more detail below, the cold start control valve 120 will be able to supply the extra oxygen necessary to bring the rich exhaust back down to stoichiometric levels to allow the catalytic converter 116 to properly oxidize the unburned hydrocarbon emissions in the exhaust. This provides a significant benefit to the environment over prior systems.

[0052] In embodiments where the cold start control valve 120 is an on/off valve, the system can modulate cold start control valve 120 to vary the amount of compressed air supplied so as to bring the exhaust down to stoichiometric levels. Other types of variable flow control valves may also be used to accomplish this same function.

[0053] Figure 1 also discloses a controller 140. Controller 140 controls the operation of the feedback valve 118 and the cold start valve 120. Controller 140 operates to optimize the amount of air flow through feedback valve 118 for different conditions. The amount of air that flows through the feedback valve 118, for optimal operation, is the minimal amount of air flow that is necessary to obtain a specific desired condition, as described above. There are two specific conditions in which controller 140 operates feedback valve 118, which are:

1) surge limit of the compressor for a given boost requirement is approaching when the engine is operating at low rpm, high load conditions; and, 2) temperature of the gas mixture entering the turbine 106 is nearing temperature limits when the engine is operating at high rpm, high load conditions.

**[0054]** As shown in Figure 1, controller 140 receives the gas mixture temperature signal 130 from a temperature sensor 138 that detects the temperature of the gas mixture of the cooling air supplied from the compressor 108 that is mixed with the hot exhaust gases produced by the catalytic converter 116. In addition, the controller 140 detects the compressed air intake pressure signal 132 that is generated by the pressure sensor 136 that is disposed in the conduit of compressed air supplied from the compressor 108. Further, an engine speed signal 126 and an engine load signal 128 that are supplied from the engine 102, or a throttle, are fed to the controller 140.

**[0055]** With respect to control of the temperature of the gas mixture that is supplied to the turbine 106 at high speed, high load conditions, controller 140 generates control signals to operate feedback valve 118 to limit the temperature of the gas mixture to a temperature that, in some cases, maximizes the operation of the turbine 106, without being so high as to damage the mechanisms of the turbine 106. In one embodiment, a temperature of approximately 925°C is an optimal temperature for the gas mixture to operate the turbine 106. Once the temperature of the gas mixture that is fed into the turbine 106 begins to exceed 900°C, the feedback valve 118 is opened, to allow compressed air from the compressor 108 to cool the hot exhaust gases from the catalytic converter 116 prior to passing into the turbine 106. The controller 140 can be designed to target a temperature of approximately 925°C, with an upper bound of 950°C and a lower bound of 900°C. The limit of just slightly more than 950°C is one at which damage to the turbine 106 may occur using conventional materials. Of course, the controller can be designed for other temperatures, depending upon the particular types of components and materials used in the turbine 106. A conventional proportional integral derivative (PID) control logic device can be used in the controller 140 to produce these controlled results.

**[0056]** The benefit of controlling the temperature of the gas mixture that enters the turbine 106 is that the use of fuel in the exhaust to limit the turbine inlet temperatures of the gas mixture is eliminated, which increases efficiency of the system. Using the flow of the cooler compressed air to cool the hot exhaust gases from the catalytic converter 116

requires a large amount of air, which contains a large mass to achieve the desired cooler temperatures of the gas mixture. The amount of air that is required to cool the hot exhaust gases from the catalytic converter 116 is large because the cooler compressed air from the compressor 108 is not a good coolant, especially when compared to liquid fuel that is inserted in the exhaust gas. The hot exhaust gases from the output of the catalytic converter 116 cause the cooler compressed gas from the compressor 108 to expand to create the gas mixture. Since a large mass of the cooler compressed air from the compressor 108 is required to lower the temperature of the hot exhaust gases from the catalytic converter 116, a large mass flow of the gas mixture flows across the turbine 106, which greatly increases the output of the turbine 106. The turbine power increases by the difference of the power created by the differential of the mass flow minus the work required to compress the compressed air flowing through the feedback valve 118. By obtaining the gas mixture temperature signal 130 from temperature sensor 138 and controlling the addition of compressed air by feedback valve 118, the maximum temperature is not exceeded.

**[0057]** Controller 140 also controls the feedback valve 118 to limit surge in the compressor 108. The surge limit is a boundary that varies as a function of the boost pressure, the flow of air through the compressor and the design of the compressor 108. Compressors, such as compressor 108, that are typically used in turbochargers, exceed a surge limit when the flow of intake air 122 is low and the pressure ratio between the intake air 122 and the compressed air is high. In conventional super-turbochargers, the flow of intake air 122 is low when the engine speed (rpm) 126 is low. At low rpm, when the compressed air is not used in large volumes by the engine 102, the mass flow of intake air 122 is low and surge occurs because the rotating compressor 108 cannot push air into a high pressure conduit without a reasonable flow of intake air 122. The feedback valve 118 allows flow through the compressed air conduit 109 and prevents or reduces surge in the compressor 108. Once surge in the compressor 108 occurs, the pressure in the compressed air conduit 109 cannot be maintained. Hence, at low rpm, high load operating conditions of the engine 102, the pressure of the compressed air in the compressed air conduit 109 may drop below desired levels. By opening the feedback valve 118, the flow of intake air 122 through the compressor 108 is increased, especially at low rpm, high load operating conditions of the engine, which allows the desired level of boost to be achieved in the compressed air conduit 109. Feedback valve 118 can simply be opened until the desired

pressure in the compressed air conduit 109 is reached. However, by simply detecting boost pressure in the compressed air conduit 109, surge will occur prior to the feedback valve 118 being opened to bring the compressor 108 out of a surge condition.

[0058] It is preferable, however, to determine a surge limit and open the feedback valve 118 in advance, prior to the occurrence of a surge condition. For a given rpm and desired boost level a surge limit can be determined. The feedback valve 118 can begin to open prior to the compressor 108 reaching a calculated surge limit. Opening the valve early allows the compressor to spool up to a higher boost pressure more quickly because the compressor stays closer to the higher efficiency points of the compressor operational parameters. Rapid boost pressure rise at low rpm can then be achieved. By opening the valve before surge occurs, a more stable control system can also be achieved.

[0059] Opening the feedback valve 118 in such a way as to improve the responsiveness of the engine 102, is achieved by allowing the engine 102 to get to a higher boost pressure more quickly when the engine 102 is at a lower rpm. Compressor 108 is also more efficient, which results in less work for the transmission 110 to achieve supercharging. Surge limit control can be modeled within standard model based control simulation code, such as MATLAB. Modeling in this manner will allow simulation of the controller 140 and auto-coding of algorithms for controller 140.

[0060] A model based control system, such as described above, is unique, in that the utilization of the transmission 110 to control the rotation of the turbine 106 and compressor 108 generates boost pressure without turbo lag. In other words, the transmission 110 can extract rotational energy from the crank shaft 112 to drive the compressor 108 to achieve a desired boost in compressed air conduit 109 very quickly and prior to the turbine 106 generating sufficient mechanical energy to drive the compressor 108 at such a desired level. In this manner, controls in a conventional turbocharger to reduce lag are reduced or eliminated. The model based control of the controller 140 should be designed to maintain the optimum efficiency of the compressor 108 within the operational parameters of the compressor 108.

[0061] The control model of controller 140 should also be carefully modeled on the pressure operational parameters, as mapped against the mass flow allowed by the engine for a given target speed and load in which target speed and load may be defined relative to the position of the throttle of the vehicle. As shown in Figure 1, the engine speed signal 126

can be obtained from engine 102 and is applied to the controller 140. Similarly, the engine load signal 128 can be obtained from the engine 102 and applied to controller 140.

Alternatively, these parameters can be obtained from a sensors located on the engine throttle (not shown). The feedback valve 118 can then be operated in response to a control signal 142 generated by controller 140. Pressure sensor 136 generates the compressed air intake pressure signal 132 that is applied to the controller 140, which calculates the control signal 142 in response to engine speed signal 126, engine load signal 128 and compressed air intake pressure signal 132.

**[0062]** During operational conditions of the engine 102, in which a surge limit is not being approached by the compressor 108 and the temperature of the gas mixture, as detected by the temperature sensor 138, is not reached, the feedback valve 118 is closed so that the system works as a conventional super-turbocharged system. This occurs over a majority of the operating parameters of the engine 102. When high load and low rpm conditions of the engine 102 occur, the feedback valve 118 is opened to prevent surge. Similarly, at high rpm, high load operating conditions of engine 102, high temperatures are produced in the exhaust gases at the output of the catalytic converter 116, so that the feedback valve 118 must be opened to reduce the temperature of the gas mixture applied to the turbine 106 below a temperature which would cause damage to the turbine 106.

**[0063]** Figure 2 is a detailed diagram of an embodiment of a high efficiency super-turbocharged engine system 200. As shown in Figure 2, engine 202 includes a super-turbocharger that has been modified, as described above with respect to Figure 1, to provide overall higher efficiency than conventional super-turbocharged engines, as well as providing high, nearly optimal efficiency in low rpm, high load operating conditions, and high, nearly optimal efficiency at high rpm, high load conditions. The super-turbocharger includes a turbine 204 that is mechanically connected by a shaft to compressor 108. Compressor 206 compresses intake air 234 to produce compressed air 288 which is supplied air to compressed air conduit 238. Compressed air conduit 238 is connected to feedback valve 260 and intercooler 242. As disclosed above, intercooler 242 functions to cool the compressed air, 288 which becomes heated during the compression process. The intercooler 242 is connected to the compressed air conduit 238 which, in turn, is connected to the intake manifold (not shown) of the engine 202. Pressure sensor 240 is connected to the compressed air conduit 238 to detect the pressure of compressed air 288 and supply a

pressure reading via the compressed intake air pressure signal 262, which is applied to controller 266. The feedback valve 260 is controlled by a feedback valve control signal 258 generated by the controller 266, as disclosed above. Under certain operating conditions, feedback valve 260 opens to supply compressed air 288 from compressed air conduit 238 to a mixing chamber 246.

**[0064]** As shown in the embodiment of Figure 2, the mixing chamber 246 simply comprises a series of openings 244 in the catalytic converter output conduit 210, which is surrounded by the compressed air conduit, 238 so that compressed air 288 supplied from the compressed air conduit 238 passes through the openings 244 to mix with the converted gaseous mixture 292 in the catalytic converter output conduit 210. Any desired type of mixing chamber can be used to mix the cooler compressed air 288 with the converted gaseous mixture 284 to lower the temperature of the cooled gaseous mixture 288. Temperature sensor 248 is located in the catalytic converter output conduit 210 to measure the temperature of the cooled gaseous mixture 286 in the catalytic converter output conduit 210. Temperature sensor 248 supplies a gas mixture temperature signal 256 to controller 266, which controls the feedback valve 260 via feedback valve control signal 258 to ensure that the temperature of the cooled gaseous mixture 286 210 do not exceed a maximum temperature that would damage to the turbine 204. Catalytic converter 252 is connected to the exhaust manifold 208 by way of catalytic converter inlet conduit 250. By locating the catalytic converter 252 proximate to the exhaust manifold 208, the hot exhaust gases from the engine 202 flow directly into the catalytic converter 252, which assists in activating the catalytic converter 252. In other words, the proximate location of the catalytic converter 252 near the outlet of the engine exhaust gases does not allow the exhaust gases to cool substantially prior to entering the catalytic converter 252, which increases the performance of the catalytic converter 252. As the exhaust gases pass through the catalytic converter 252, the catalytic converter 252 adds additional heat to the exhaust gases, since the exhaust gases are catalyzed by the catalytic converter 252 in an exothermic reaction that occurs in catalytic converter 252. This very hot, converted gaseous mixture 284 at the output of the catalytic converter 252 is supplied to the catalytic converter output conduit 210 and is cooled by the compressed air 288. Depending upon the temperature of the very hot converted gaseous mixture 284, which varies depending upon the operating conditions of the engine 202, a different amount of compressed air 288 will be added to the converted

gaseous mixture 284, such as during high speed, high load conditions. During low engine speed, high engine load conditions, the feedback valve 260 also functions to allow intake air to flow through the compressor to avoid surge. Surge is similar to aerodynamic stall of the compressor blades, which occurs as a result of the low flow conditions through the compressor during low engine speed conditions. As disclosed above, rotational mechanical energy is transferred from the engine crank shaft 222 through the continuously variable transmission 214, that drives compressor 206, at a speed that is controlled by CVT control signal 264, that is sufficient to spin the compressor 206 to avoid surge. When surge occurs, the pressure in the intake manifold (not shown) falls because the compressor 206 is unable to compress the intake air. By allowing air to flow through the compressor 206 as a result of the feedback valve 260 being opened, pressure can be maintained in the intake manifold so that, when high torque is required at low engine speeds, the high torque can be achieved because of the high intake manifold pressure.

**[0065]** As disclosed above, when the engine 202 is operating under high speed, high load conditions, the catalytic converter 252 causes a large amount of heat to be generated in the exhaust gases that are supplied to the catalytic converter output conduit 210. By supplying compressed, cooling air 292 to the catalytic converter output conduit 210, the hot converted gaseous mixture 284, under high speed, high load conditions are cooled. As the load and speed of the engine increases, hotter converted gases are produced and more of the compressed cooling air 292 is required. If the turbine 204 does not provide sufficient rotational energy to drive the compressor 206, such as under low speed, high load conditions, the engine crank shaft 222 can supply rotational energy to the compressor 206 via drive belt 218, drive pulley 220, shaft 216, reduction gear 224 and transmission 232. Again, any portion of the propulsion train of a vehicle can be used to supply rotational energy to the compressor 206, and Figure 2 discloses one implementation in accordance with one disclosed embodiment.

**[0066]** As also illustrated in Figure 2, a mixing valve 236 is also connected to the compressed air conduit 238 and mixing conduit 212. Mixing conduit 212 is connected to the catalytic converter inlet conduit 250, which is upstream from the catalytic converter 252. The purpose of the mixing control valve 236 is to provide compressed air 280 to the input of the catalytic converter 252 during startup conditions, as disclosed above, and other rich fuel mixture conditions. Under startup conditions, prior to the catalytic converter 252 reaching

full operational temperatures, additional oxygen is provided via compressed air 280, through the mixing conduit 212, to initiate the catalytic process. The additional oxygen that is provided via the mixing conduit 212 assists in the initiation of the catalytic process. As explained in more detail below, additional oxygen can be supplied to the input of the catalytic converter 252 during rich fuel engine operating conditions, such as when driving in open throttle conditions, to bring the catalytic converter to stoichiometric operating conditions, which reduces pollutants and increases the temperature of exhaust gases exiting the catalytic converter 252, which can be used to increase the output of the superturbocharger illustrated in Figure 2. Controller 266 controls mixing valve 236 via mixing valve control signal 254 in response to the engine speed signal 268, engine load signal 270, and the gas mixture temperature signal 256.

[0067] Hence, the high efficiency, spark ignition, super-turbocharged engine system 200 operates in a manner similar to a super-turbocharger, with the exception that feedback valve 260 supplies a portion of the compressed air 288 from the compressor to the input of the turbine for two reasons. One reason is to cool the converted gaseous mixture 284 prior to entering the turbine so that the full energy of the exhaust gases can be utilized and a waste gate is not needed under high speed, high load conditions. The other reason is to provide a flow of air through the compressor to prevent surge at low rpm, high load conditions. In addition, the catalytic converter 252 can be connected in the exhaust stream before the exhaust gases reach the turbine so that the heat generated by the catalytic converter 252 can be used in driving the turbine 204, and expanding the compressed air 238 that is mixed with the hot gases from the catalytic converter 252, which increases efficiency of the system. Further, the mixing valve 236 can be used to initiate the catalytic process in the catalytic converter 252 by providing oxygen to the exhaust gases during startup conditions, and reduce pollutants and add more heat to the exhaust gases during other rich fuel mixture operating conditions

[0068] As mentioned above, other rich air/fuel mixtures can occur, especially on engines used in vehicles. For example, when a vehicle is accelerated by opening the throttle, a rich air/fuel mixture is generated, and the engine 202, as well as the catalytic converter 252, do not operate in a stoichiometric manner. As a result, CO gases and hydrocarbons are emitted in the exhaust gases 230. Although the engine 200 can create greater horsepower when a rich fuel mixture is used, which allows for acceleration of the

vehicle, the rich fuel mixture is not fully burned by the engine 202, or the catalytic converter 252. By controlling the mixing valve 236 to add more oxygen to the exhaust gases exiting the exhaust manifold 208, and entering the catalytic converter inlet conduit 250, the additional oxygen provided by the compressed air 280 allows the carbon monoxide and hydrocarbons to be oxidized in the catalytic converter 252. An O<sub>2</sub> sensor 272 is located in the catalytic converter inlet conduit 250 that provides an O<sub>2</sub> sensor input 274 that is applied to the controller 266. The O<sub>2</sub> sensor input detects the amount of oxygen in the gaseous mixture at the input of the catalytic converter 252 and generates the mixing valve control signal 254 to operate the mixing valve 236. In this manner, the mixing valve 236 can be opened to supply enough oxygen to the catalytic converter inlet conduit 250 to adjust the gaseous mixture 290 entering the catalytic converter 252, which comprises the rich fuel mixture of the exhaust from exhaust manifold 208 and the compressed air 280, to oxidize the carbon monoxide and hydrocarbons, while maintaining stoichiometric operation of the catalytic converter 252. Both the engine speed signal 268 and the engine load signal 270 can be used to determine when a rich fuel mixture is being applied to the engine 202 and thereby adjust the opening of mixing valve 236 by generating a mixing valve control signal 252 by controller 266 to anticipate the generation of rich fuel exhaust in exhaust manifold 208. Since the rich fuel mixture is oxidized in the catalytic converter 252, additional heat is created by catalytic converter 252. Hence, temperature sensor 248 will detect a higher temperature in the gases in the catalytic converter output conduit 210, and feedback valve 260 may be opened to add additional compressed cooling air 292 to the catalytic converter output conduit 210 to ensure that the cooled gaseous mixture 286 does not exceed a maximum temperature, which may be approximately 950° C, that could damage turbine 204. Use of the mixing valve 236 in this manner allows the catalytic converter 252 to operate in a stoichiometric manner in most or all operating conditions, significantly reducing the pollutants that are emitted by the high efficiency super-turbocharged engine system 200.

**[0069]** The mixing valve 236, of Figure 2, can also be used in a manner that does not create stoichiometric operation of catalytic converter 252. For example, some classes of race car engines, and vehicle engines in some countries, do not require pollution control. In that case, the mixing valve 236 can be opened to provide enough oxygen to ensure that all of the carbon monoxide and hydrocarbons are oxidized in the catalytic converter 252

without necessarily maintaining stoichiometric operation of the catalytic converter 252. Racing engines typically use a very rich mixture that increases the output power of the engine 202. In addition, the extra fuel helps to cool the engine components. Additional compressed air can be added, via mixing valve 236, to not only add oxygen to oxidize hydrocarbons and carbon monoxide, but to also add cooling gases at the input of the catalytic converter 252. The oxidation of very rich fuel mixtures may cause the catalytic converter 252 to operate at too high a temperature, which can be reduced by adding additional air via mixing valve 236.

**[0070]** Figure 3 is a schematic diagram of another embodiment of a high efficiency super-turbocharged engine system 300. The super-turbocharged engine system 300 differs in at least one respect from the embodiment of Figures 1 and 2 in that an additional compressor 328 is provided. As illustrated in Figure 3, engine 340 includes a turbine 344 that mechanically drives a compressor 356. Compressor 356 compresses air from air intake 360 and supplies the compressed air 388 to conduit 312. Conduit 312 is connected to an intercooler 362 that cools the compressed air 388. The intercooler 362 is connected to the compressed air conduit 368 which, in turn, is connected to the intake manifold (not shown) of the engine 340. As also shown in Figure 3, controller 354 receives an engine speed signal 350 and an engine load signal 352. These signals are used to calculate a super-turbocharger ratio control signal 310 that is applied to the variable transmission or electric motor/generator 326. Power 334 from the engine 340 or propulsion train of a vehicle is coupled to the variable transmission or electric motor/generator 332 so that power 334 can be transferred between the variable transmission or electric motor/generator 332 and a mechanical propulsion train or electrical propulsion system.

**[0071]** As also shown in Figure 3, a separate compressor 328 is connected to a variable transmission or electric motor 326. Power 324 from the propulsion train can be used to drive variable transmission 326. Alternatively, electric power from the engine system 300 can be used to drive an electric motor 326. Compressor 328 compresses the air from the cooling gas intake 322 to provide compressed cooling gas 380, which is applied to a compressed air conduit 320. The compressed cooling gas 380 in compressed air conduit 320 is applied to mixing chamber 316, having openings 314 in the catalytic converter output conduit 306. Any desired type of mixing chamber can be used to mix the compressed cooling gas 380 with the converted exhaust gases 384 to lower the temperature of the cooled

exhaust gases 386 in the catalytic converter output conduit 306. Temperature sensor 364 is disposed in the catalytic converter output conduit 306 downstream from the mixing chamber 316 to measure the temperature of the cooled exhaust gases 386. Temperature sensor 364 supplies a gas mixture temperature signal 348 to the controller 354, which controls the operation of the variable transmission or electric motor 332. Controller 354 generates a transmission/motor control signal 308 that is applied to the variable transmission or electric motor 326 to control the speed of the compressor 328 and the amount of the compressed cooling gas 380 that is supplied to the compressed air conduit 320. The amount of compressed cooling gas 380 that is supplied to the compressed air conduit 320 is controlled to ensure that the temperature of the cooled exhaust gases 386 that enter the turbine 344 do not exceed a maximum temperature that would damage the turbine 344. This maximum temperature may be in the range of 900 to 950 °C. Exhaust gases from the turbine 344 are then exhausted by exhaust 366.

[0072] As also illustrated in Figure 3, the catalytic converter inlet conduit 342 is connected to the exhaust manifold 318 at a location close to the exhaust manifold 318 so that the hot exhaust gases from the exhaust manifold 318 activate the catalyst in the catalytic converter 346. The hot converted exhaust gases 384 that are converted by catalytic converter 346 exit the catalytic converter 346 and are applied to catalytic converter output conduit 306. The converted exhaust gases 384 are subsequently mixed with compressed cooling gas 380.

[0073] Hence, the additional compressor 328 and variable transmission or electric motor 326, as illustrated in Figure 3, replace the feedback valve 118 of Figure 1 by supplying a source of cooler compressed cooling gas 380 via compressed air conduit 320 to ensure that the hot, converted exhaust gases 384 from the catalytic converter, in catalytic converter output conduit 306, are cooled sufficiently to prevent damage to the turbine 344. The embodiment of Figure 3 does not provide, however, a manner of limiting surge through the use of a feedback valve, such as feedback valve 260 in Figure 2. Hence, the embodiment of Figure 3, as well as the embodiment illustrated in Figure 4, can be modified to include a feedback valve 118 that can be opened when surge limits are approaching, such as low RPM, high load operating conditions of the engine to prevent surge. A feedback valve, such as feedback valve 260, in Figure 2, can also assist in adding additional cooler gases to the converted hot exhaust gases in the catalytic converter output conduit 306 to further

assist in lowering the temperature of the cooled exhaust gases 386 to an optimal temperature, and to prevent damage to the turbine 344.

**[0074]** Figure 4 is another embodiment of a high efficiency super-turbocharged engine system 400. As shown in Figure 4, engine 402 includes a super-turbocharger that comprises high speed transmission 406, turbine 408, exhaust 410, compressor 404 and intake air 462. The super-turbocharger also includes a variable speed transmission or electric motor/generator 428 that is coupled to a power system 430, such as a mechanical propulsion train or electric propulsion system. Compressed air from compressor 404 is applied to conduit 412. Intercooler 460 cools the compressed air and applies the compressed air to compressed air conduit 458. Compressed air conduit 458 is coupled to an input manifold (not shown) of engine 402.

**[0075]** As illustrated in Figure 4 and as disclosed above, power 430 can be either transferred from the super-turbocharger to a mechanical propulsion train or electrical propulsion train, or be transferred from the mechanical or electrical propulsion train back into the super-turbocharger to run the super-turbocharger during certain conditions, such as, for example, during turbo lag conditions. The variable transmission or electric/motor generator 428 can either be a mechanical continuously variable transmission or can constitute a motor/generator. Various types of electric motors/generators can be used. For example, motor/generators similar to the motor/generators that are used on electric cars for propulsion and braking can be used. When reduction gear 426 is driving an electric motor/generator 428, electrical power generated by the electric motor/generator can be supplied to an electric propulsion system to assist in propelling the car. Alternatively, an electric motor/generator 428 can function as a motor that is driven by electrical power from the electrical system of a vehicle to drive the reduction gear 426 during certain conditions, such as conditions when turbo lag may occur, as one example. Variable transmission or electric motor/generator 428 operates in a manner similar to the variable transmission or electric motor/generator 326 of Figure 3. The variable transmission or electronic motor/generator 428 functions in response to the super-turbocharger ratio control signal 452. Engine load signal 456 and engine speed signal 454 are applied to controller 470, which controls the variable transmission or electric motor/generator 428 via the super-turbocharger ratio control signal 452.

[0076] The system of Figure 4 also includes a catalytic converter 468 that is connected to catalytic converter inlet conduit 440. Catalytic converter inlet conduit 440 is, in turn, connected to the exhaust manifold 418. Catalytic converter 468 is located near the exhaust manifold 418 that allows the hot exhaust gases 470 from the exhaust manifold 418 to activate the catalysts in the catalytic converter. Catalytic converter 468 may operate in a stoichiometric region as controlled by the vehicle fuel system. Catalytic converter 468 creates additional heat in the converted exhaust gases 472, which is supplied to the catalytic converter output conduit 446. Variable transmission 424 is coupled to reduction gear 426 and operates under the control of the variable transmission/electric motor control signal 448 that is generated by the controller 470. Variable transmission 424 operates compressor 422 that compresses gases from the cooling gas intake 420 and applies the compressed cooling gas 478 to compressed gas conduit 432. The compressed gas in the compressed cooling gas conduit 432 is mixed with the hot, converted exhaust gases 472 in the mixing chamber 416. Openings 414 allow the compressed cooling gas 478 to flow from compressed gas conduit 432 into the catalytic converter output conduit 440 to be mixed with the converted exhaust gases 472 exiting the catalytic converter 468. Temperature sensor 464 measures the temperature downstream from the mixing chamber 416. Again, the cooled exhaust gases 474 must be below a maximum temperature that would harm the turbine 408, which is approximately 900 °C to 950 °C in many embodiments. The temperature sensor 464 sends a gas mixture temperature signal 450 to the controller 470 that generates the variable transmission/electric motor control signal 448 that is used to control the speed of the compressor 422, which, in turn, controls the amount of compressed cooling gas 478 in the compressed gas conduit 432 that is mixed with the converted exhaust gases 472 in the catalytic converter output conduit 446 to maintain the temperature of the compressed cooling gas 478 at an optimal temperature of approximately 900 °C. Hence, the high efficiency super-turbocharged engine system 402 utilizes an additional variable transmission 424 that is coupled to the reduction gear 426 to add compressed cooling gas 478 to the converted exhaust gases 472 prior to the compressed cooling gas 478 entering turbine 408. In this manner, the compressed air 476 from compressor 404 and conduit 412 is not extracted for the purpose of cooling the converted exhaust gases 472.

[0077] Other gases can be used, other than fresh air, as a compressed cooling gas 478 that is supplied to cooling gas intake 420. For example, tailpipe exhaust gases, crank case

gases, RAM air input gases, etc., can be used as a source of cooling gas. Exhaust gases contain a large amount of water vapor and carbon dioxide that can effectively cool the converted exhaust gases 472 emitted from exhaust manifold 418. As also indicated above, a pump can be connected to pump the crank case gases from the crank case to lower the air pressure in the crank case and limit aerodynamic effects of the moving parts in the crank case. Since the crank case gases include oil vapors, introduction of the oil vapors at the front end of the catalytic converter 836 helps in reducing emissions, since the catalytic converter 836 will oxidize those oil vapors.

**[0078]** The embodiments illustrated in Figures 1-3 are primarily intended to be operated with engines that have an air/fuel mixture from an engine running at or slightly above the stoichiometric point. This is normally in the region of approximately 14.6-14.8 parts of air to one part fuel, by weight, for most gasoline mixtures, as disclosed in more detail below. In this manner, a three-way catalytic converter can reduce NO<sub>x</sub> and oxidize carbon monoxide and unburned hydrocarbons to produce low emissions. As disclosed below, the embodiments of Figures 5 and 6 are primarily intended to function with engines that utilize a rich gas/fuel mixture by adding oxygen to the input of the catalytic converter. The embodiments of Figures 5 and 6 are not concerned with the generation of NO<sub>x</sub> gases, but rather, are directed to achieving the maximum output power that can be supplied by the engine by utilizing a rich gas/fuel mixture for combustion and recovering waste heat through oxidation of carbon monoxide and unburned hydrocarbons in the catalytic converter.

**[0079]** Figure 5 is another embodiment of a high efficiency super-turbocharged engine system 500 that uses an additional compressor 526. The embodiment of Figure 5 is used with an engine 502 that utilizes a rich gas/fuel mixture to produce a large amount of horsepower from the engine 502. For example, the embodiment of Figure 5 may be employed in a race car or other engine that is not subject to pollution requirements, especially with respect to NO<sub>x</sub> gases. The embodiment of Figure 5 does oxidize hydrocarbon pollutants and carbon monoxide pollutants, but the catalytic converter 502 does not operate in a stoichiometric manner to reduce NO<sub>x</sub> pollutants.

**[0080]** As illustrated in Figure 5, variable transmission or electric motor/generator 532 transfers power 534 to and from the propulsion train and/or an electrical system. A high speed transmission 506 couples the turbine 508 and the compressor 504 to the reduction

gear 568. Compressor 504 compresses air from air intake 540. The compressed air is applied to conduit 530, which is connected to intercooler 544. Intercooler 544 cools the compressed air and applies the compressed air to compressed air conduit 542. Compressed air conduit 542 is coupled to the intake manifold of the engine 502. Variable transmission or electric motor/generator 532 operates under the control of a super-turbocharger ratio control signal 562 that is generated by the controller 514 from the engine speed signal 564 and the engine load signal 566, as explained in more detail above.

**[0081]** As also shown in Figure 5, an additional compressor 526 is operated by a variable transmission or electric motor 524 from an electrical or mechanical power source 522. Electric power from the power source 534 can be used to operate an electric motor 524. A variable transmission or electric motor/generator 532 can be operated by mechanical power from a reduction gear 568 or mechanical rotational power from engine 502 or a propulsion train to which engine 502 is coupled. Compressor 526 compresses air received from the cooling gas intake 528 and applies the compressed air to the compressed air conduit 520. The variable transmission or electric motor 524 operates under the control of the variable transmission/electric motor/generator control signal 558. The compressed air in the compressed air conduit 520 is applied to the mixing chamber 516, which has a series of openings 546 in the catalytic converter inlet conduit 548 so that the compressed air in compressed air conduit 520 is mixed with the hot exhaust gases from the exhaust manifold 518 to produce gaseous mixture 572. The purpose of adding additional compressed air from the compressed air conduit 520 upstream from the catalytic converter 510 is to add more oxygen and/or cooling gases to the exhaust gases that supplied to the catalytic converter 510.

**[0082]** In the embodiment illustrated in Figure 5, it is not necessarily intended that the catalytic converter 510 be operated in the stoichiometric region. The high efficiency super-turbocharged engine system 500 is a system that can be used on a race car or other very high powered engine systems that may emit NO<sub>x</sub> gases. In these types of engine systems, the engines are run with a rich fuel mixture in order to generate a large amount of power from the engine 502. A rich fuel mixture is a mixture of fuel and air in which all of the fuel is not burned during the combustion cycle and, as such, the exhaust contains unburned fuel. In normal passenger and commercial vehicles that are subject to pollution standards, the

engine systems are carefully balanced for a three-way catalytic converter to simultaneously perform the tasks of:

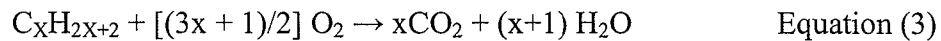
1. Reduction of nitrogen oxides to nitrogen and oxygen via:



2. Oxidation of carbon monoxide to carbon dioxide via:



3. Oxidation of unburned hydrocarbons (HC) to carbon dioxide and water via:



[0083] These reactions occur most efficiently when the catalytic converter receives exhaust from an engine running at or slightly above the stoichiometric point. This is between 14.6 and 14.8 parts air to 1 part fuel, by mass, for gasoline. Within a narrow fuel/air ratio band surrounding stoichiometry, conversion of all three pollutants is nearly complete. For example, most catalytic converters operate with 97 percent efficiency. When there is more oxygen than required, the engine system is said to be running lean, and the system is in oxidizing condition. In that case, the two oxidation reactions, i.e. Equations 2 and 3 above, are favored at the expense of the reduction of  $\text{NO}_x$  (Equation 1). On the other hand, when there is excessive fuel, the engine is running rich, and the reduction of  $\text{NO}_x$  is favored (Equation 1), at the expense of CO and HC oxidation (Equations 2 and 3 above).

[0084] Referring again to Figure 5, the addition of compressed air via compressed air conduit 520 to the exhaust gases in the catalytic converter inlet conduit 548 to produce gaseous mixture 572 will favor Equation 2 and Equation 3 above. Since a racing engine, or other engine that is generating a large amount of power, is running with a rich fuel mixture, such as when a vehicle is accelerated or operated with an open throttle, this will cause the catalytic converter 510 to oxidize a large amount of the rich fuel mixture that is present in the exhaust gases from the engine. Rather than allowing the rich fuel mixture to pass through the catalytic converter 510 to the exhaust 512, the addition of oxygen that is present in the compressed air from compressor 526 will allow the catalytic converter 510 to substantially fully perform the oxidation reactions set forth in Equations 2 and 3 above. The process of oxidizing unburned fuel in the catalytic converter 510 will generate a large amount of heat in the catalytic converter 510. Temperature sensor 552 generates a gas mixture temperature signal 560 that is applied to the controller 514. Again, it is necessary to maintain the temperature of the converted gaseous mixture 574 at a level below

approximately 950 °C so that damage does not occur to the catalytic converter 510 or the turbine 508. In that regard, controller 514 generates the variable transmission/electric motor control signal 558 that controls the variable transmission or electric motor 524 to produce additional cooling gases in compressed air conduit 520 to maintain the temperature in the catalytic converter output conduit 556 at a nearly optimal temperature around 900 °C – 950° C. More or less compressed gas can be provided by the compressor 526 to maintain the temperature measured by the temperature sensor 552 at around 900 °C. Again, 900 °C – 950° C is a nearly optimal temperature because it is lower than the temperature that will cause damage to the turbine 508 and catalytic converter 510, but still high enough to generate the high velocity hot gases in the catalytic converter output conduit 556. The hotter the converted gaseous mixture 574, the greater the velocity of the converted gaseous mixture 574, so that the hotter, converted gaseous mixture 574 are capable of turning the turbine 508 at a higher rate of speed than converted gaseous mixture 574 at a lower temperature. Again, the temperature of 900 °C – 950° C is exemplary only and is based upon the materials of the system. For example, if turbine 508 can be constructed of materials that can withstand higher temperatures, a higher temperature may be a more optimal temperature.

**[0085]** As also illustrated in Figure 5, oxygen sensor 550 is used to measure the oxygen level of the gases being applied to the catalytic converter 510. An oxygen sensor signal 554, generated by the oxygen sensor 550, is applied to the controller 514. The controller 514 controls the oxygen level of the mixture of exhaust gases and compressed air that are applied to the catalytic converter 510 by generating the variable transmission/electric motor control signal 558 that is applied to the variable transmission or electric motor 524, which controls the compressor 526. Controller 514 is programmed to ensure that a sufficient amount of oxygen is in the gaseous mixture 572 that is applied to the catalytic converter 510 so that the oxidation set forth in Equations 2 and 3 above is complete. Hence, a sufficient amount of compressed air will be applied to the catalytic converter inlet conduit 548 to ensure oxidation in accordance with Equations 2 and 3 above. Additional compressed air will be applied by compressor 526 when the temperature as detected by temperature sensor 552 begins to reach 900° C – 950° C. In that manner, the oxygen sensor 550 must detect a sufficient amount of oxygen in the gaseous mixture 572 to ensure oxidation in accordance with Equations 2 and 3, while maintaining the temperature below a maximum temperature

level in response to the gas mixture temperature signal 560, which detects the temperature of the converted gaseous mixture 574 exiting the catalytic converter 510. Programming of the controller 514 can be accomplished using the techniques described above.

[0086] Additionally, the high efficiency super-turbocharged engine system 500, illustrated in Figure 5, can also be operated so that the catalytic converter 510 operates in a stoichiometric fashion. For example, if the engine system 500 is employed on a vehicle, additional oxygen can be added to the catalytic converter inlet conduit 548 to maintain the balance of the reactions of Equations 1-3, so that the catalytic converter 510 operates in a stoichiometric region. A typical situation in an engine system 500 that is disposed in a vehicle is that a rich fuel mixture is used when the throttle is opened vehicle to accelerate the vehicle and obtain more power from the engine 502. In this instance, additional oxygen can be added via the compressor 526, compressed air conduit 520, mixing chamber 516 and openings 546 to balance Equations 1-3 and cause the catalytic converter 510 to operate stoichiometrically. In this manner, pollutants can be greatly reduced in exhaust 512, even during periods of acceleration of the vehicle.

[0087] Figure 6 illustrates a system that is similar to Figure 5, that is used with a high powered engine system 600, such as that used in a racing vehicle, or to reduce pollutants in open throttle situations. Racing engines are designed to run with a rich air/fuel mixture to ensure that a large amount of power can be generated from the engine 602. A variable transmission or electric motor/generator 630 transfers power 632 between a mechanical propulsion system or electrical propulsion system in response to the super-turbocharger ratio control signal 656 generated by controller 638 in response to engine speed signal 658 and engine load signal 660. A turbine 604 and compressor 608 are coupled to high speed transmission 606 that supplies rotational mechanical energy to reduction gear 628. Compressor 608 compresses air from air intake 612 and supplies the compressed air 676 to conduit 634. The compressed air 676 is cooled in intercooler 614 and applied to the compressed air conduit 636. The compressed air 676 in compressed air conduit 636 is applied to the intake manifold (not shown) to increase the power of the engine 602. Turbine 604 operates in response to a hot, converted gaseous mixture 674 from catalytic converter output conduit 650. The hot, converted gaseous mixture 674 operates the blades of the turbine 604 and is exhausted through exhaust 610.

[0088] As illustrated in Figure 6, an additional compressor 624 is coupled to a variable transmission 626 that is coupled to reduction gear 628. The variable transmission 626 spins the compressor 624 at a desired speed in response to variable transmission/motor control signal 652. Compressor 624 compresses gases from cooling gas intake 622 and supplies the compressed gas 670 to compressed gas conduit 620. Again, the source of the cooling gas intake 622 can comprise any desired gas, including exhaust gases, crank case gases, fresh air or other sources of gas. The compressed gas 670 in compressed gas conduit 620 is applied to mixing chamber 616, which includes openings 662 in the catalytic converter inlet conduit 640. The catalytic converter inlet conduit 640 is also coupled to the exhaust manifold 618. Catalytic converter 646 is coupled to the catalytic converter inlet conduit 640 proximate to the exhaust manifold 618 so that the hot exhaust gases from the exhaust manifold 618 can be applied to the catalytic converter 646. Temperature sensor 644 detects the temperature of the gaseous mixture 672 of the compressed gas and the exhaust gases that are applied to the catalytic converter 646. Oxygen sensor 642 generates an oxygen sensor signal 648 that is applied to controller 638. Temperature sensor 644 monitors the temperature of the converted gaseous 674 that is exiting the catalytic converter 646. Temperature sensor 644 generates a gas mixture temperature sensor signal 654, which is applied to controller 638.

[0089] Controller 638 operates essentially in the same manner as controller 514 of Figure 5. Since engine 602 may operate with a rich fuel mixture, a sufficient amount of compressed gas 670 is supplied to catalytic converter 646, by compressor 624, in response to the variable transmission/motor control signal 652, to cause a substantially complete oxidation of hydrocarbons and carbon monoxide in accordance with Equations 2 and 3. This causes the catalytic converter 646 to add a large amount of heat to the converted gaseous mixture 674, which is supplied to the catalytic converter output conduit 650 and subsequently to the turbine 604. Oxygen sensor 642 generates an oxygen sensor signal 648 that is applied to controller 638, which ensures that a sufficient amount of oxygen is present in gaseous mixture 672, as a result of the compressed gas 670 supplied by compressor 624, to ensure oxidation in accordance with Equations 2 and 3, in catalytic converter 646. Temperature sensor 644 generates gas mixture temperature signal 654 that is applied to controller 638 to ensure that the correct amount of compressed gas 670 is applied to the catalytic converter inlet conduit 640 to ensure that the temperature of approximately 900 °C

– 950° C is maintained in the converted gaseous mixture 674, so that turbine 604 is not damaged. Variable transmission/motor control signal 652 controls the speed at which the compressor 624 is rotated which, in turn, controls the amount of compressed gas that compressor 624 applies to the compressed gas conduit 620.

[0090] As indicated above, with respect to Figure 5, oxygen may be added to the gaseous mixture 672 by compressor 624 during acceleration or open throttle conditions of the engine 602. In that case, the engine 602 is not running stoichiometrically, but rather, a rich fuel mixture is being applied to the engine 602. As such, additional oxygen can be supplied to the gaseous mixture 672 which is just sufficient to allow the catalytic converter 646 to operate stoichiometrically so that Equations 1-3 are balanced and the three sources of pollution, i.e., NO<sub>x</sub>, carbon monoxide and hydrocarbons, are all substantially eliminated.

[0091] The energy required to operate compressors 526, 624 in Figures 5 and 6, respectively, is about half of the power that can be generated by turbines 508, 604, as a result of the additional heat that is generated by catalytic converters 510, 646. In this manner, a large amount of additional energy can be extracted from the rich running engines illustrated in Figures 5 and 6. Not only do the systems illustrated in Figures 5 and 6 extract additional energy to increase the power output of the engines illustrated in Figures 5 and 6, the oxidation described in Equations 2 and 3 significantly reduces pollutants in the exhaust gases of rich running engine systems, such as race cars. Although NO<sub>x</sub> is not reduced when extra oxygen is supplied to the input of catalytic converter 646, carbon monoxide and hydrocarbons are significantly oxidized from the exhaust output of these rich running engines. It should also be recognized that, when engine 602 is running rich, engine 602 creates fewer NO<sub>x</sub> gases in the combustion chamber, which functions to reduce the output of NO<sub>x</sub> gases, even though extra oxygen is added by compressor 624 to the input of the catalytic converter 646 which reduces the effectiveness of Equation 1. Smaller compressors, such as compressors 526, 624 in Figures 5 and 6, respectively, can be used since a large amount of compressed gas 670 is not necessary to cause both oxidation and the cooling of the exhaust gases necessary to operate the engine systems illustrated in Figure 5 and 6. Inexpensive piston, centrifugal or diaphragm compressors can be used to supply the compressed air that is required. These compressors can operate, as explained above, from an electric motor or from a variable transmission that is connected to the propulsion train. In this manner, the systems illustrated in Figures 5 and 6 can be easily constructed at low

cost. In addition, the catalytic converters 510, 646 may comprise high flow catalytic converters that are capable of passing a large amount of the gaseous mixture through the catalytic converter. In this fashion, the catalytic converters 510, 646 do not restrict the flow of the exhaust gas to the turbines 508, 604.

[0092] Figure 7 is a graph 700 illustrating the temperatures of the gaseous mixture in the catalytic converter output conduit 556 of Figure 5 and the catalytic converter output conduit 650 of Figure 6. As illustrated in Figure 7, during the portion 702 of the curve, the temperature increases as the catalytic converter 510, 646 begins operation and additional oxygen is provided via the compressed air. At point 703, controllers 514, 638 determine that more air will be required to maintain the gaseous mixture at 900 °C – 950° C. As such, a sufficient amount of air is added to maintain the temperature of the gaseous mixture at the output of the catalytic converter 510, 646 at approximately 900 °C – 950° C, as illustrated by portion 704 of the curve. If additional compressed air was not added, the temperature of the gaseous mixture at the output of the catalytic converters 510, 646 would otherwise increase up to approximately 1100 °C, as shown by curve 706. At point 705, the controllers 514, 638 determine that there is a sufficient amount of oxygen in response to the oxygen sensor signal 554, 648, but that the larger amount of air that is being supplied by compressor 526, 624 would cause temperatures of the gaseous mixture at the output of the catalytic converter 510, 646 to decrease, as illustrated by curve 708. Hence, the amount of compressed air is reduced so that the temperature of the gaseous mixture is maintained at approximately 900° C – 950° C, as illustrated by portion 709 of the curve. In this manner, the temperature of the gaseous mixture at the output of the catalytic converters 510, 646 is maintained at a substantially optimal level to extract the most amount of energy from the hot exhaust gases by turbines 508, 604, while also ensuring, through detection of the oxygen sensors 550, 642, that a sufficient amount of oxygen is present in the gaseous mixture at the input of the catalytic converters 510, 646, as detected by oxygen sensors 550, 642 to ensure that a complete oxidation occurs, in accordance with Equations 2 and 3 above.

[0093] Figure 8 is a schematic illustration of another embodiment of a high efficiency super-turbocharged engine system 800. As shown in Figure 8, engine 802 utilizes a superturbocharger that includes a turbine 804 and a compressor 806. Connected to the turbine 804 and compressor 806 is a transmission 808 that transfers power between the variable transmission or electric motor/generator 820 and the turbine 804/compressor 806.

Power 822 is transferred between the variable transmission or electric motor generator 820 and an engine output or power train, as described above. Intake gas 824 is compressed by the compressor 806 and exhaust gases 810 are exhausted from the turbine 804.

[0094] As illustrated in Figure 8, compressor 806 supplies compressed air 876 to conduit 860. The compressed air 876 in conduit 860 is applied to intercooler 858, which cools the compressed air 876. The cooled compressed air is then applied to the intake manifold (not shown) of the engine 802 via compressed air conduit 856. Mixing valve 842 is connected to mixing conduit 818 that supplies compressed air 870 to the catalytic converter inlet conduit 830 via mixing chamber 814. Mixing valve 842 operates under the control of controller mixing valve signal 844. Openings 812 in the catalytic converter inlet conduit 830 allow the compressed air 870 to flow into the catalytic converter inlet conduit 830 and mix with the exhaust gases from the exhaust manifold 816. The pressure of the compressed air 870 in mixing conduit 818 is greater than the average pressure of the exhaust gases in the catalytic converter inlet conduit 830, so that the compressed air 870 flows into and mixes with the exhaust gases in the catalytic converter inlet conduit 830 to produce gaseous mixture 872. As indicated above, the intake gas 824 may comprise fresh intake air from the surrounding environment or other gases. If fresh air is supplied through the mixing conduit 818 to the mixing chamber 814, the addition of oxygen to the catalytic converter 836 will assist in oxidizing carbon monoxide and hydrocarbons that exist in the exhaust gases from exhaust manifold 816. By adding additional oxygen to the exhaust gases that exceeds the stoichiometric point for the air/fuel ratio, the catalytic converter 836 will effectively oxidize both the hydrocarbons and carbon monoxide gases that exist in the exhaust gases, in accordance with the processes set forth in Equation 2 and Equation 3. However, the additional oxygen, that exceeds the stoichiometric point, will reduce the processes set forth in Equation 1, so that there will be a less effective reduction of NO<sub>x</sub> gases.

[0095] As also shown in Figure 8, the catalytic converter inlet conduit 830 is connected to the input of the catalytic converter 836. Catalytic converter 836 may comprise a high flow catalytic converter that creates little or no back pressure on the exhaust emitted from exhaust manifold 816. High flow catalytic converters can be used in all of the embodiments disclosed herein. An oxygen sensor 832 can assist in creating gaseous mixtures that have a stoichiometric ratio, so that the catalytic converter operates in a stoichiometric manner.

Oxygen sensor 832 senses the oxygen level of the gaseous mixture 872. An oxygen sensor signal 838, generated by the oxygen sensor 832, is applied to the controller 850. Controller 850 calculates the proper oxygen level to create a stoichiometric ratio of the gaseous mixture 872 to reach a stoichiometric point. Controller 850 then generates a controller mixing valve signal 844 that controls the mixing valve 842 to adjust the amount of compressed air 870 that is mixed with the exhaust gases in mixing chamber 814 to create a stoichiometric ratio of these gases.

[0096] The catalytic converter can then perform the chemical reactions indicated in Equations 1-3, above. As such, carbon monoxide and hydrocarbons are oxidized in the catalytic converter 836, while NO<sub>x</sub> gases are also reduced, since a stoichiometric ratio of the air/fuel mixture is provided to the catalytic converter 836. In addition, data signal 880 can provide data from the vehicle computer to controller 850. The vehicle computer controls the air/fuel ratio of the mixture entering the engine combustion chamber. When a non-stoichiometric ratio of the air/fuel mixture is sent to the engine, that ratio of air/fuel is known by the vehicle computer. The data signal 880 includes air/fuel ratio data relating to the air/fuel ratio. Controller 850 can begin the process of controlling the opening or closing of the mixing valve 842 via the controller mixing valve signal 844 in anticipation of a change in the air/fuel ratio of the exhaust gases emitted from the exhaust manifold. For example, if the throttle is opened on the vehicle, the vehicle computer generates a control signal that controls the air/fuel ratio to control the throttle. The control signal is also applied as data signal 880 to controller 850. Controller 850 calculates the new air/fuel ratio and generates a controller mixing valve signal 844 to open the mixing valve 842 by a predetermined amount to add more compressed air 870 to the catalytic converter inlet conduit 830 to increase the oxygen content of the gaseous mixture 872. Oxygen sensor 832 generates an O<sub>2</sub> sensor signal 838 that is applied to controller 850 to confirm that the proper oxygen level of the gaseous mixture 872 exists at the input to the catalytic converter 836. Controller 850 can continue to adjust the mixing valve 842, as the air/fuel ratio changes, in response to the data signal 880. The delay between the opening of the throttle, which creates a rich fuel mixture, and the existence of the rich fuel mixture ratio in the exhaust emitted from the exhaust manifold 816 is known, or can be calculated, by controller 850. Controller 850 also calculates the delay between the opening of the mixing valve 842 and the supply of compressed air to the catalytic converter inlet conduit 830, for a given

pressure of compressed air 870, so that the opening of the mixing valve 842 can be timed so that the additional oxygen from the compressed gas reaches the catalytic converter inlet conduit 830 approximately simultaneously with the rich fuel mixture emitted by the exhaust manifold 816. In this manner, a stoichiometric ratio can be continuously applied to the catalytic converter 836, so that the catalytic converter 836 can operate in a stoichiometric manner and substantially reduce pollutants in accordance with Equations 1-3. The catalytic converter 836 may also be operated in a non-stoichiometric manner, as described below.

[0097] As also shown in Figure 8, temperature sensor 834 detects the temperature of the converted gaseous mixture 874 exiting the catalytic converter 836. Converted gaseous mixture 874 flows into catalytic converter output conduit 840 and is channeled to the turbine 804 to drive the turbine 804. The converted gaseous mixture 874 is then exhausted at exhaust 810. Controller 850 receives the O<sub>2</sub> sensor signal 838, indicating the amount of oxygen in the gaseous mixture 872 applied to the catalytic converter, and the gas mixture temperature signal 846, indicating the temperature of the converted gaseous mixture 874 flowing from the catalytic converter 836. Controller 850 generates a controller mixing valve signal 844 in response to the engine speed signal 852 and the engine load signal 854, as well as the O<sub>2</sub> sensor signal 838 and gas mixture temperature signal 846, to control the operation of the mixing valve 842. For example, the compressed air 870 that flows from the conduit 860 through the mixing control valve 842 may function to cool the gaseous mixture 872 entering the catalytic converter 836, as well as provide additional oxygen for oxidizing a rich fuel mixture without creating a stoichiometric ratio. For example, the O<sub>2</sub> sensor 832 may indicate to controller 850 that additional oxygen is needed to oxidize a rich fuel mixture to bring the catalytic converter 836 up to stoichiometric operating levels. Temperature sensor 834 may then indicate that additional compressed air may be needed to cool the gases emitted from the catalytic converter 836, so that the turbine 804 is not damaged. Controller 850 can operate the mixing valve 842 to ensure that an adequate supply of intake air is supplied to the catalytic converter input conduit 830, so that catalytic converter 836 can operate stoichiometrically in the presence of a rich fuel mixture and, if necessary, provide additional cooling gases, so that the converted gaseous mixture 874 does not exceed a temperature which would damage turbine 804. In that case, the additional compressed air 870 would cause the gaseous 872 to not be a stoichiometric ratio, but the converted exhaust gases can be cooled to prevent damage to the turbine 804.

**[0098]** Figure 9 is a schematic illustration of another embodiment of a high efficiency spark ignition super-turbocharged engine system 900. The engine system includes an engine 902, a turbine 904, a compressor 906 and a transmission 908. Transmission 908 transfers power between the turbine/compressor shaft (not shown) and continuously variable transmission 924. Power is also transferred between the continuously variable transmission 924 and shaft 926, drive belt 928, drive pulley 930 and crank shaft 974. CVT control signal 952 operates the continuously variable transmission 924 with respect to coupling the rotational energy from the transmission 908 to crank shaft 974 at the proper rotational speed. Alternatively, continuously variable transmission 924 can be connected to an electric motor generator, as disclosed above. Further, rather than coupling power to a crank shaft 974, power can be coupled to a propulsion train of a vehicle, such as a vehicle transmission.

**[0099]** As also shown in Figure 9, compressor 906 functions to compress air from an air intake 910, which supplies compressed air 996 to conduit 964. Pressure sensor 966 generates a compressed air intake pressure signal 954 that is fed to the controller 956. Conduit 964 supplies the compressed air 996 to intercooler 970, which cools the compressed air 996. The cooled compressed air 992 is then supplied to the compressed air conduit 968, which is coupled to the intake manifold (not shown) of engine 902. The cooled compressed air 992 at the output of the intercooler 970 is also supplied to an intercooler conduit 934. Controller 956 generates an intercooler valve signal 950 that is applied to the intercooler valve 962 to control the operation of the intercooler valve 962. When the intercooler valve 962 is opened, cooled compressed air 992 is supplied by the intercooler conduit 934 to the mixing chamber 916. Openings 914 allow the cooled compressed air 992 to enter the catalytic converter output conduit 922 to cool the converted gaseous mixture 990 emitted from the catalytic converter 944. Temperature sensor 932 detects the temperature of the cooled gaseous mixture 994 and generates a gas mixture temperature signal 948 that is applied to controller 956. If the temperature of the cooled gaseous mixture 994 entering the turbine 904, as indicated by the gas mixture temperature signal 948, is too high, the intercooler valve 962 is controlled by intercooler valve signal 950 to open an additional amount to further cool the cooled gaseous mixture 994 entering the turbine 904.

**[00100]** As also shown in Figure 9, mixing valve 972 operates in response to mixing valve signal 946 to supply compressed air 996 to the mixing conduit 920. Mixing conduit 920 is coupled to the mixing chamber 978 to supply compressed air 986 from the mixing conduit 920 to the catalytic converter inlet conduit 940. The compressed air 986 in the mixing conduit 920 normally constitutes compressed air that contains oxygen. Since cooling air is supplied by intercooler conduit 936, via mixing chamber 916, to the converted exhaust gases emitted by the catalytic converter 944, compressed air 986 that is supplied to the catalytic converter inlet conduit 940 does not need to both oxidize hydrocarbons and carbon monoxide and provide cooling gases to cool the gaseous mixture 988. In other words, all of the cooling of the converted gaseous mixture 990 can be accomplished by the cooled compressed air 992. In this manner, the compressed air 986 provided by mixing conduit 920 can be for the sole purpose of creating a stoichiometric ratio of gases in the catalytic converter inlet conduit 940. In a manner similar to that disclosed above with respect to Figure 8, a data signal 982 from the vehicle computer is received by the controller 956, which indicates the ratio of the air/fuel mixture that is being applied to the combustion chambers of engine 902. Data signal 982 is used by the controller 956 to control the opening of mixing valve 972 via mixing valve signal 946. The mixing valve signal 946 opens the mixing valve 972 to allow a sufficient amount of compressed air 996 into the mixing conduit 920, which is inserted in the catalytic converter inlet conduit 940 via mixing chamber 978 and openings 980 to create a stoichiometric ratio of gases that are applied to the catalytic converter 944, in the manner described with respect to Figure 8. O<sub>2</sub> sensor 942 confirms the oxygen level of the gaseous mixture 988 and generates O<sub>2</sub> sensor signal 976 that is applied to the controller 956 to confirm that the desired oxygen level has been achieved in gaseous mixture 988 to create a stoichiometric ratio in gaseous mixture 988. Mixing valve 972 can be operated in a continuous manner in response to mixing valve signal 946 to continuously create a stoichiometric ratio in gaseous mixture 988 for the various operating conditions of the vehicle.

**[00101]** Alternatively, mixing valve 972 can operate in response to the O<sub>2</sub> sensor signal 976 to simply ensure that enough oxygen is supplied to the gaseous mixture 988 to oxidize hydrocarbons and carbon monoxide without creating a stoichiometric ratio of gaseous mixture 988 that is applied to catalytic converter 944. In that case, Equations 2 and 3 are favored with respect to Equation 1. As such, catalytic converter 944, will not function to

reduce NO<sub>x</sub> gases. For example, O<sub>2</sub> sensor 942 can generate an O<sub>2</sub> sensor signal 976, that is applied to controller 956, to indicate the oxygen level in the gaseous mixture 988 that is applied to the catalytic converter 944. In response to the O<sub>2</sub> sensor signal 976, controller 956 generates mixing valve signal 946 to control the level of oxygen in the gaseous mixture 988 that is applied to the catalytic converter 944. In this manner, additional oxygen can be supplied to ensure that there is a full oxidation of carbon monoxide and hydrocarbons without regard to reduction in NO<sub>x</sub> gases. The converted gases at the output of the catalytic converter 944 are then transmitted to the catalytic converter output conduit 922, where these gases are mixed with the cooled compressed air 996 from intercooler conduit 934. The cooled gaseous mixture 994 is channeled to the input of turbine 904, which is driven by cooled gaseous mixture 994 and which is exhausted by exhaust 912.

[00102] As further illustrated in Figure 9, the compressed air intake pressure signal 954 is applied to controller 956. Controller 956 determines if a potential surge condition may be created from the compressed air intake pressure signal 954, as well as the engine speed signal 958 and engine load signal 960. If so, either mixing valve 972 or intercooler valve 962 can be opened to avoid a surge condition. It may be preferable to open the intercooler valve 962, which would simply add additional cooling gases to the converted exhaust gases exiting the catalytic converter 944, rather than opening the mixing valve 972, since opening the mixing valve 972 may result in a non-stoichiometric ratio of gases in the catalytic converter inlet conduit 940.

[00103] Figure 10 is another embodiment of a high efficiency spark ignition super-turbocharged engine system 1000. Engine 1002 operates with a super-turbocharger that includes a turbine 1004 and a compressor 1006. Compressor 1006 compresses air from air intake 1010 and generates compressed air that is applied to conduit 1066. Pressure sensor 1068 is located in conduit 1066 to detect the pressure of the compressed air 1026 and generate a compressed air intake pressure signal 1056 that is applied to controller 1058. Controller 1058 reads the compressed air intake pressure signal 1056, as well as the engine speed signal 1060 and engine load signal 1062 to determine if a surge condition may be created. In that case, either mixing valve 1074, or intercooler valve 1064, can be opened in response to mixing valve control signal 1048, or intercooler valve control signal 1052, respectively.

[00104] Figure 10 is similar to Figure 9, in some respects, in that cooled compressed air 1008 can be applied via intercooler valve 1064 to mixing chamber 1016 and flow through openings 1014 to cool the converted gaseous mixture 1018 in the catalytic converter output conduit 1020 to produce the cooled gaseous mixture 1040, which drives turbine 1004. However, the primary source of cooling is from the compressed air 1026 in compressed air conduit 1022. Temperature sensor 1076 generates a gas mixture temperature signal 1050 that indicates the temperature of the converted gaseous mixture 1018 downstream from the mixing chamber 1016. If the temperature of the converted gaseous mixture 1018, at the input of turbine 1004, begins to increase towards a maximum temperature, such as about 950° C, the mixing valve 1074 is opened in response to the mixing valve control signal 1048, generated by controller 1058. If the mixing valve 1074 is opened completely, and the temperature of the converted gaseous mixture 1018, at the input to the turbine 1004 continues to rise, intercooler valve 1064 may be opened in response to an intercooler control valve control signal 1052 generated by controller 1058. In that case, mixing valve 1074 may be closed, or partially closed, so that cooled compressed air 1008 from intercooler 1072, that is present in intercooler conduit 1030, may be required to sufficiently cool the converted gaseous mixture 1018. Since the cooled compressed air 1008 is cooler than the compressed air 1026, the cooled compressed air 1008 may be able to sufficiently cool the converted gaseous mixture 1018, or a combination of the cooled compressed air 1008 and the compressed air 1026 may be needed to sufficiently cool the converted gaseous mixture 1018. If the controller 1058 detects that the gas temperature signal 1050 continues to rise, even though cooled compressed air 1008 and compressed air 1026 are applied to the converted gaseous mixture 1018, controller 1058 may generate a CVT control signal 1054, which will cause the compressor 1006 to be operated at a higher speed, to create more compressed air 1026 and cooled compressed air 1008. In that regard, pressure sensor 1068 creates a compressed air intake pressure signal 1056 that indicates the pressure in conduit 1066 to further determine if a sufficient amount of compressed air is present in conduit 1066. Pressure sensor 1068, as well as the pressure sensors in the other embodiments, also provides to the controller, such as controller 1058, to avoid surge conditions, as explained in more detail above.

[00105] In the embodiment illustrated in Figure 10, compressed air, such as compressed air 1026, is not applied to the input of the catalytic converter 1044. Hence, engine 1002

may be operated with a stoichiometric air/fuel ratio, or a non-stoichiometric air/fuel ratio. In any event, the catalytic converter 1044 may operate with exhaust gases that have a stoichiometric ratio, or non-stoichiometric ratio. In either case, catalytic converter 1044 will attempt to perform the reactions of Equations 1-3 to reduce pollutants in the exhaust 1012.

**[00106]** Figure 11 is another embodiment of a high efficiency spark ignition super-turbocharged engine 1100. The super-turbocharged engine system 1100 includes an engine 1102 that has a super-turbocharger that includes a turbine 1104 and a compressor 1106. Variable transmission 1132 is connected to a compressor 1130 which compresses an intake gas from cooling gas intake 1128. The intake gas normally comprises air, but may comprise other gases such as described above. Variable transmission 1132 operates in response to a transmission control signal 1152 generated by controller 1158. The variable transmission 1132 spins the compressor 1130 to create the amount of compressed air 1008 that is desired for cooling of the converted gaseous mixture 1114 and oxidation of hydrocarbons in gaseous mixture 1112. A mixing valve 1074 controls the amount of the compressed air 1108 that is supplied to the mixing chamber 1118. Openings 1116 allow the compressed air 1108 to enter the catalytic converter inlet conduit 1140 through openings 1116 to produce the gaseous mixture 1112. Gaseous mixture 1112 comprises exhaust gases from exhaust manifold 1124 and compressed air 1108. Compressed air 1108 is also fed to mixing chamber 1122. Openings 1120 allow the compressed air 1108 to flow into the catalytic converter output conduit 1150 and mix with the converted gaseous mixture 1114. An optional valve 1134 can be included to control the amount of compressed air 1108 that is supplied to the mixing chamber 1122, in response to control valve signal 1137.

**[00107]** In accordance with the embodiment of Figure 11, the amount of compressed air 1108 that is supplied by mixing valve 1126 is controlled to produce a gaseous mixture 1112 having an air/fuel ratio that has a stoichiometric ratio. In accordance with one alternative embodiment, a fuel ratio signal 1136 from the vehicle computer can be sent to controller 1158 which indicates the air/fuel ratio of the mixture that is applied to the combustion chambers of engine 1102. The fuel ratio signal 1136 is received by controller 1158, which calculates the oxygen needed to create a gaseous mixture 1112 that has a stoichiometric ratio. Controller 1158 generates a mixing valve signal 1144 in response to the fuel ratio signal 1136. Mixing valve signal 1144 is applied to the mixing valve 1126 so that the

correct amount of compressed air 1108 is inserted into the catalytic converter inlet conduit 1140 to create a gaseous mixture 1112 that has a stoichiometric ratio. O<sub>2</sub> sensor 1142 detects the oxygen content and generates an O<sub>2</sub> sensor signal 1148 that is applied to controller 1158 to ensure that the correct amount of oxygen has been inserted in the catalytic converter inlet conduit 1140 to create a stoichiometric air/fuel ratio. The catalytic converter 1146 then converts the gaseous mixture 1112 to create the converted gaseous mixture 1114 in catalytic converter output conduit 1150. Compressed air 1108 is then applied to mixing chamber 1122. The compressed air 1108 flows through openings 1120 and mixes with the converted gaseous mixture 1114 to create the cooled gaseous mixture 1160 in response to a valve control signal generated by controller 1158. An optional valve 1134 can be provided to control the amount of cooling air that is inserted in the mixing chamber 1122. However, the transmission control signal 1152 can operate the variable transmission 1132 to control the amount of compressed air 1108 that is inserted in the mixing chamber 1122 so that valve 1134 is not needed. Valve 1134 can be controlled by controller 1158 using a valve control signal (not shown). Temperature sensor 1168 detects the temperature of the cooled gaseous mixture 1160 and generates a gaseous mixture temperature signal 1154. Controller 1158 monitors the temperature of the cooled gaseous mixture 1160 and controls the operation of the variable transmission 1132 by way of transmission control signal 1152 to control the amount of compressed air 1108 that is inserted in catalytic converter output conduit 1150 to ensure that the cooled gaseous mixture 1160 does not exceed a temperature that would damage turbine 1104. Alternatively, optional valve 1134 can also be controlled by the controller 1158 to control the amount of compressed air 1108 that is inserted into the catalytic converter output conduit 1150. The cooled gaseous mixture 1160 is then inserted in turbine 1104. Turbine 1104 is driven by the cooled gaseous mixture 1160, which, in turn, drives the compressor 1106.

**[00108]** Figure 12 illustrates another embodiment of a high efficiency spark ignition super-turbocharged engine system 1200. The super-turbocharged engine system 1200 includes an engine 1202. Engine 1202 is coupled to a super turbocharger that includes a turbine 1210 and a compressor 1204. Compressor 1204 compresses intake air supplied by air intake 1208 to generate compressed air 1248 in conduit 1228. Intercooler 1232 cools the compressed air 1248 and generates cooled compressed air 1250 in compressed air conduit 1230 that is applied to the intake manifold of engine 1202.

**[00109]** As also shown in Figure 12, exhaust gases 1242 from exhaust manifold 1234 are inserted into the catalytic converter inlet conduit 1220. The catalytic converter 1222 converts the exhaust gases 1242 to generate converted exhaust gases 1244 in the catalytic converter output conduit 1224. Feedback valve 1226 is mounted in conduit 1228. Conduit 1228 is connected to catalytic converter output conduit 1224. When feedback valve 1226 is open, in response to a control signal, cooling air 1246 from the conduit 1228 mixes with the converted exhaust gases 1244. Conduit length 1240 is sufficient to allow substantial mixing of converted exhaust gases 1244 and the cooling air 1246 so that the cooled gaseous mixture 1212 is mixed and cooled prior to entering the turbine 1210. The engine 1202 can operate with either a stoichiometric air/fuel ratio or a non-stoichiometric air/fuel ratio, such as a rich fuel ratio. When the engine 1202 operates with a stoichiometric air/fuel ratio, catalytic converter 1222 performs the chemical reactions of equations 1-3 to substantially reduce pollutants and the converted exhaust gases 1244. When a non-stoichiometric ratio, such as a rich ratio is used, the catalytic converter 1222 is not as effective as hydrocarbons and carbon monoxide in the exhaust gas are not fully oxidized by the catalytic converter 1222. However, cooling air 1246 reduces the temperature of the converted exhaust gases 1244 prior to entering the turbine 1210. In that regard, during an open throttle condition for a vehicle in which engine 1202 is mounted, a rich fuel mixture is used in engine 1202. This creates higher levels of hydro carbons and carbon monoxide in the exhaust gases 1242 that are converted by catalytic converter 1222. Cooling air 1246 ensures that the temperature of the cooled gaseous mixture 1212 does not exceed a temperature which would cause damage to turbine 1210.

**[00110]** Figure 13 is a schematic illustration of another embodiment of a high efficiency spark ignition super-turbocharged engine system 1300. The super-turbocharged engine system 1300 includes an engine 1302 having a super-turbocharger that includes a turbine 1304 and a compressor 1306. Compressor 1306 compresses air from the air intake 1310 to generate compressed air 1320 in conduit 1350. Compressed air 1320 flows through intercooler 1352 which cools the compressed air to create cooled compressed air 1338 in compressed air conduit 1354. The cooled compressed air 1338 in compressed air conduit 1354 is applied to the intake manifold (not shown) of the engine 1302. Exhaust gases 1316 are emitted by the exhaust manifold 1362 and flow through conduit 1330. Feedback valve 1336 allows the compressed air 1320 to flow to mixing chamber 1360. Openings 1358

allow the compressed air 1320 to flow into the catalytic converter output conduit 1364. Temperature sensor 1366 generates a gas mixture temperature signal 1332 that is applied to controller 1346. Controller 1346 generates a controller feedback valve signal 1334 that is applied to the feedback valve 1336 to controller the temperature of the cooled gaseous mixture 1314 detected by temperature sensor 1366. The temperature of the cooled gaseous mixture 1314 is maintained below a maximum temperature that would damage turbine 1304.

[00111] Figure 14 is a schematic illustration of a high efficiency spark ignition super-turbocharged engine system 1400. The super-turbocharged engine system 1400 includes an engine 1402 that is equipped with a super-turbocharger. The super-turbocharger includes a turbine 1404 and a compressor 1406. Compressor 1406 compresses intake air provided by air intake 1410 to provide compressed air 1484 in conduit 1462. Intercooler 1466 cools the compressed air 1484 to create cooled compressed air 1486 in compressed air conduit 1464. The cooled compressed air 1486 is applied to the intake manifold (not shown) of the engine 1402.

[00112] As also illustrated in Figure 14, a variable transmission or electric motor 1426 is operated under the control of compressor power control signal 1450 that is generated by controller 1456. The variable transmission or electric motor 1426 is operated by power source 1424. The power source 1424 can be an electrical power source that operates an electric motor 1426 or a mechanical power source that operates a variable transmission 1426. Compressor 1428 is coupled to the variable transmission or electric motor 1426 and generates compressed cooling gas 1432. The compressor 1428 generates the compressed cooling gas 1432 from the gas provided at the cooling gas intake 1430. In general, the cooling gas comprises of fresh air but can comprise any of the other gases described above. The compressed cooling gas is supplied to the mixing chamber 1416. The mixing chamber 1416 has openings 1414 that allow the compressed cooling gas 1432 to flow into the catalytic converter inlet conduit 1440, and mix with exhaust gases from exhaust manifold 1422, to produce a gaseous mixture 1434. In addition, the compressed cooling gas 1432 is supplied to mixing chamber 1420. Mixing chamber 1420 has openings 1418 in catalytic converter output conduit 1448 that allows the converted gaseous mixture 1480 to flow into the catalytic converter output conduit 1448 to produce cooled gaseous mixture 1482. The cooled gaseous mixture is supplied to turbine 1404, to drive turbine 1404, and is exhausted

from exhaust outlet 1412. If the engine 1402 is running rich, the compressor 1428 can provide additional oxygen in the form of the compressed cooling gas 1432 that is applied to the mixing chamber 1416 to create a stoichiometric ratio of the gaseous mixture 1434. The stoichiometric ratio of the gaseous mixture 1434 can be produced in catalytic converter inlet conduit 1440 by adjusting the operation of variable transmission or electric motor 1426 in response to compressor power control signal 1450 that is provided by controller 1456. Controller 1456 controls the variable transmission or electric motor 1426 via compressor power control signal 1450 to supply more or less compressed cooling gas 1432 to the catalytic converter inlet conduit 1440. Also, oxygen sensor 1442 monitors the oxygen level in the catalytic converter inlet conduit 1440 and generates an O<sub>2</sub> sensor signal 1446 that provides controller 1456 with a signal indicating the oxygen level present in the catalytic converter inlet conduit 1440. The controller 1456 can also control the oxygen level in the catalytic converter inlet conduit 1440 by controlling the amount of compressed cooling gas 1432 that is supplied to mixing chamber 1416 by controlling the operation of variable transmission or electric motor thorough the use of O<sub>2</sub> sensor signal 1446. Alternatively, a data signal 1408 can be supplied from the vehicle computer that indicates the air/fuel ratio of the gaseous mixture that is being applied to the combustion chamber of engine 1402. Controller 1456 then generates the compressor power control signal 1450 in response to the data signal 1408. Temperature sensor 1468 generates a gas mixture temperature signal 1452 that is also applied to controller 1456. Again, the variable transmission electric motor 1426 can be adjusted by the controller 1456 which generates a compressor power control signal 1450 in response to the gas mixture temperature signal 1452 to ensure that the temperature of the cooled gaseous mixture 1482 does not exceed a maximum temperature that could damage turbine 1404.

[00113] Figure 15A illustrates another embodiment of a high efficiency spark ignition super-turbocharged engine system 1500. The super-turbocharged engine system 1500 includes an engine 1502 that is equipped with a super-turbocharger. The super-turbocharger includes a turbine 1504 and a compressor 1506. Compressor 1506 compresses intake air from air intake 1510 to create compressed air 1548 in conduit 1514. Intercooler 1518 cools the compressed air 1548 to create cooled compressed air 1550 in compressed air conduit 1516, that is applied to the intake manifold (not shown) of the engine 1502.

[00114] As also illustrated in Figure 15A, a variable transmission or electric motor 1550 is operated in response to a compressor power control signal 1519 generated by controller 1527. A compressor 1526 is coupled to the variable transmission or electric motor 1520 and compresses a cooling gas supplied by cooling gas intake 1528. The cooling gas may comprise fresh air or other gases described above. The compressed gas 1522 produced by compressor 1526 is supplied to conduit 1562. The compressed gas is channeled through conduit 1562 to balance valve 1560. Balance valve is operated in response to balance valve signal 1592 that is generated by controller 1527. The compressed gas 1522 is applied to the mixing chamber 1578 and flows into the NO<sub>x</sub> converter inlet conduit 1588 through openings 1580 to create gaseous mixture 1524. Gaseous mixture 1524 is a mixture of the compressed gas 1522 and exhaust gases from exhaust manifold 1576. O<sub>2</sub> sensor 1590 monitors the oxygen level of the gaseous mixture 1524 and generates an O<sub>2</sub> sensor signal 1596 that is applied to controller 1527. Controller 1527 controls the operation of the balance valve 1560 via balance valve signal 1592 to supply more or less compressed gas 1522 to the NO<sub>x</sub> converter inlet conduit 1588. The NO<sub>x</sub> converter 1594 functions to reduce the NO<sub>x</sub> gases in accordance with Equation 1 above. Hydrocarbon/carbon monoxide converter 1572 functions to oxidize hydrocarbons and carbon monoxide in the NO<sub>x</sub> converted gaseous mixture 1541 that exits the NO<sub>x</sub> converter 1594. In other words, the reduction of pollutants occurs in two stages. NO<sub>x</sub> converter 1594 converts NO<sub>x</sub> gases. The NO<sub>x</sub> converted gaseous mixture 1541 is then applied to the hydrocarbon/carbon monoxide converter 1572 which oxidizes hydrocarbons and carbon monoxide in the NO<sub>x</sub> converted gaseous mixture 1541. From Equation 1, it is understood that NO<sub>x</sub> gases are reduced when the fuel ratio is rich. From Equations 2 and 3 above, additional oxygen allows the hydrocarbon/carbon monoxide converter 1572 to fully oxidize the hydrocarbons and carbon monoxide. If a very rich mixture, such as 30% over rich mixture, is combusted by engine 1502, the exhaust gases from exhaust manifold 1576 may be extremely rich with hydrocarbons and carbon monoxide. Combusting all of the hydrocarbons and carbon monoxide in hydrocarbon/carbon monoxide converter 1572 may cause the hydrocarbon/carbon monoxide converter 1572 to overheat. In that regard, oxygen can be supplied from the compressed gas 1522 via balance valve 1560 to combust some of the hydrocarbons in converter 1594, which may comprise the three-way catalytic converter that is capable of oxidizing hydrocarbons and carbon monoxide. In this manner, the existence of

hydrocarbon and carbon monoxide in the NO<sub>x</sub> converted gaseous mixture 1541 is somewhat reduced so that the hydrocarbon/carbon monoxide converter 1572 does not have to oxidize all of the hydrocarbons and carbon monoxide and, as such, may avoid overheating. O<sub>2</sub> sensor 1590 provides an O<sub>2</sub> sensor signal 1596 to the controller 1527 to monitor the addition of oxygen by way of compressed gas 1522 to the NO<sub>x</sub> converter inlet conduit 1588.

[00115] As also illustrated in Figure 15A, conduit 1562 is connected to conduit 1582 which supplies the compressed gas 1522 to a mixing chamber 1570 when valve 1584 is open. Compressed gas 1522 flows through the openings 1574 to create gaseous mixture 1543. Valve 1584 operates in response to the control valve signal 1537 which is generated by controller 1527. O<sub>2</sub> sensor 1586 monitors the oxygen level in the NO<sub>x</sub> converted gas mixture 1541 and generates an O<sub>2</sub> sensor signal 1525 that is applied to controller 1527. Controller 1527 opens the valve 1584 by way of control valve signal 1537 to add compressed gas 1522 through openings 1574 to the NO<sub>x</sub> converted gaseous mixture 1541 to ensure that there is sufficient oxygen in the gaseous mixture 1543 that is entering the hydrocarbon/carbon monoxide converter 1572 to fully combust all of the hydrocarbons and carbon monoxide. It is not necessary to create a stoichiometric ratio in the gaseous mixture 1543 since NO<sub>x</sub> gases have been converted in NO<sub>x</sub> converter 1594. Temperature sensor 1533 monitors the temperature of the oxidized gaseous mixture 1545 exiting the hydrocarbon/carbon monoxide converter 1572 and generates a gaseous mixture temperature signal 1521 that is applied to controller 1527. Controller 1527 utilizes the gas mixture temperature signal 1521 to generate a control valve signal 1535 that controls the operation of valve 1566 that is disposed in conduit 1564. Valve 1566 allows compressed gas 1522 to flow into mixing chamber 1568 and through openings 1575 to mix with the oxidized gaseous mixture 1545 to cool the oxidized gaseous mixture 1545. The cooled gaseous mixture 1547 is then applied to turbine 1504. The operation of valve 1566 ensures that the cooled gaseous mixture 1547 does not exceed a temperature which would damage turbine 1504.

[00116] The advantage of super-turbocharged engine system 1500, illustrated in Figure 15A, is that the engine can be allowed to run rich without creating any additional pollution. By allowing the engine 1502 to run rich, the liquid fuel in the engine assists in cooling the internal engine parts which increases the longevity of engine 1502. Also, NO<sub>x</sub> converter

1594 operates more efficiently with a rich fuel mixture. Further, the rich fuel mixture is fully oxidized in hydrocarbon/carbon monoxide converter 1572 so that hydrocarbons and carbon monoxide are not present in exhaust 1512. Further, rich running engines are normally considered to be less efficient because of the wasted fuel in the exhaust. However, the heat generated by the oxidation of the hydrocarbons and carbon monoxide in hydrocarbon/carbon monoxide converter 1572 is at least partially retrieved by operating the turbine 1504 with the oxidized gaseous mixture 1545. This additional heat generated in the oxidized gaseous mixture 1545 drives the turbine 1504 in a manner that allows a large portion of the energy from the rich fuel mixture to be retrieved. Valve 1566 is operated so that the temperature of the cooled gaseous mixture 1547 is in the range of 900 °C -950° C which is just below the temperature of which the turbine 1504 could be damaged. In addition, the engine 1502 creates additional horsepower when run on a rich fuel mixture which also adds to the efficiency of the super-turbocharged engine system 1500. Hence, the super-turbocharged engine system 1500, illustrated in Figure 15A, increases the output horsepower of the engine 1502, does not create any pollutants and is capable of retrieving what would otherwise be a wasted heat in the cooled gaseous mixture 1597 to operate the turbine 1504. In addition, internal engine parts of engine 1502 run cooler since the rich fuel mixture functions to cool the engine parts and the NO<sub>x</sub> converter 1594 is more effective.

[00117] To further simplify the operation of the engine system 1500, the addition of compressed gas 1522 to the NO<sub>x</sub> converter inlet conduit 1588 can be eliminated. Part of the reason for adding compressed gas 1522 to the gaseous mixture 1524 is to partially oxidize the rich fuel mixture in the NO<sub>x</sub> converter 1594 which may function as a three-way converter, rather than just simply NO<sub>x</sub> converter. As indicated above, the reason for partially oxidizing the rich fuel mixture is to prevent the hydrocarbon/carbon monoxide converter 1572 from overheating because of the large amount of hydrocarbons and carbon monoxide in the NO<sub>x</sub> converted gaseous mixture 1541. However, an additional amount of compressed gas 1522 can be added to the NO<sub>x</sub> converted gaseous mixture 1541 in the NO<sub>x</sub> converter output conduit 1598 which is beyond the amount that is required to fully oxidize the hydrocarbons and carbon monoxide. In other words, an additional amount of the compressed gas 1522 can be inserted in the NO<sub>x</sub> converter output conduit 1598 to not only oxidize all the hydrocarbons and carbon monoxide in the hydrocarbon/carbon monoxide converter 1572 but also provide cooling gases to reduce the operating temperature of the

hydrocarbon/carbon monoxide converter 1572. In this manner, the compressed gas 1522 supplied by the mixing chamber 1570 can be supplied in an amount that will prevent the hydrocarbon/carbon monoxide converter 1572 from overheating. The gas mixture temperature signal 1521 supplies temperature data at the output of the hydrocarbon/carbon monoxide converter 1572 to controller 1527 so that the controller 1527 can operate valve 1584 via control valve signal 1537 to prevent the hydrocarbon/carbon monoxide converter 1572 from overheating, while still maintaining a suitable operating temperature for operation of the hydrocarbon/carbon monoxide converter 1572. In this manner, balance valve 1560 can be eliminated.

**[00118]** Figure 15B is a schematic illustration of a modification of the high efficiency spark ignition super-turbocharged engine system 1500 of Figure 15A. As shown in Figure 15B, a single conduit 1582 is used to supply compressed air 1522 for the purpose of both providing oxygen to the hydrocarbon/carbon monoxide converter 1572 and providing cooling gas. In comparison with Figure 15A, mixing chamber 1578 and balance valve 1560 have been removed as well as conduit 1564, valve 1566 and mixing chamber 1568. Conduit 1582 and valve 1584 can supply the oxygen necessary for the hydrocarbon/carbon monoxide converter 1572 to fully oxidize all of the hydrocarbons and carbon monoxide that exist in the NO<sub>x</sub> converted gaseous mixture 1541. Further, additional compressed air 1522 can be added to the NO<sub>x</sub> converted gaseous mixture 1541 to cool the oxidized gaseous mixture 1545 to maintain the temperature of the oxidized gaseous mixture 1545 below a maximum temperature that would cause damage to turbine 1504. Temperature sensor 1533 produces a gas mixture temperature signal 1521 that is sent to the controller 1527. The controller can simply monitor the temperature of the oxidized gaseous mixture 1545 and control the valve 1584 using control valve signal 1537 to ensure that a sufficient amount of compressed gas 1522 is supplied to the NO<sub>x</sub> converter output conduit 1598 to maintain the temperature of the oxidized gaseous mixture 1545 below a temperature that would damage turbine 1504. However, a sufficient amount of oxygen must be supplied to the NO<sub>x</sub> converted gaseous mixture 1541 to ensure that all of the hydrocarbons and carbon monoxide are oxidized in the hydrocarbon/carbon monoxide converter 1572. For example, during cold start conditions, the NO<sub>x</sub> converted gaseous mixture 1541 is relatively cool and does not need additional compressed gas 1522 for cooling. However, additional compressed gas 1522 is needed to initiate and assist the catalyst in hydrocarbon/carbon monoxide converter

1572 in performing the oxidation process of hydrocarbons and carbon monoxide. In that regard, O<sub>2</sub> sensor 1586 monitors the oxygen level in the NO<sub>x</sub> converted gaseous mixture 1541 and generates an O<sub>2</sub> sensor signal 1525 that is sent to the controller 1527 indicating the oxygen levels present in the NO<sub>x</sub> converted gaseous mixture 1541. If additional oxygen is needed in the gaseous mixture 1543 entering the hydrocarbon/carbon monoxide converter 1572 to ensure full oxidation of all of the hydrocarbons and carbon monoxide that exists in the NO<sub>x</sub> converted gaseous mixture 1541, controller 1527 can open valve 1584 to ensure that a sufficient amount of compressed air 1522 is supplied to the NO<sub>x</sub> converter output conduit 1598 to fully oxidize the hydrocarbons and carbon monoxide.

[00119] Further, valve 1584 is not necessary if the variable transmission 1520 that operates compressor 1526 is controlled by controller 1527 via compressor power control signal 1519 to supply the desired amount of compressed gas 1522 in response to the O<sub>2</sub> sensor signal 1525 and the gas mixture temperature signal 1521. Alternatively, compressor 1526 can be run at a constant speed so that a sufficient amount of compressed gas 1522 can be supplied to both oxidize and cool the NO<sub>x</sub> converted gaseous mixture 1541 either without any control or by simply controlling valve 1584. If the system is run without valve 1584, compressor 1526 simply supplies a set amount of compressed gas 1522, which ensures both full oxidation and enough compressed gas 1522 to cool the gaseous mixture 1543 under all operating conditions. The only disadvantage in such a system is that the temperature of the hydrocarbon/carbon monoxide converter 1572 may be lowered and not operate as efficiently as the hydrocarbon/carbon monoxide converter 1572 could operate at a higher temperature. Further, the additional mass flow of air, under many conditions, will lower the temperature of the cooled gaseous mixture 1547 so that the turbine 1504 would not operate as efficiently as turbine 1504 would operate when the cooled gaseous mixture 1547 is near the maximum temperature that would otherwise cause damage to turbine 1504. Compressor 1526 can also be operated using an electric motor that is powered by the electrical system of the super-turbocharged engine system 1500. An electric motor 1520 can also be controlled by controller 1527 to supply the correct amount of compressed gas 1522 so that valve 1584 is not required.

[00120] The super-turbocharged engine system 1500 illustrated in Figures 15A and 15B, as well as the other embodiments disclosed herein, are unique in that they use compressed gas such as compressed gas 1522 as a coolant. Compressed gases are not normally

considered to be an effective coolant since the properties of compressed gases are not especially effective as a coolant. Liquids such as water or liquid fuel are normally considered to be effective coolants. However, the use of a compressed gas provides the oxygen and a cooling medium for cooling the hot exhaust gases. Although a large amount of compressed air is needed for cooling, the additional mass flow is used to run the turbine 1504 at higher power levels. In addition, the turbine 1504 is kept from over speeding by transmitting the additional power back to either the crankshaft of the engine or to the propulsion train of a vehicle.

[00121] Figure 16 is a schematic illustration of another embodiment of a high efficiency spark ignition super-turbocharged engine system 1600. As shown in Figure 16, the super-turbocharged engine system 1600 includes an engine having a super-turbocharger. The super-turbocharger includes a turbine 1604 and a compressor 1606. Compressor 1606 compresses air supplied by air intake 1610 to produce the compressed air 1674 in conduit 1616. Intercooler 1618 cools the compressed air to produce cooled compressed air 1622 in compressed air conduit 1620, which is supplied to the intake manifold (not shown) of engine 1602. Feedback valve 1664 is mounted in the conduit 1616 and supplies compressed air 1674 to the mixing chamber 1640. Openings 1638 allows the compressed air 1674 to flow into the NO<sub>x</sub> converter output conduit 1682 to mix with the NO<sub>x</sub> converted gaseous mixture 1632. Exhaust gases from exhaust manifold 1644 flow into the NO<sub>x</sub> converter in the NO<sub>x</sub> converter inlet conduit 1646. NO<sub>x</sub> converter 1648 converts the exhaust gases to reduce NO<sub>x</sub> gases and supplies the NO<sub>x</sub> converted gaseous mixture 1632 to the NO<sub>x</sub> converter output conduit 1682. Gaseous mixture 1630 flows into the NO<sub>x</sub> converter 1648 which converts the NO<sub>x</sub> gases. The NO<sub>x</sub> converted gaseous mixture 1632 then flows into NO<sub>x</sub> converter output conduit 1682. Oxygen sensor 1666 monitors the oxygen level of the NO<sub>x</sub> converted gaseous mixture 1632 and generates O<sub>2</sub> sensor signal 1668 that is sent to controller 1680. Controller 1680 generates a controller mixing valve signal 1660 to operate the feedback valve 1664 to supply compressed air 1674 to the NO<sub>x</sub> converter output conduit 1682 to be mixed with the NO<sub>x</sub> converted gaseous mixture 1632. The compressed air 1674 that is supplied to the NO<sub>x</sub> converter output conduit 1682 by feedback valve 1664 provides oxygen as well as cooling gases that are mixed with the NO<sub>x</sub> converted gaseous mixture 1632 to create the cooled gaseous mixture 1636. The cooled gaseous mixture 1636 flows into the hydrocarbon/carbon monoxide converter 1686 which oxidizes the hydrocarbons and

carbon monoxide present in the cooled gaseous mixture 1636. Temperature sensor 1684 monitors the temperature of the hydrocarbon/carbon monoxide converted gaseous mixture 1634 exiting the hydrocarbon/carbon monoxide converter 1686 and generates a gaseous mixture temperature signal 1662 that is supplied to controller 1680. Controller 1680, in response, generates a controller mixing valve signal 1660 that controls the feedback valve 1664 to supply additional compressed air 1674 to the cooled gaseous mixture 1636 if the temperature of the gaseous mixture at the output of the hydrocarbon/carbon monoxide converter 1686 is approaching a temperature that would damage turbine 1604. The hydrocarbon/carbon monoxide converted gaseous mixture 1634 is supplied to turbine 1604, to drive turbine 1604. The hydrocarbon/carbon monoxide converted gaseous mixture 1634 is then exhausted from turbine 1604 via exhaust 1612. O<sub>2</sub> sensor 1666 also monitors the oxygen level in the NO<sub>x</sub> converted gaseous mixture 1632 and generates the O<sub>2</sub> sensor signal 1668 which is fed to controller 1680. The controller 1680 also uses the O<sub>2</sub> sensor signal 1668 to control the feedback valve 1664 by way of controller mixing valve signal 1660 to ensure that there is sufficient oxygen present in the cooled gaseous mixture 1636 to fully oxidize the hydrocarbons and carbon monoxide that are present in the NO<sub>x</sub> converted gaseous mixture 1632. Hence, controller 1680 functions to control the feedback valve 1664 to provide both enough oxygen to ensure complete oxidation of hydrocarbons and carbon monoxide in hydrocarbon/carbon monoxide converter 1686 and enough cooling gases to cool the cooled gaseous mixture 1636 so that damage does not occur to turbine 1604. In this manner, the hydrocarbon/carbon monoxide converted gaseous mixture 1634 maintains a temperature that does not damage turbine 1604 while all of the hydrocarbons and carbon monoxide have been oxidized in hydrocarbon/carbon monoxide converter 1686.

**[00122]** Figure 16 also illustrates an optional conduit 1642 having a mixing valve 1624. Mixing valve 1624 is operated by controller 1680 through the use of controller feedback valve signal 1670. As illustrated in Figure 16, compressed air 1626 can optionally be provided to mixing chamber 1628 to add oxygen and cooling gases to the gaseous mixture 1630 rather than, or in addition to, the compressed air 1674 added in mixing chamber 1640. In this manner, an additional amount of compressed air 1626 can be added for both cooling and oxidation of hydrocarbons and carbon monoxide in hydrocarbon/carbon monoxide converter 1686. In that regard, conduit 1642 simply shows an alternative location for adding compressed gas. Alternatively, NO<sub>x</sub> converter 1648 may comprise a three-way

converter. In that case, compressed air 1626 supplies a certain amount of oxygen that would allow oxidation of some of the hydrocarbons and carbon monoxide in a three-way converter 1648 so that all of the hydrocarbons and carbon monoxide do not necessarily have to be oxidized in hydrocarbon/carbon monoxide converter 1686. For example, if the gaseous mixture 1630 is a very rich fuel mixture, such as a fuel mixture that is 30 percent over rich, a large amount of hydrocarbons and carbon monoxide must be oxidized. In that case, hydrocarbon/carbon monoxide converter 1686 could overheat and a sufficient amount of compressed air 1674 may not be able to provide enough cooling to lower the temperature of the hydrocarbon/carbon monoxide converted gaseous mixture 1634 to a temperature that would prevent turbine 1604 from being damaged. In this case, part of the hydrocarbons and carbon monoxide are oxidized in a three-way converter 1648 so that all of the oxidation does not have to occur in hydrocarbon/carbon monoxide converter 1686.

**[00123]** Figure 17 is a schematic illustration of a high efficiency spark ignition super-turbocharged engine system 1700. The super-turbocharged engine system 1700 includes an engine 1702 that has a super-turbocharger. The super-turbocharger includes a turbine 1704 and a compressor 1706. Super-turbocharged engine system 1700 is similar to the super-turbocharged engine system 1600 of Figure 16 with the conduit 1642, mixing valve 1624 and mixing chamber 1628 removed. As illustrated in Figure 17, compressor 1706 generates a source of compressed air 1766 from air supplied by air intake 1712. Compressed air 1766 is supplied to conduit 1778. Compressed air 1766 flows through intercooler 1730 which cools the compressed air 1766 to create cooled compressed air 1764 in compressed air conduit 1732 which is coupled to the intake manifold (not shown) of engine 1702. Exhaust gases 1714 emitted by exhaust manifold 1744 flow into NO<sub>x</sub> converter inlet conduit 1746. Exhaust gases 1714 then flow from NO<sub>x</sub> converter inlet conduit 1746 into NO<sub>x</sub> converter 1748, which converts the NO<sub>x</sub> gases to produce NO<sub>x</sub> converted exhaust gases 1716 in NO<sub>x</sub> converter output conduit 1742. Engine 1702 can be allowed to run rich during open throttle conditions and other rich running conditions, which allows the NO<sub>x</sub> converter 1748 to operate effectively and allow the engine 1702 to generate a smaller amount of NO<sub>x</sub> gases in the combustion chambers of engine 1702. Oxygen sensor 1750 monitors the oxygen level of the NO<sub>x</sub> converted exhaust gases 1716 and generates an O<sub>2</sub> sensor signal 1752 that is fed to the controller 1770 that indicates the amount of oxygen present in the NO<sub>x</sub> converted exhaust gases 1716. A sufficient amount of oxygen must be supplied to the NO<sub>x</sub> converted

exhaust gases 1716 to ensure that all of the hydrocarbons and carbon monoxide are oxidized in the hydrocarbon/carbon monoxide converter 1738. Controller 1770 generates a controller feedback valve signal 1760 that controls the amount of compressed air 1766 that is applied to mixing chamber 1736. The compressed air 1766 flows through the openings 1734 and mixes with the NO<sub>x</sub> converted exhaust gases 1716 to create a cooled gaseous mixture 1720. Temperature sensor 1740 monitors the temperature of the hydrocarbon/carbon monoxide converted gaseous mixture 1722 at the output of the hydrocarbon/carbon monoxide converter 1738 and generates a gas mixture temperature signal 1756 that is applied to controller 1770. Controller 1770 reads the gaseous mixture temperature signal 1756 and controls the feedback valve 1758 via controller feedback valve signal 1760 to open and close the feedback valve 1758 to maintain the temperature of the hydrocarbon/carbon monoxide converted gaseous mixture 1722 at a temperature that does not cause damage to turbine 1704. As pointed out above, temperatures in the range of 900 °C to 950 °C, which is just below the temperature at which damage could be caused to turbine 1704, allow for high extraction of energy by turbine 1704 from the hydrocarbon/carbon monoxide converted gaseous mixture 1722. The hydrocarbon/carbon monoxide converted gaseous mixture 1722 is supplied to turbine 1704 to drive turbine 1704. The hydrocarbon/carbon monoxide gaseous mixture 1722 is then exhausted from turbine 1704 via exhaust 1710.

[00124] Figure 18 is a sectional view of an embodiment of dual catalytic converter 1800. As shown in Figure 18, the dual catalytic converter 1800 has an inlet 1802 in which gaseous mixtures, such as exhaust gases that include nitrogen oxide, carbon monoxide and hydrocarbons, are inserted in the initial stage of the dual catalytic converter 1800, which comprises the NO<sub>x</sub> converter section 1804. The NO<sub>x</sub> converter 1804 initially reduces the NO<sub>x</sub> gases in the gaseous mixture that is applied to the catalytic converter 1800. Fresh air is supplied by one of the compressors illustrated in the various embodiments disclosed above to valve 1814 which controls the amount of air that is supplied to conduit 1812. Conduit 1812 is connected to mixing chamber 1806 which mixes the NO<sub>x</sub> converted gases, from NO<sub>x</sub> converter section 1804, with the fresh air. The fresh air contains a sufficient amount of oxygen to cause the hydrocarbons and carbon monoxide to be oxidized in the hydrocarbon/carbon monoxide converter section 1808. The converted gases then flow out of outlet 1810.

[00125] The advantage of the catalytic converter 1800, illustrated in Figure 18, is that a stoichiometric mixture of gases does not have to be provided to inlet 1802. In fact, a rich fuel gaseous mixture assists in allowing the NO<sub>x</sub> converter section 1804 to operate more effectively. The addition of oxygen to the mixing chamber 1806 allows nearly complete oxidation of the hydrocarbons and carbon monoxide in the hydrocarbon/carbon monoxide converter 1808. In this manner, the converted gases at outlet 1810 are extremely low in pollutants. The dual catalytic converter 1800 is normally not operated in a fashion in which a rich fuel mixture is inserted at the inlet 1802 since the heat created in the oxidation of a rich fuel mixture is normally not recoverable. However, the use of a dual catalytic converter 1800 allows for recapture of the heat generated in the hydrocarbon/carbon monoxide converter section 1808 since the hot exhaust gases are cooled to a nearly optimal temperature, with increased mass flow in the turbine which recaptures the heat energy. In other words, the dual catalytic converter 1800 as well as the two converters 1748, 1738 illustrated in Figure 17 and the two converters 1648, 1686, illustrated in Figure 16, allow for effective reduction in pollutants, while not reducing the efficiency of the engine systems, since the heat generated is recaptured in the increased temperatures and increased mass flow of the exhaust gases entering the turbines. Further, the ability to use a rich fuel mixture to run an engine allows for the internal parts of the engine to be cooled by the fuel which increases the longevity of the engine. Moreover, the rich fuel mixture, which initially is applied to a NO<sub>x</sub> converter, allows the NO<sub>x</sub> converter to work better. The ability to add additional oxygen to the hydrocarbon/carbon monoxide converter, rather than a stoichiometric mixture, allows for full oxidation of hydrocarbons and carbon monoxide so that the exhaust has lower pollutants than standard three-way catalytic converters. Of course, the dual catalytic converter 1800 can be utilized in the embodiments of Figures 15A, 15B, 16 and 17.

[00126] The foregoing description of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed, and other modifications and variations may be possible in light of the above teachings. The embodiment was chosen and described in order to best explain the principles of the invention and its practical application to thereby enable others skilled in the art to best utilize the invention in various embodiments and various modifications as are suited to the particular use contemplated. It is intended that the appended claims be

construed to include other alternative embodiments of the invention except insofar as limited by the prior art.

## CLAIMS

### WHAT IS CLAIMED IS:

1. A method of improving performance of an engine system having a super turbocharger, said engine system having an engine that operates with a rich fuel mixture comprising:
  - generating an amount of compressed air from a compressor in response to a control signal;
  - mixing said amount of said compressed air with exhaust gases from said engine to produce a gaseous mixture of said exhaust gases and said compressed air;
  - supplying said gaseous mixture to a catalytic converter;
  - detecting oxygen levels of said gaseous mixture that enter said catalytic converter;
  - detecting said temperature levels of said gaseous mixture exiting said catalytic converter;
  - adjusting said amount of compressed air, in response to said oxygen levels, to provide a sufficient amount of said compressed air to substantially oxidize hydrocarbons and carbon monoxide present in said gaseous mixture in said catalytic converter, while maintaining a predetermined substantially optimal temperature level of said gaseous mixture;
  - supplying said gaseous mixture to a turbine of said super-turbocharger to drive said super-turbocharger.
2. The method of claim 1 wherein said predetermined substantially optimal temperature level is a temperature level that will not damage said turbine.

3. The method of claim 1 wherein said predetermined substantially optimal temperature level is approximately 950° C.
4. The method of claim 1 wherein said compressor is a compressor used by said superturbocharger.
5. The method of claim 1 wherein said compressor is an additional electrically driven compressor.
6. The method of claim 1 wherein said compressor is an additional mechanically driven compressor that is mechanically coupled to said super-turbocharger.
7. An engine system that operates with a rich fuel mixture comprising:
  - a super-turbocharger having a turbine and a compressor;
  - an additional compressor that supplies an amount of compressed air in response to a control signal;
  - a mixing chamber that mixes exhaust gases from said engine system with said amount of compressed air to produce a gaseous mixture of said exhaust gases and said compressed air;
  - a catalytic converter coupled to said mixing chamber that receives said gaseous mixture;
  - an oxygen sensor that senses oxygen levels of said gaseous mixture entering said catalytic converter and generates an oxygen sensor signal;
  - a temperature sensor that senses said temperature levels of said gaseous mixture exiting said catalytic converter and generates a temperature sensor signal;
  - a controller that generates said control signal in response to said oxygen sensor signal and said temperature sensor signal so that said amount of compressed air supplied by said additional compressor to said catalytic converter is sufficient for

said catalytic converter to substantially oxidize hydrocarbons and carbon monoxide in said gaseous mixture while maintaining a predetermined substantially optimal temperature level of said gaseous mixture exiting said catalytic converter;

supplying said gaseous mixture to said turbine to drive said super-turbocharger.

8. The engine system of claim 7 wherein said predetermined substantially optimal temperature level is a temperature level that is less than a temperature that will damage said turbine.

9. The engine system of claim 7 wherein said predetermined substantially optimal temperature level is approximately 950° C.

10. The engine system of claim 7 wherein said predetermined substantially optimal temperature level is within approximately 100° C less than a temperature level that would damage said turbine.

11. The engine system of claim 7 wherein said additional compressor is an electrically driven compressor.

12. The engine system of claim 7 wherein said additional compressor is a mechanically driven compressor that has a variable transmission that is mechanically coupled to said turbine and is controlled by said controller.

13. The engine system of claim 8 wherein said additional compressor is an electrically driven compressor.

14. The engine system of claim 8 wherein said additional compressor is a mechanically driven compressor that has a variable transmission that is mechanically coupled to said turbine and is controlled by said controller.

15. A method of improving performance of an engine system having a super-turbocharger comprising:

providing a catalytic converter that receives exhaust gases from said engine system and produces an exothermic reaction that adds heat to said exhaust gases to generate converted hot exhaust gases at an output of said catalytic converter;

providing compressed air from a compressor;

mixing a portion of said compressed air with said converted hot exhaust gases from said catalytic converter to create a gaseous mixture having a temperature that does not exceed a predetermined maximum temperature so as to prevent damage to said turbine of said super-turbocharger;

driving said turbine with said gaseous mixture;

transferring excess turbine rotational mechanical energy from said turbine to a propulsion train that would otherwise cause said turbine to rotate at a speed which would cause damage to said compressor.

16. The method of claim 15 further comprising:

transferring propulsion train rotational mechanical energy from said propulsion train to said compressor to reduce turbo lag.

17. The method of claim 15 wherein said process of providing compressed air further comprises:

providing compressed air from a compressor of said superturbocharger.

18. The method of claim 15 wherein said process of providing compressed air further comprises:

providing compressed air from an additional compressor that is not a compressor of said superturbocharger that provides compressed air for said engine system.

19. A method of improving performance of a super-turbocharged engine system comprising:

providing an engine;

providing a catalytic converter that is connected to an exhaust outlet proximate to said engine that receives engine exhaust gases from said engine that activate an exothermic reaction in said catalytic converter which adds additional energy to said engine exhaust gases and produces catalytic converter exhaust gases at an output of said catalytic converter that are hotter than said engine exhaust gases;

providing a flow of compressed air to an intake of said engine;

providing a flow of additional compressed air;

mixing said additional compressed air with said catalytic converter exhaust gases downstream from said catalytic converter to produce a gaseous mixture of said catalytic converter exhaust gases and said additional compressed air;

generating a control signal to regulate said flow of said additional compressed air into said mixing chamber to maintain said gaseous mixture below a maximum temperature;

supplying said gaseous mixture to a turbine that produces turbine rotational mechanical energy in response to flow of said gaseous mixture;

transmitting said turbine rotational mechanical energy from said turbine to said compressor that uses said turbine rotational mechanical energy to compress a

source of air to produce said compressed air when said flow of said gas mixture through said turbine is sufficient to drive said compressor;

extracting at least a portion of said turbine rotational mechanical energy from said turbine and applying said portion of said turbine rotational mechanical energy to a propulsion train when said portion of said turbine rotational mechanical energy from said turbine is not needed to run said compressor;

providing propulsion train rotational mechanical energy from said propulsion train to said compressor to prevent turbo-lag when said flow of said gaseous mixture through said turbine is not sufficient to drive said compressor.

20. The method of claim 19 wherein said maximum temperature of said gaseous mixture is below a temperature at which said gas mixture would otherwise cause damage to said turbine.

21. The method of claim 20 wherein said maximum temperature of said gas mixture is below approximately 950°C.

22. The method of claim 20 wherein said efficiency of said engine is improved by not using a waste gate to expel excess gases of said gas mixture.

23. The method of claim 22 wherein said process of extracting excess turbine rotational mechanical energy from said turbine and providing propulsion train rotational mechanical energy from said propulsion train to said compressor comprises:

using a transmission that couples said excess turbine rotational mechanical energy and said propulsion train rotational mechanical energy between said propulsion train and a shaft connecting said turbine and said compressor.

24. The method of claim 23 wherein said process of mixing said additional compressed air with said catalytic converter exhaust gases comprises:

providing a mixing chamber having at least one opening in an exhaust conduit that is connected to a compressed air conduit so that said additional compressed air flows through said at least one opening and mixes with said hotter exhaust gases in said exhaust conduit.

25. The method of claim 19 wherein said process of providing a flow of additional compressed air comprises:

providing a flow of additional compressed air from a compressor that provides said flow of compressed air to said intake of said engine.

26. The method of claim 19 wherein said process of providing a flow of additional compressed air comprises:

providing a flow of additional compressed air from a compressor that does not provide said flow of compressed air to said intake of said engine.

27. A super-turbocharged engine comprising:

an engine;

a catalytic converter connected to an exhaust conduit proximate to an exhaust outlet of said engine such that hot exhaust gases from said engine activate an exothermic reaction in said catalytic converter that adds energy to said hot exhaust gases and produces converted exhaust gases;

a compressor connected to a source of air that provides compressed air that is applied to an intake of said engine;

an additional compressor that provides an amount of additional compressed air that has a pressure that is greater than a pressure level of said exhaust gases;

a conduit that supplies said additional compressed air to said converted exhaust gases so that said additional compressed air is mixed with said converted exhaust gases to produce a gaseous mixture;

a turbine that is mechanically coupled to said compressor and generates turbine rotational mechanical energy from said gaseous mixture;

a controller that generates a control signal that regulates said amount of said additional compressed air to maintain said gaseous mixture below a maximum temperature;

a transmission that provides propulsion train rotational mechanical energy from a propulsion train to said compressor to reduce turbo-lag when said flow of said exhaust through said turbine is not sufficient to drive said compressor to a desired boost level, and extracts excess turbine rotational mechanical energy from said turbine to maintain rotational speeds of said compressor below a predetermined maximum rotational speed at which damage would occur to said compressor.

28. The engine system of claim 27 wherein said additional compressor is an electrical compressor.

29. The engine system of claim 27 wherein said additional compressor is a mechanical compressor that is coupled to a variable transmission that is mechanically coupled to said turbine and is controlled by said controller.

30. A method of increasing the performance of a piston engine system having a super turbocharger:

applying exhaust gases from said piston engine system to an NO<sub>x</sub> converter, which converts said exhaust gases to produce NO<sub>x</sub> converted gases;

generating an amount of compressed air from a compressor in response to a control signal;

mixing said amount of said compressed air with said NO<sub>x</sub> converted gases to produce a gaseous mixture of said NO<sub>x</sub> converted gases and said compressed air;

supplying said gaseous mixture to a hydrocarbon/carbon monoxide converter to produce hydrocarbon/carbon monoxide converted gases;

detecting said temperature level of said hydrocarbon/carbon monoxide converted gases;

adjusting said amount of compressed air to adjust said temperature level of said hydrocarbon/carbon monoxide converted gases to a desired temperature level.

31. The method of claim 30 wherein said desired temperature level is a temperature level that will not damage said turbine.

32. The method of claim 30 wherein said process of mixing said amount of compressed air with said converted gases comprises:

mixing said amount of compressed air that is sufficient to substantially fully oxidize hydrocarbons and carbon monoxide in said NO<sub>x</sub> converted gases.

33. A method of increasing the performance of a piston engine system having a super turbocharger:

applying exhaust gases from said piston engine system to an NO<sub>x</sub> converter, which converts said exhaust gases to produce NO<sub>x</sub> converted gases;

generating a first amount of compressed air;

mixing said first amount of said compressed air with said NO<sub>x</sub> converted gases to produce a first gaseous mixture of said NO<sub>x</sub> converted gases and said compressed air;

supplying said first gaseous mixture to a hydrocarbon/carbon monoxide converter to produce hydrocarbon/carbon monoxide converted gases;

generating a second amount of compressed air;

mixing said second amount of compressed air with said hydrocarbon/carbon monoxide converted gases to cool said hydrocarbon/carbon monoxide converted gases to a desired temperature to produce cooled hydrocarbon/carbon monoxide converted gases;

driving a turbine of said superturbocharger with said cooled hydrocarbon/carbon monoxide converted gases.

34. The method of claim 33 wherein said desired temperature is a temperature that will not damage said turbine.

35. The method of claim 33 wherein said first amount of compressed air is an amount that will allow said hydrocarbon/carbon monoxide converter to substantially fully oxidize hydrocarbons and carbon monoxide in said NO<sub>x</sub> converted gases.

36. A super-turbocharged engine system comprising:

a piston engine that generates exhaust gases;

a NO<sub>x</sub> converter coupled to receive said exhaust gases and produce NO<sub>x</sub> converted gases;

a compressor connected to a source of air that provides compressed air that is applied to an intake of said engine;

a feedback valve that supplies a portion of said compressed air that is mixed with said NO<sub>x</sub> converted gases to produce a gaseous mixture;

a hydrocarbon/carbon monoxide converter connected to receive said gaseous mixture and oxidize hydrocarbons and carbon monoxide in said gaseous mixture to produce a hydrocarbon/carbon monoxide converted gaseous mixture;

a turbine that is coupled to receive said hydrocarbon/carbon monoxide gaseous mixture and generate turbine rotational mechanical energy from said hydrocarbon/carbon monoxide converted gaseous mixture.

37. The super-turbocharged engine system of claim 36 further comprising:

a controller that generates a control signal that regulates said amount of said compressed air to maintain said gaseous mixture below a maximum temperature.

38. The super-turbocharged engine system of claim 37 further comprising:

a transmission that extracts excess turbine rotational mechanical energy from said turbine and convert said excess turbine rotational mechanical energy to propulsion train rotational mechanical energy.

39. The super-turbocharged engine system of claim 36 wherein said portion of said compressed air is sufficient to cause said hydrocarbons and carbon monoxide to be substantially fully oxidized in said hydrocarbon/carbon monoxide converter.

40. The super-turbocharged engine system of claim 36 wherein said portion of said compressed air is sufficient to cool said hydrocarbon/carbon monoxide converted gaseous mixture to a desired temperature.

41. The super-turbocharged engine system of claim 39 wherein said portion of said compressed air is sufficient to cool said hydrocarbon/carbon monoxide converted gaseous mixture to a desired temperature.

42. The super-turbocharged engine system of claim 38 wherein said transmission provides propulsion train rotational mechanical energy from a propulsion train to said

compressor to reduce turbo-lag when said flow of said exhaust through said turbine is not sufficient to drive said compressor to a desired boost level.

43. The super-turbocharged engine system of claim 38 wherein said transmission extracts excess turbine rotational mechanical energy from said turbine to maintain rotational speeds of said compressor to drive said compressor to a desired boost level.

44. The super-turbocharged engine system of claim 38 wherein said transmission extracts excess turbine rotational mechanical energy from said turbine to maintain rotational speeds of said compressor below a predetermined maximum rotational speed at which damage would occur to said compressor.

45. The super-turbocharged engine system of claim 38 wherein said transmission provides propulsion train rotational mechanical energy from a propulsion train to said compressor to drive said compressor to a desired boost level when said flow of said exhaust through said turbine is not sufficient.

46. The super-turbocharged engine system of claim 45 wherein said feedback valve allows said portion of said compressed air to be mixed with said NO<sub>x</sub> converted gases to avoid surge and achieve a desired boost level when said flow of compressed air through said compressor would otherwise cause surge in said compressor.

47. The super-turbocharged engine system of claim 36 further comprising:

another feedback valve that supplies another portion of said compressed air that is mixed with said hydrocarbon/carbon monoxide gaseous mixture to cool said hydrocarbon/carbon monoxide gaseous mixture to a temperature level below a maximum temperature level that would cause damage to said turbine.

48. A super-turbocharged engine system comprising:

a piston engine that generates exhaust gases;

a NO<sub>x</sub> converter coupled to receive said exhaust gases and produce NO<sub>x</sub> converted gases;

a compressor that generates a source of compressed air;

a conduit that supplies said compressed air to said NO<sub>x</sub> converted gases so that said NO<sub>x</sub> converted gases are mixed with said compressed air to produce a gaseous mixture;

a hydrocarbon/carbon monoxide converter coupled to receive said gaseous mixture and oxidize hydrocarbons and carbon monoxide present in said gaseous mixture to produce a hydrocarbon/carbon monoxide converted gaseous mixture;

a turbine that is coupled to receive said hydrocarbon/carbon monoxide gaseous mixture and generate turbine rotational mechanical energy from said hydrocarbon/carbon monoxide converted gaseous mixture.

49. The super-turbocharged engine system of claim 48 further comprising:

a controller that generates a control signal that regulates said amount of said compressed air to maintain said gaseous mixture below a maximum temperature.

50. The super-turbocharged engine system of claim 48 further comprising:

a transmission that extracts excess turbine rotational mechanical energy from said turbine and converts it to propulsion train rotational mechanical energy.

51. The super-turbocharged engine system of claim 48 wherein said compressed air is sufficient to cause said hydrocarbons and carbon monoxide to be substantially fully oxidized in said hydrocarbon/carbon monoxide converter.

52. The super-turbocharged engine system of claim 48 wherein said compressed air is sufficient to cool said hydrocarbon/carbon monoxide converted gaseous mixture to a desired temperature.

53. The super-turbocharged engine system of claim 51 wherein said compressed air is sufficient to cool said hydrocarbon/carbon monoxide converted gaseous mixture to a desired temperature.

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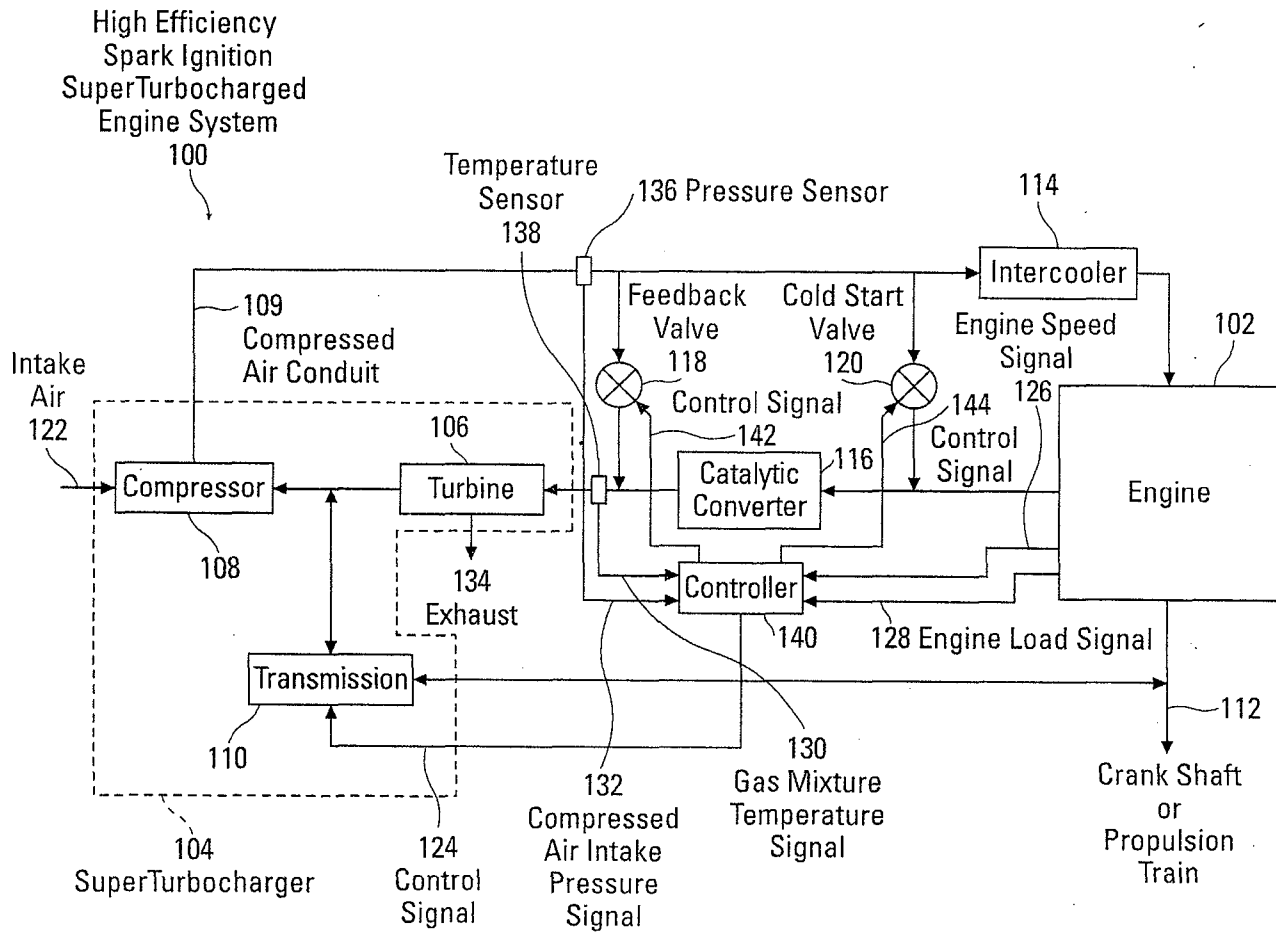


Fig. 1

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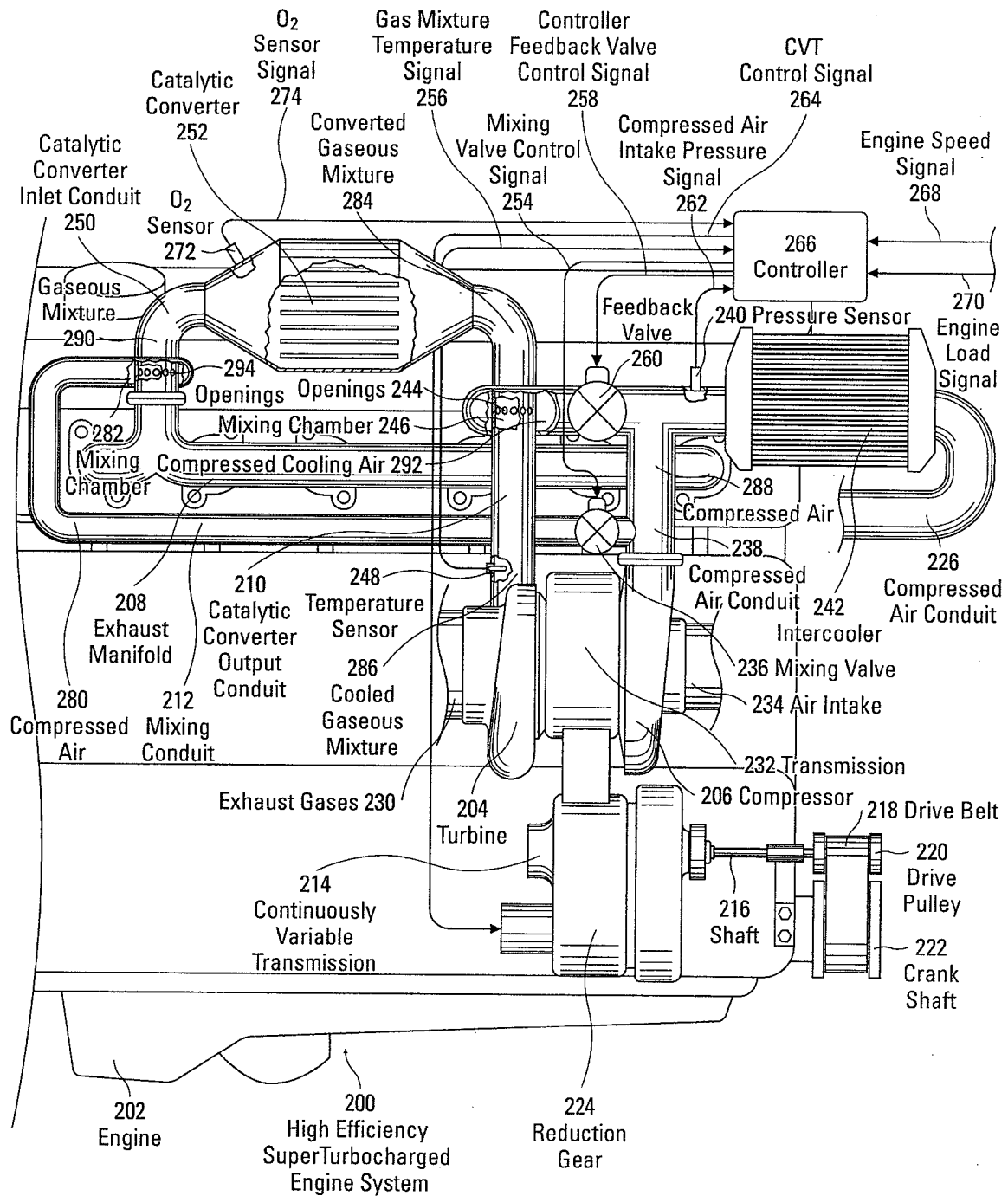


Fig. 2

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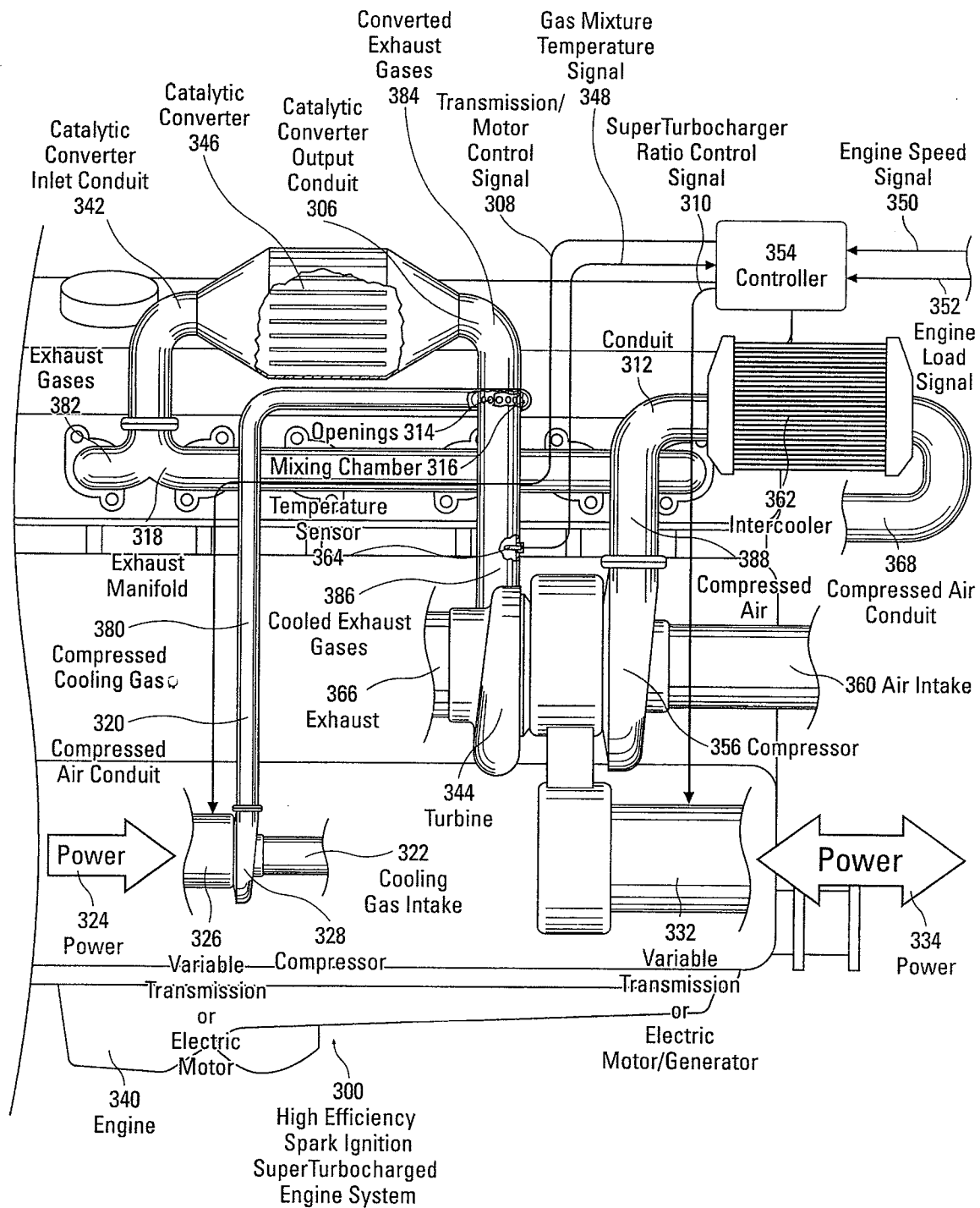


Fig. 3

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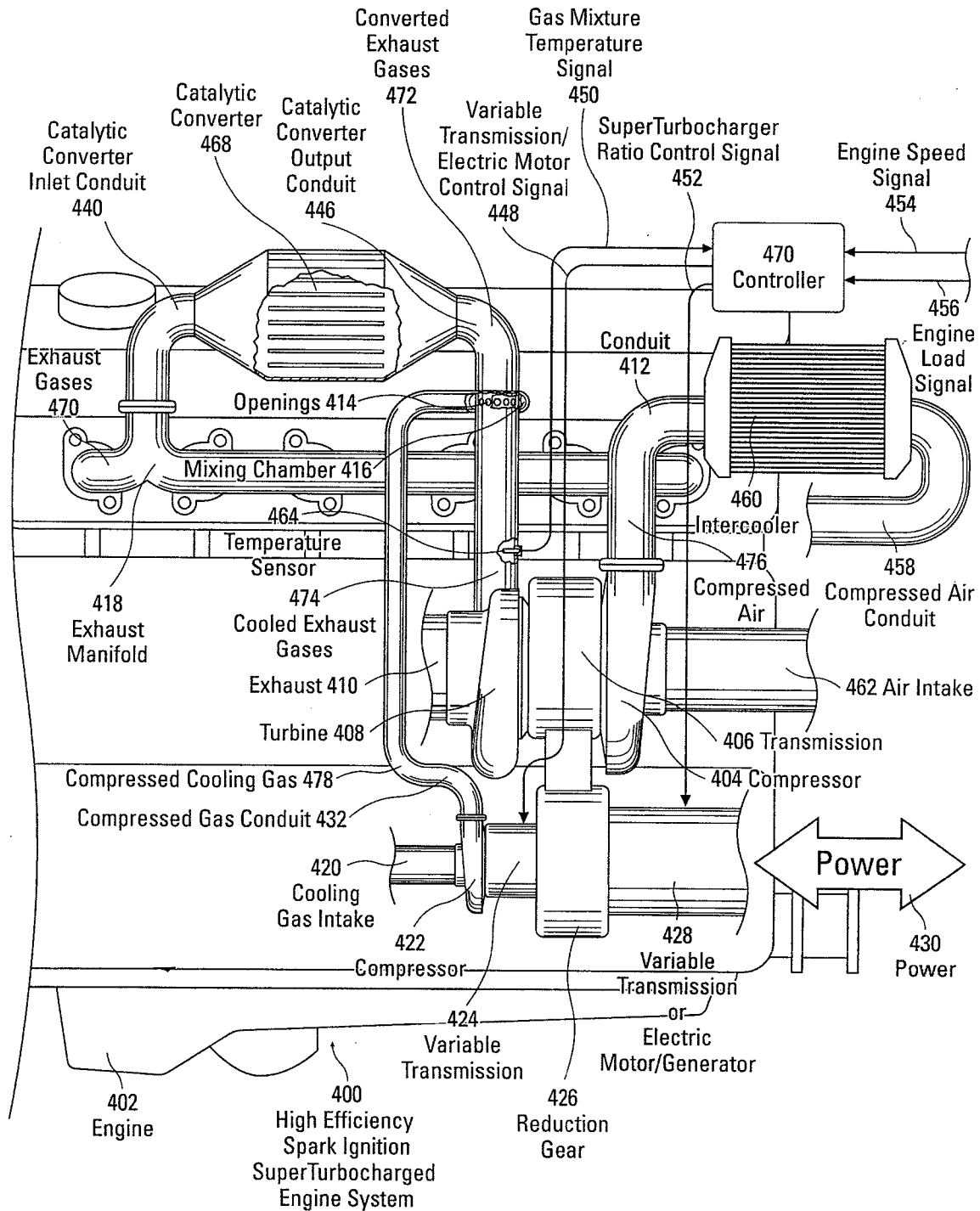


Fig. 4

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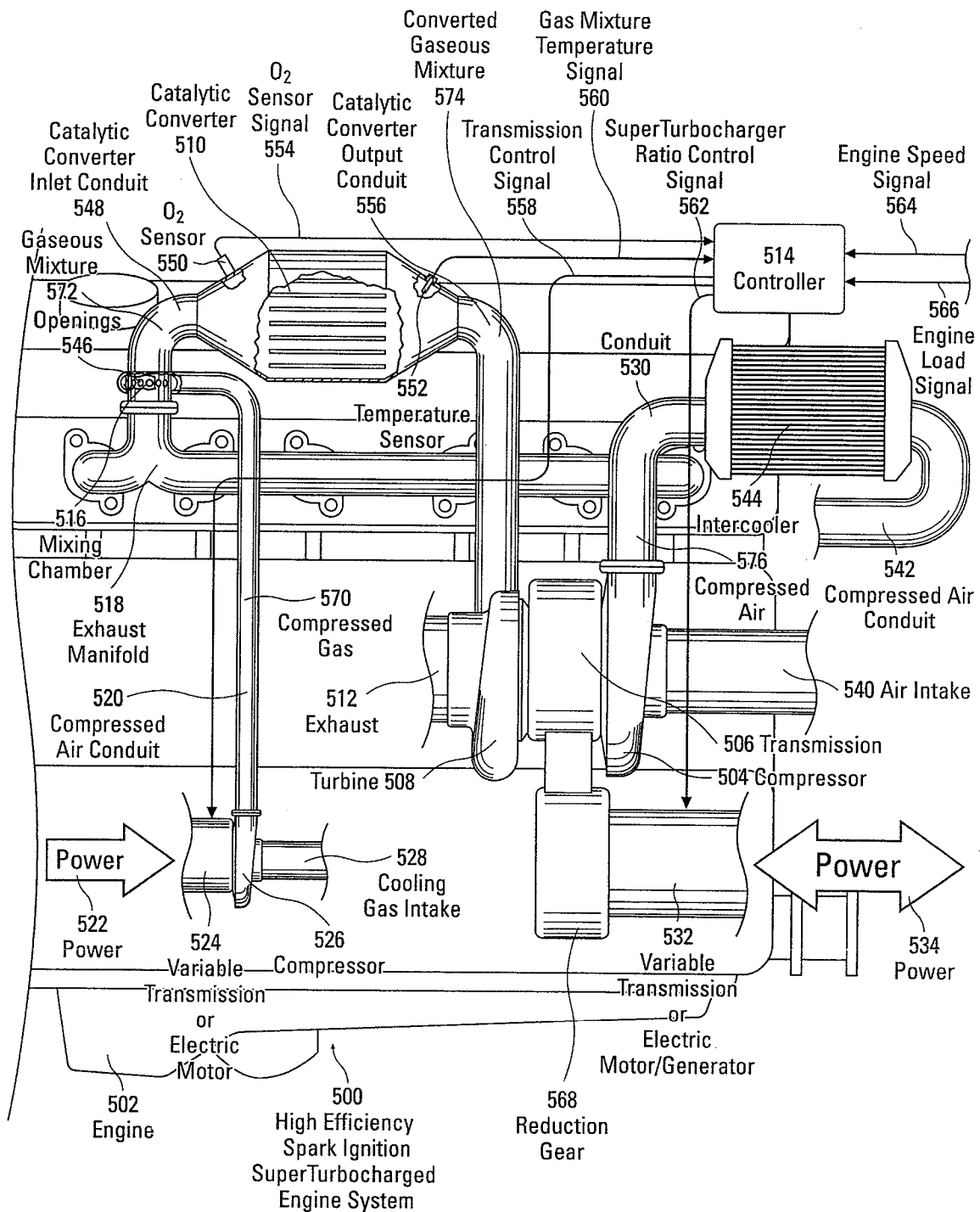


Fig. 5

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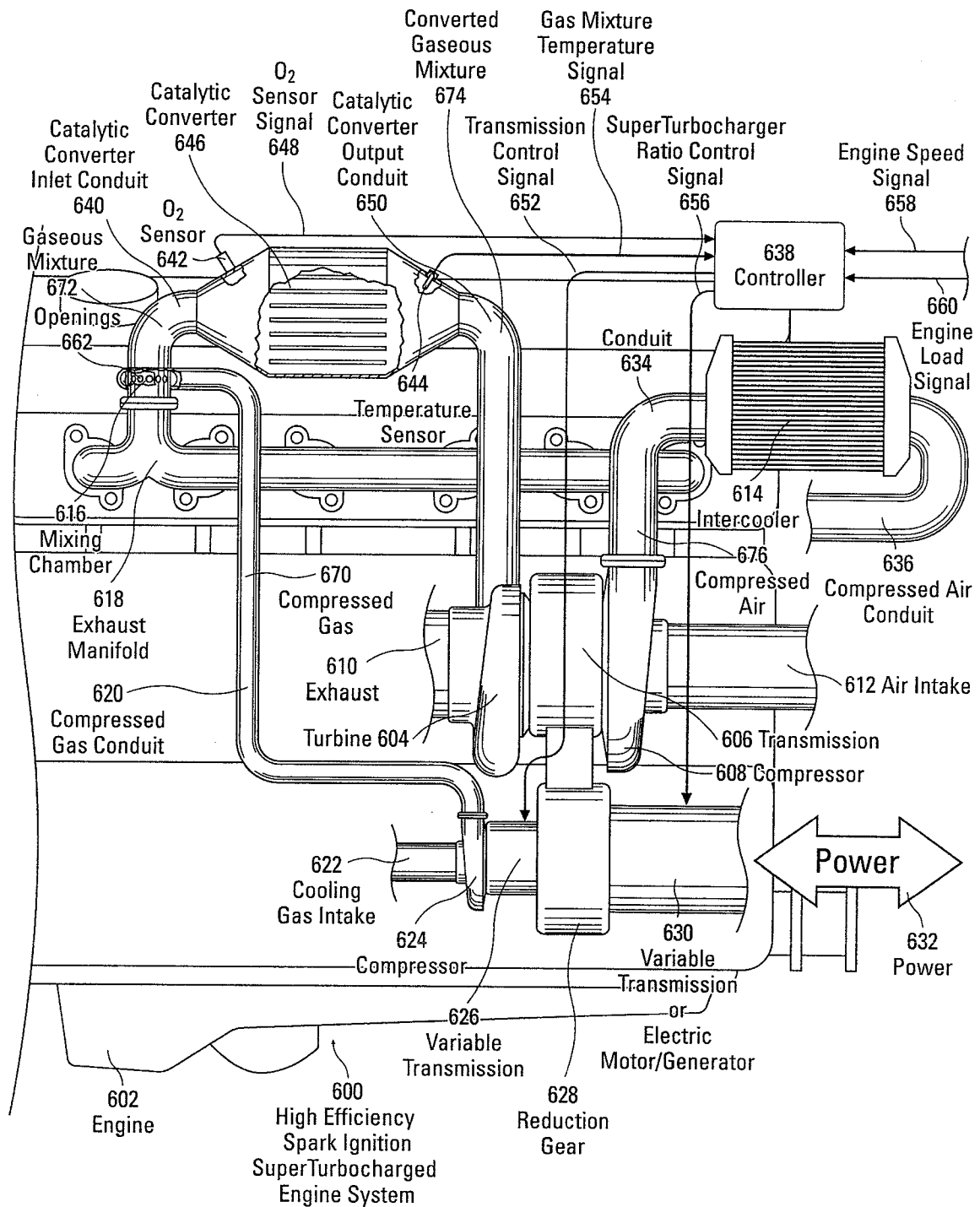


Fig. 6

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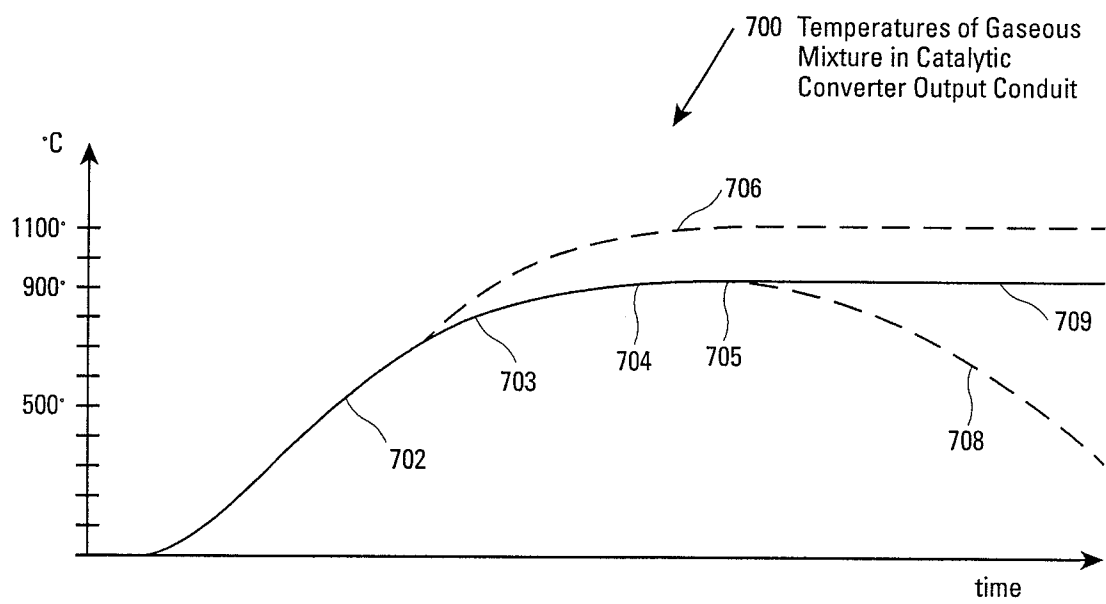


Fig. 7

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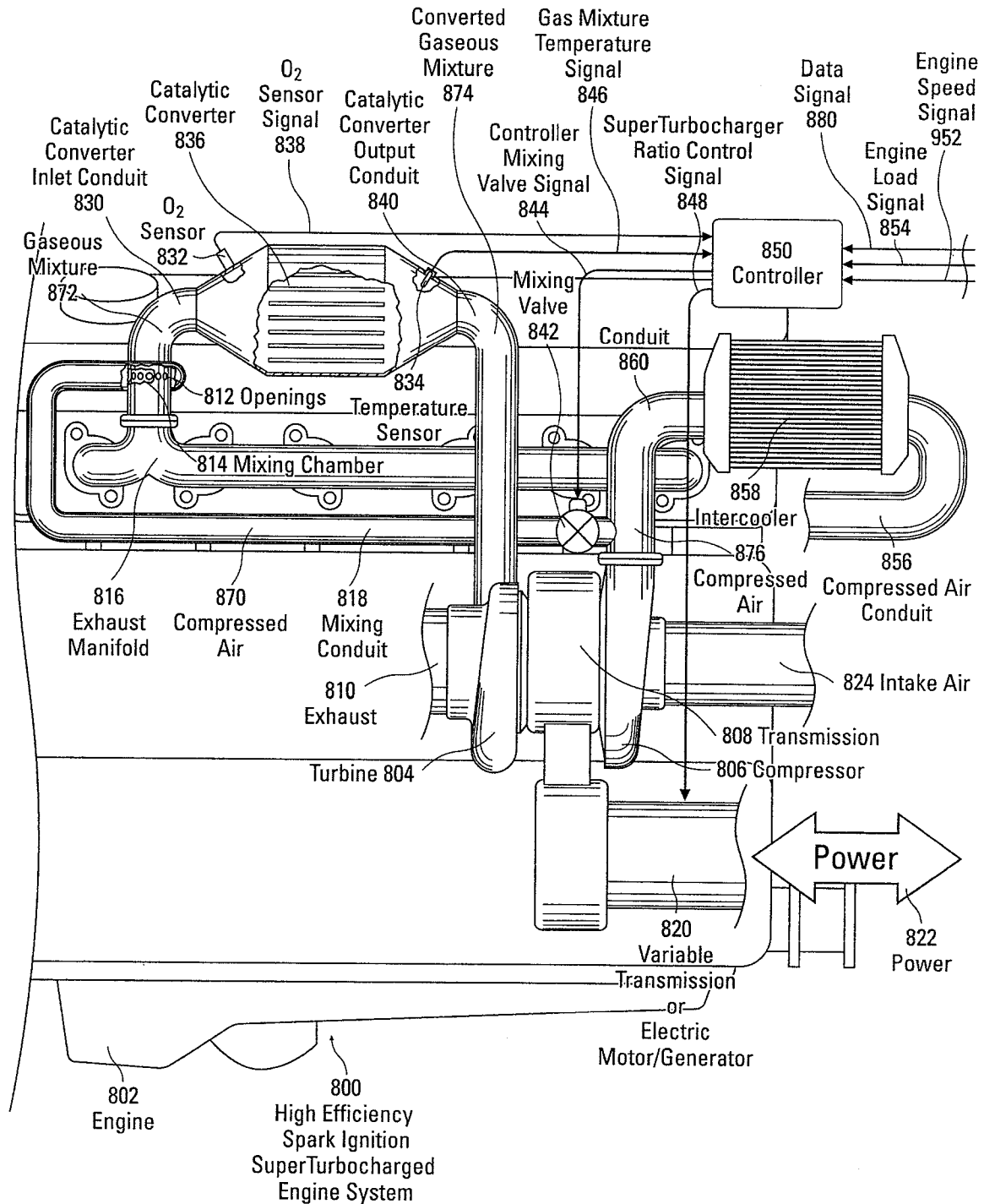


Fig. 8

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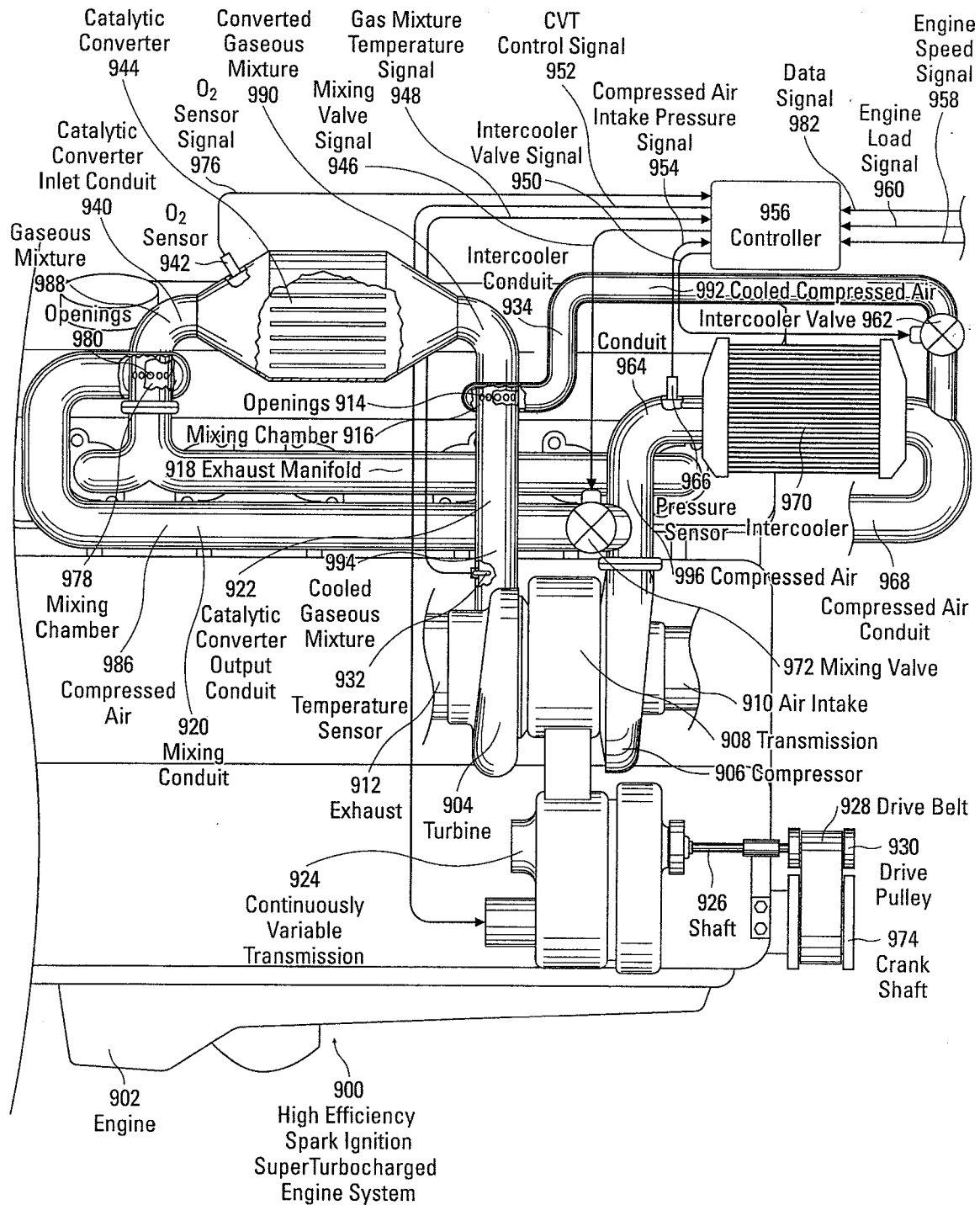


Fig. 9

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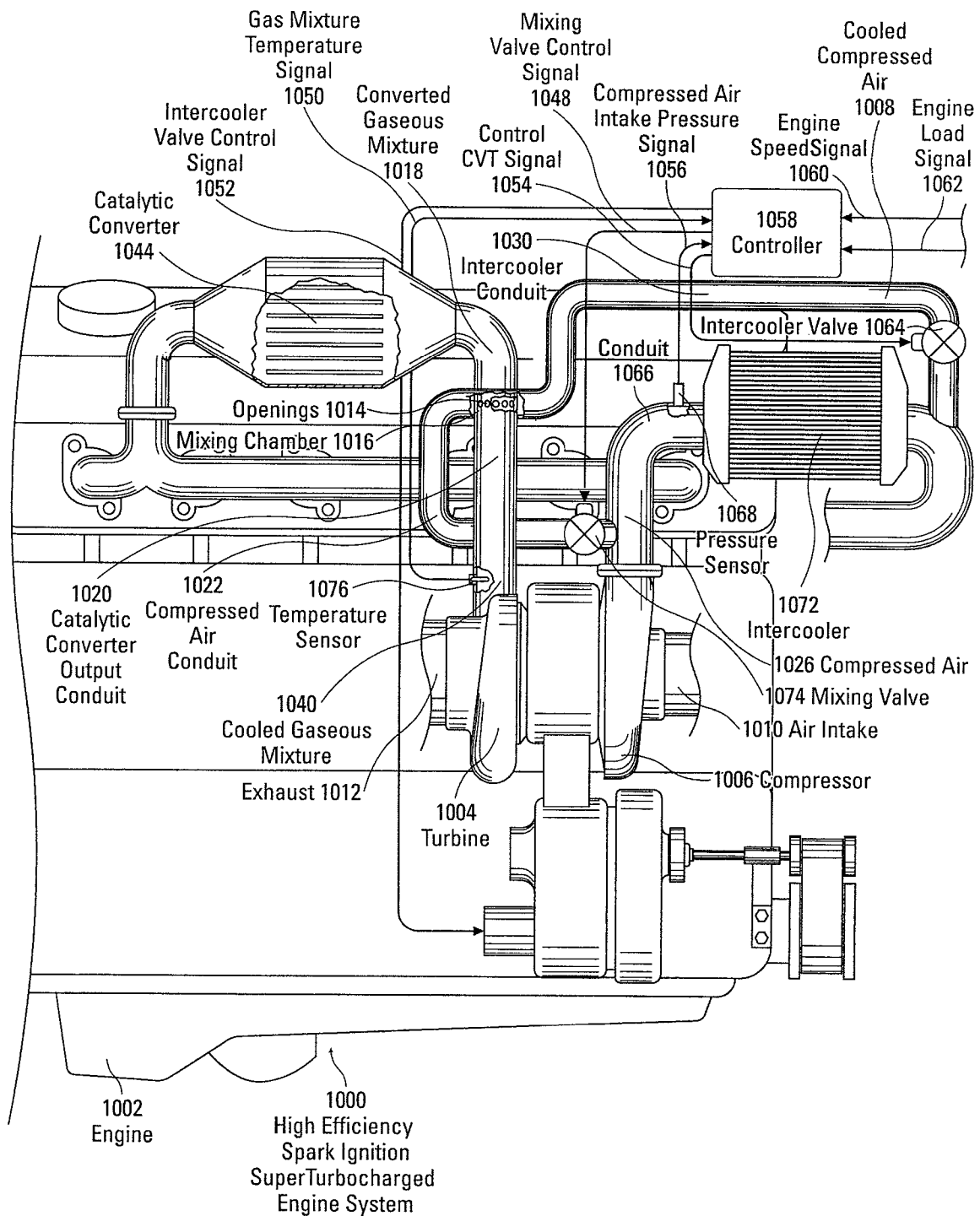


Fig. 10

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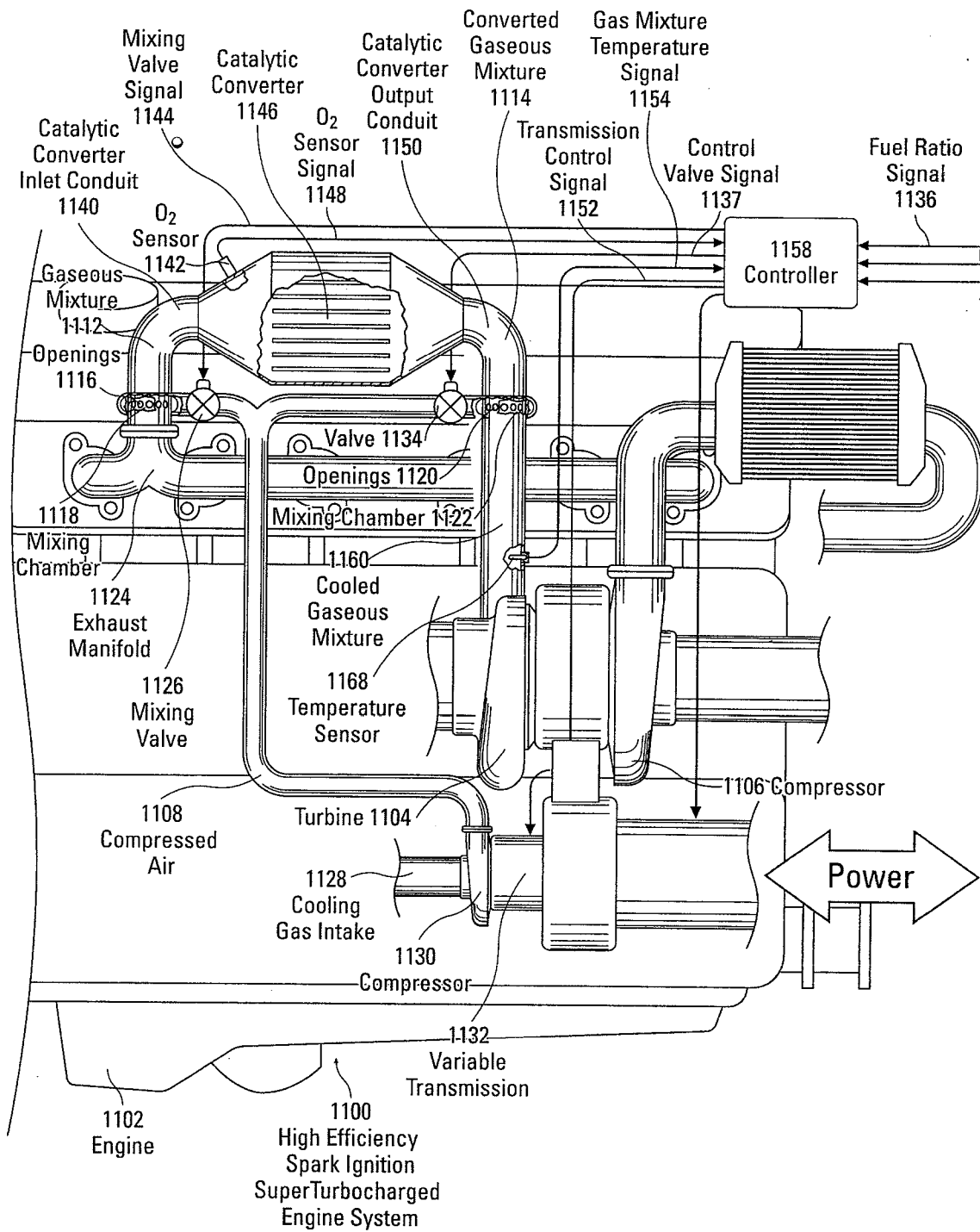


Fig. 11

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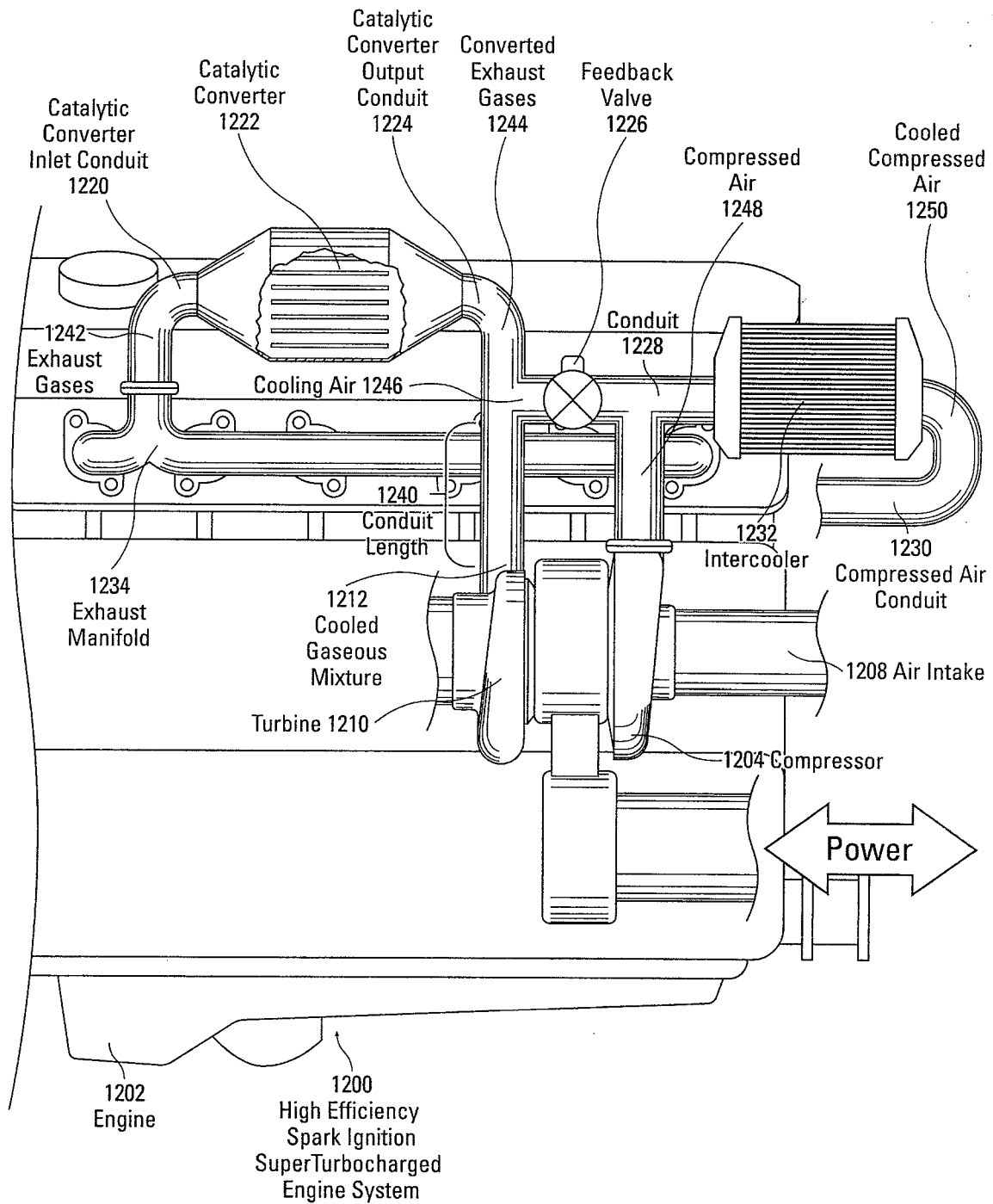


Fig. 12

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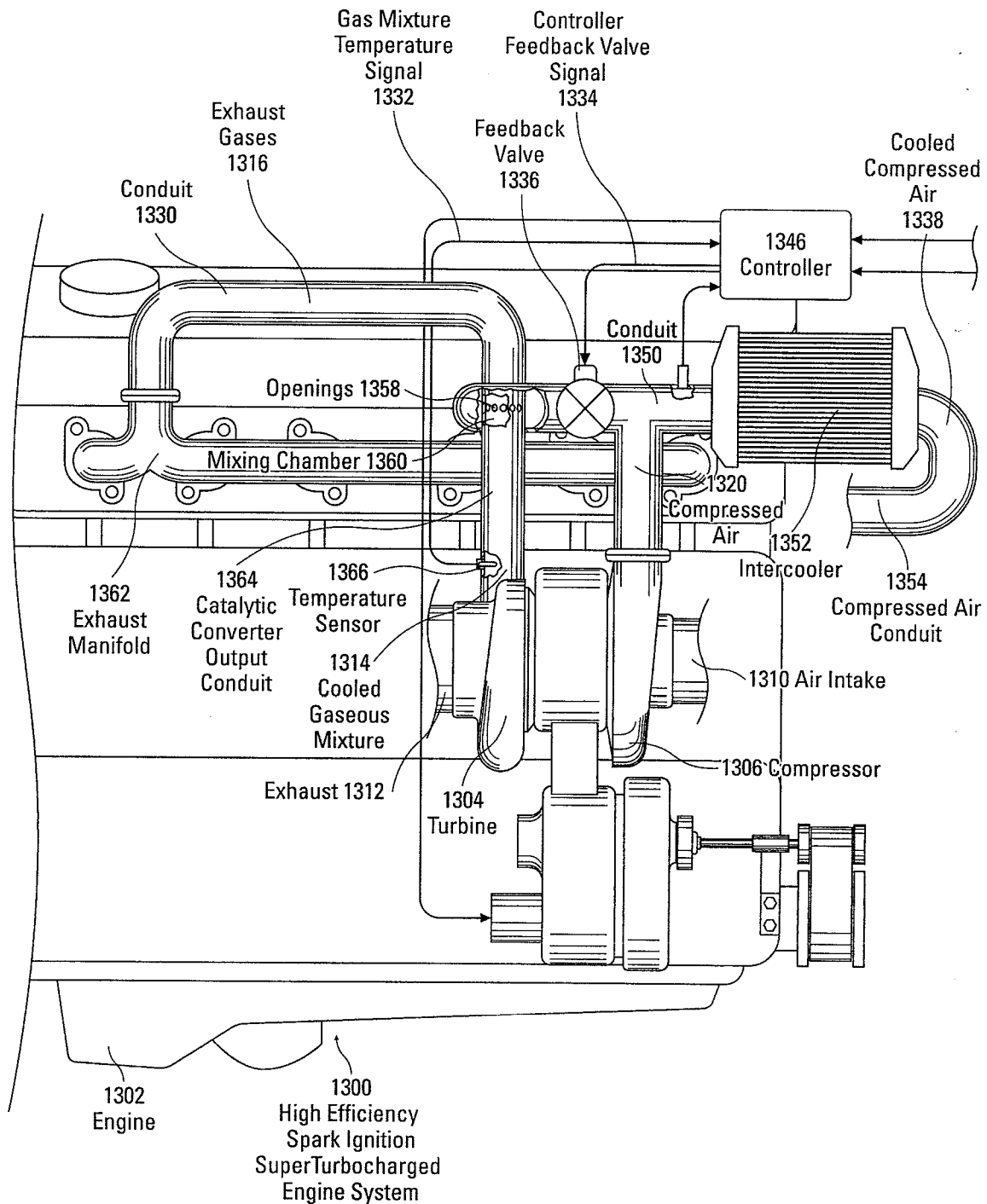


Fig. 13

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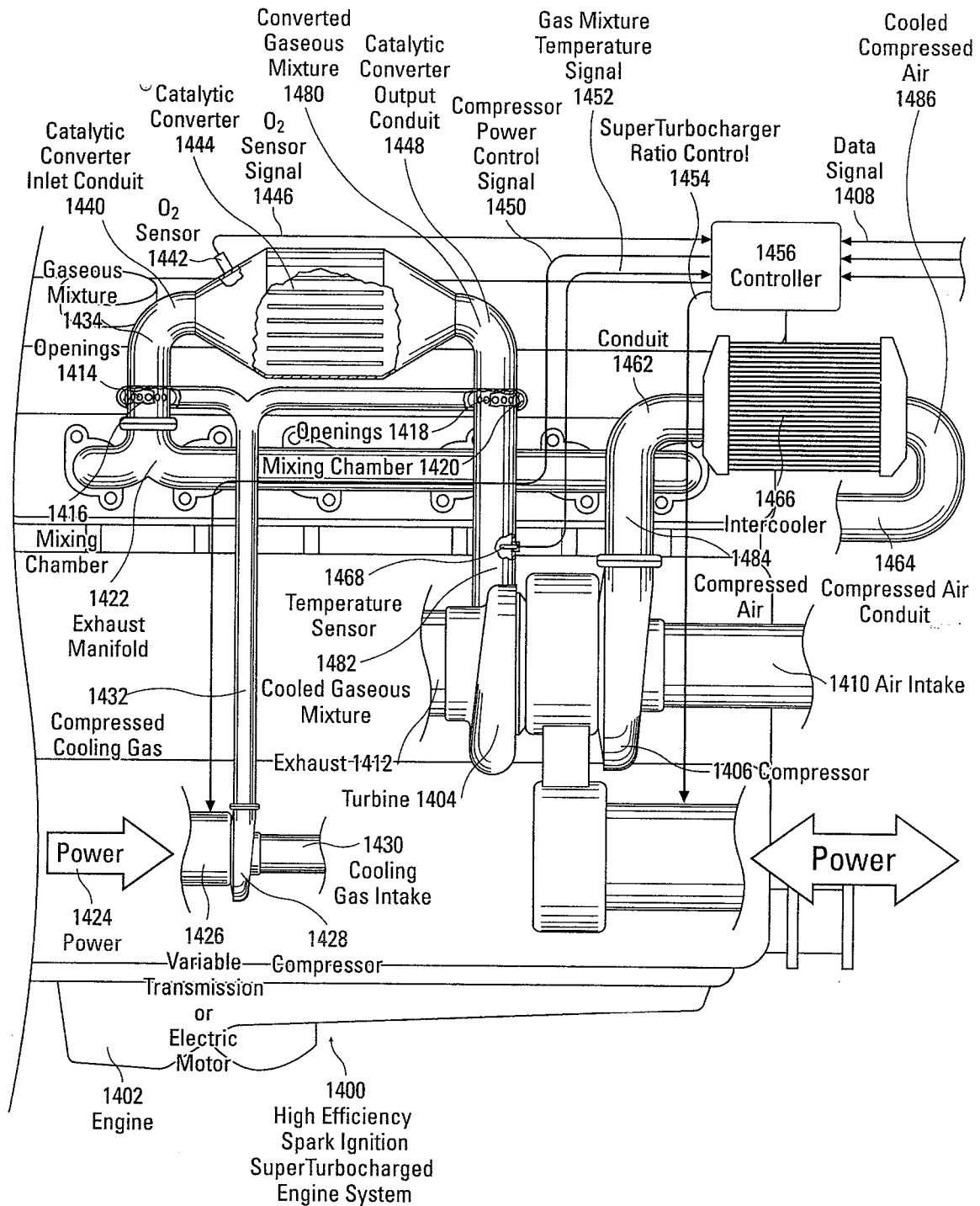


Fig. 14

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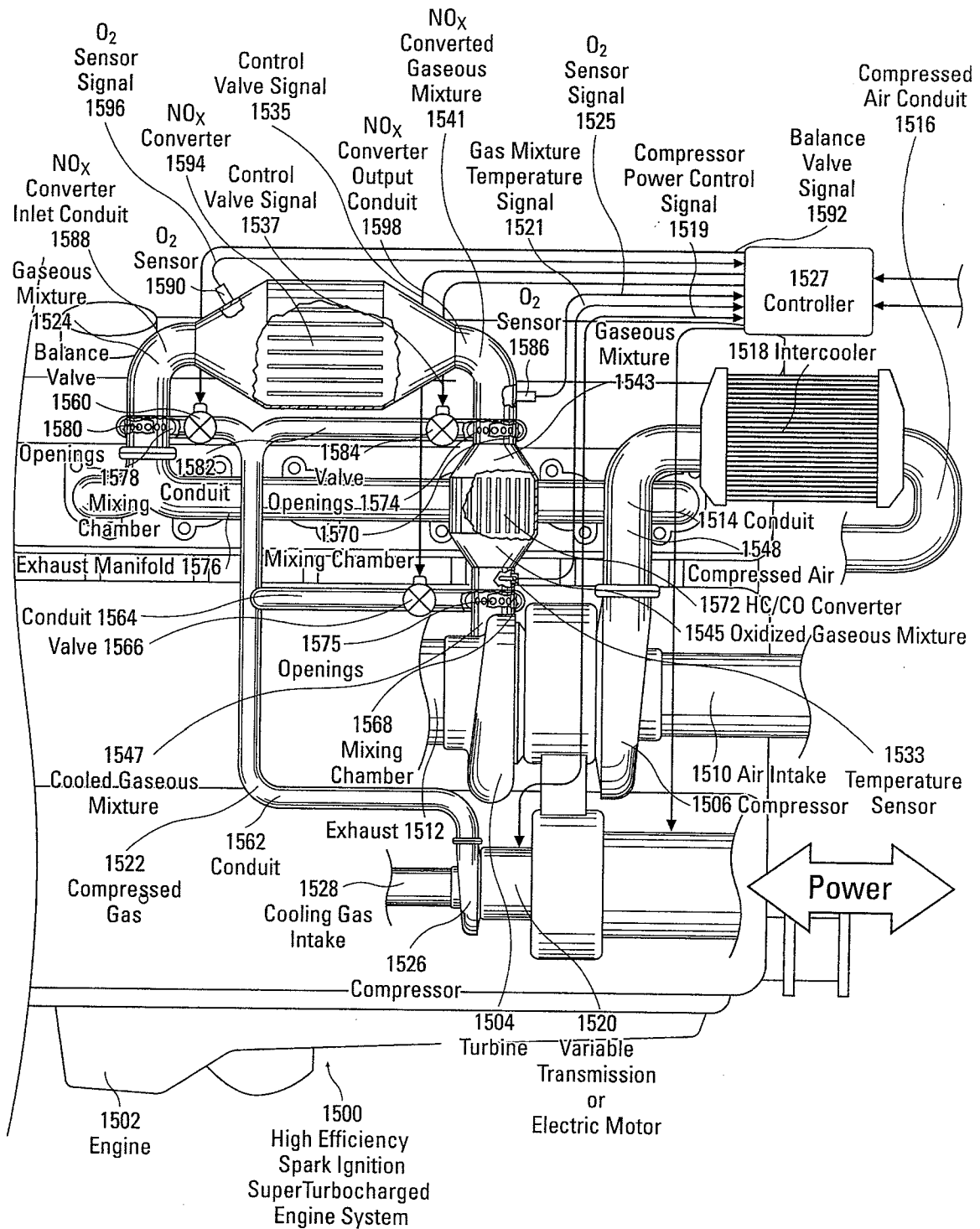


**Fig. 15A**

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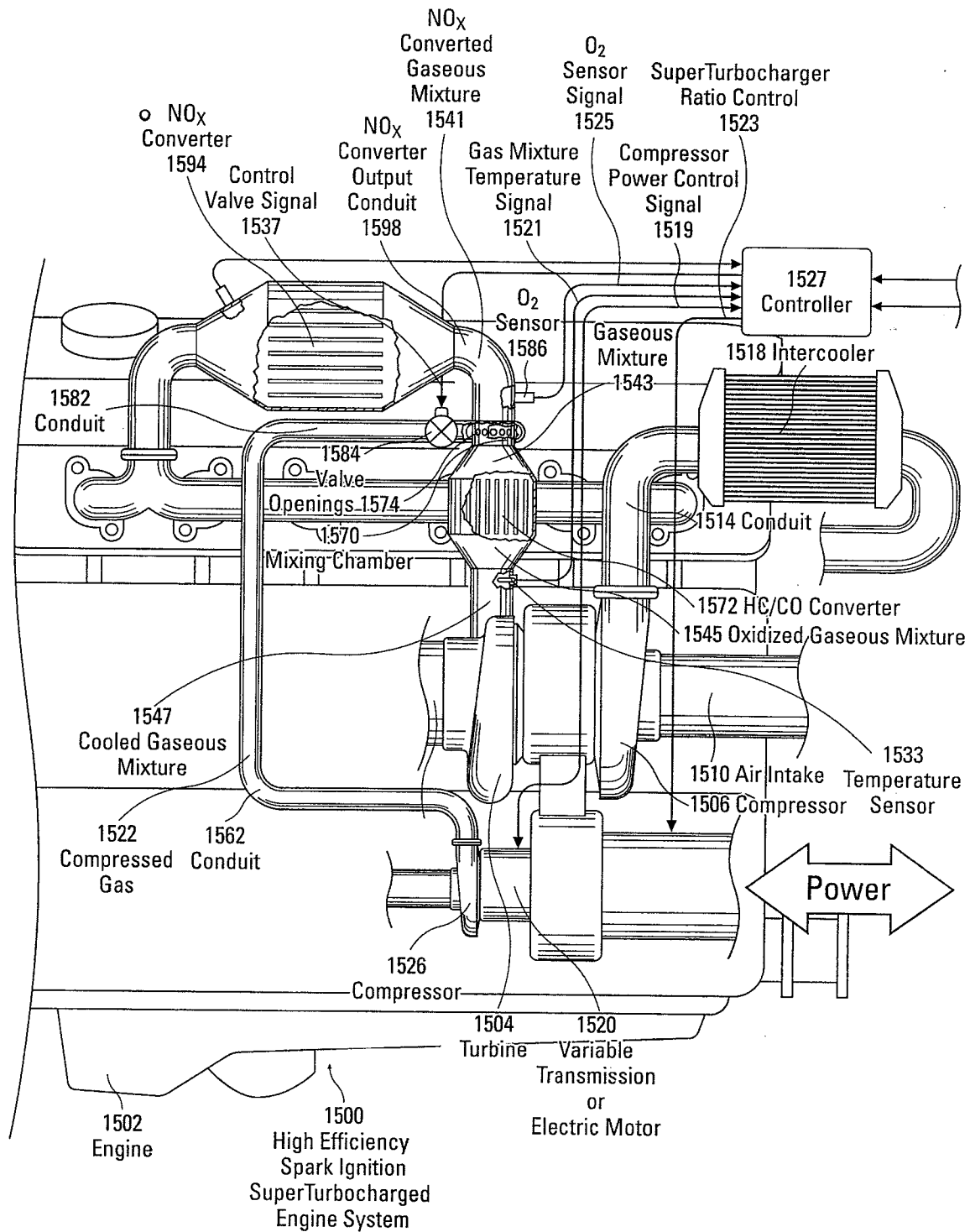


Fig. 15B

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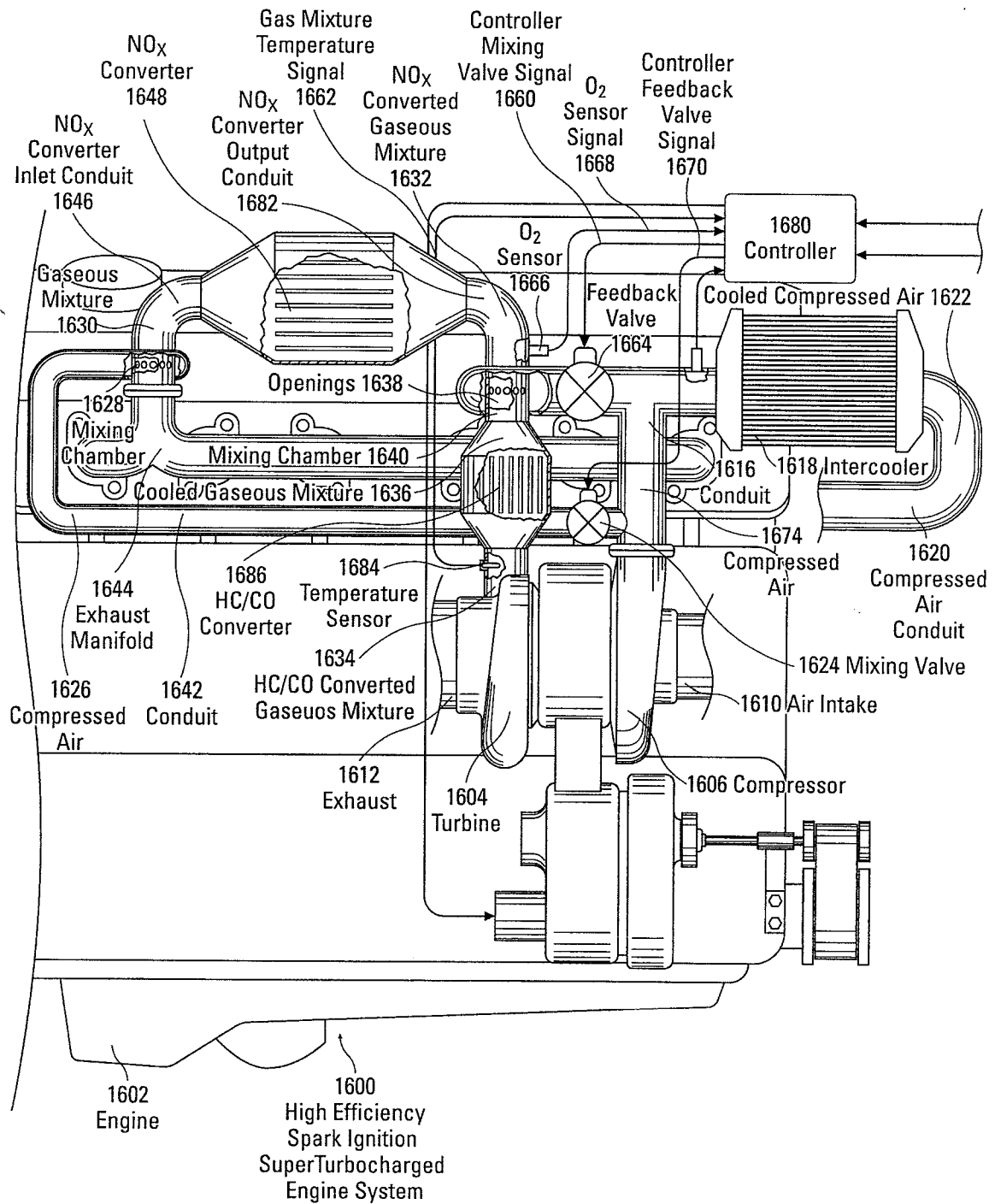


Fig. 16

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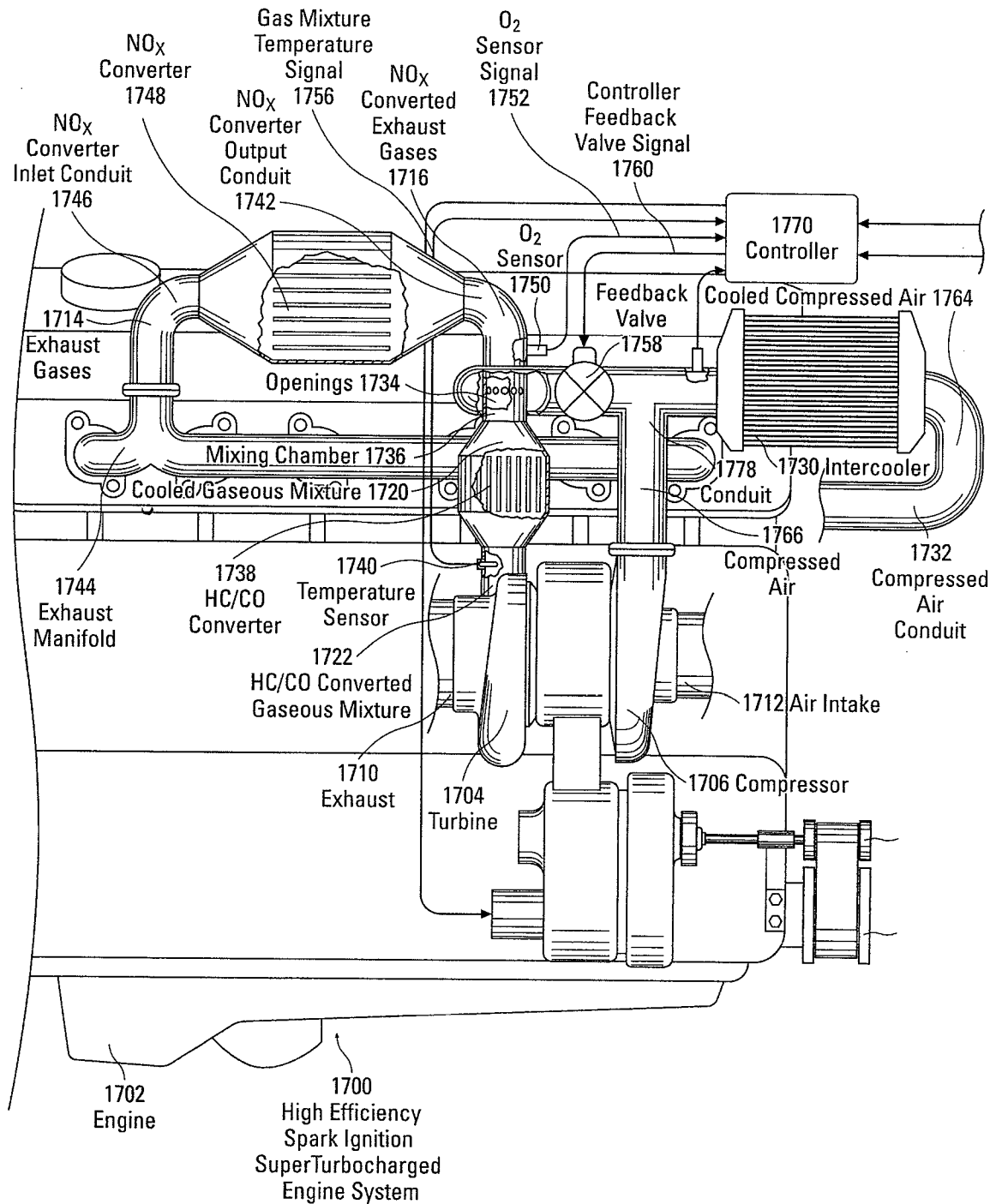


Fig. 17

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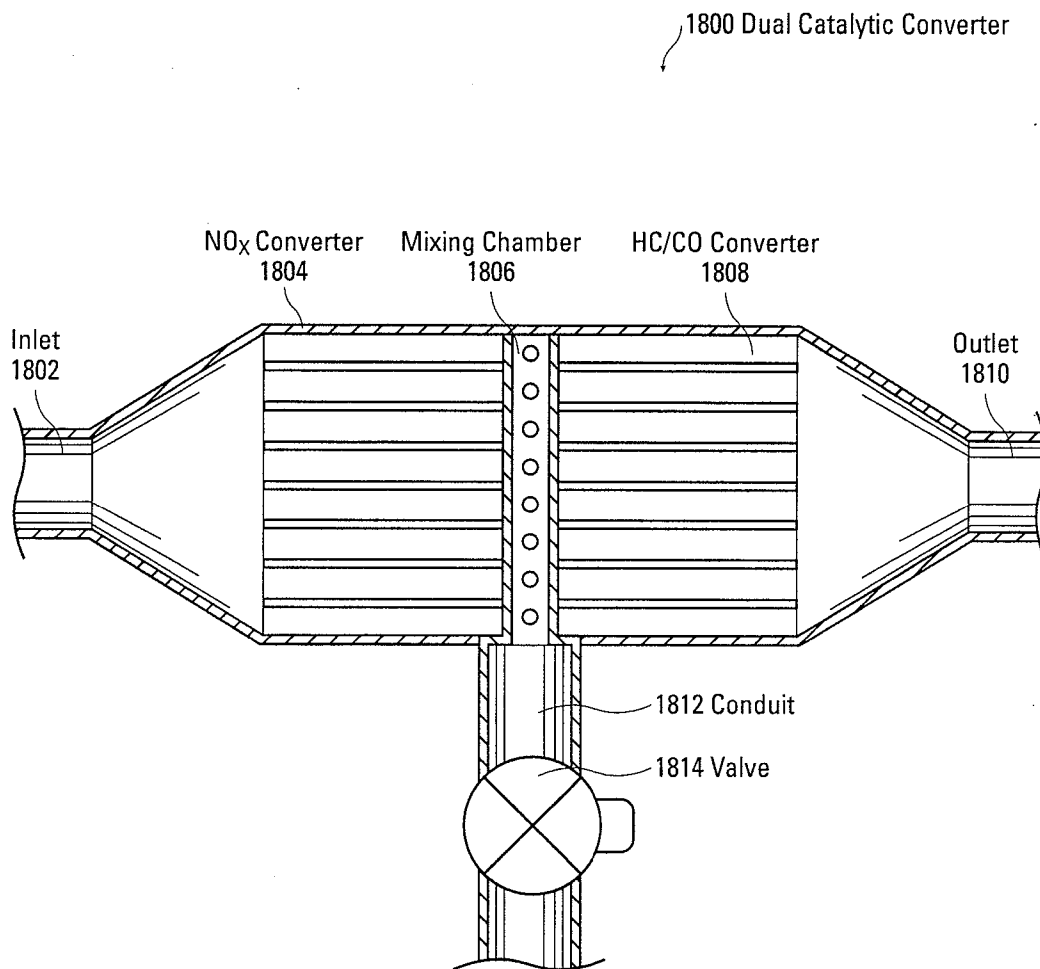


Fig. 18

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 11/22298

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - F02B 33/00 (2011.01)

USPC - 123/559.2

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

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - F02B 33/00 (2011.01)

USPC - 123/559.2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
USPC - 123/308, 58.7, 527, 528, 559.1, 568.15 (text search - see terms below)

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

PubWEST(USPT,PGPB,EPAB,JPAB); Google Scholar; Google Patents

Search Terms: charge, compressor, engine, catalytic, converter, detect, sense, oxygen, O2, temperature, supply, direct, flow, provide, additional, second, turbine, lag, transmission, NOx, nitrogen, oxide, hydrocarbon, carbon, monoxide, mix, exhaust, super,...etc.

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                         | Relevant to claim No.   |
|-----------|------------------------------------------------------------------------------------------------------------|-------------------------|
| Y         | US 2009/0277431 A1 (Nitzke et al.) 12 November 2009 (12.11.2009), fig 1, para [0043]-[0046]                | 1-53                    |
| Y         | US 6,227,180 B1 (Hoffmann et al.) 08 May 2001 (08.05.2001), col 3, ln 50-54 and ln 65-67 to col 4, ln 1-33 | 1-53                    |
| Y         | US 2007/0062189 A1 (Keppeler et al.) 22 March 2007 (22.03.2007), para [0013]                               | 1-29, 31, 33-53         |
| Y         | US 2003/0196436 A1 (Hoecker et al.) 23 October 2003 (23.10.2003), para [0036]                              | 5-14, 18 and 26-29      |
| Y         | US 4,729,225 A (Bucher) 08 March 1988 (08.03.1988), col 3, ln 1-12, col 5, ln 37-68 to col 6, ln 1-12      | 15-29, 38, 42-46 and 50 |
| Y         | US 5,586,540 A (Marzec et al.) 24 December 1996 (24.12.1996), fig 1.                                       | 33                      |
| Y         | US 2008/0133110 A1 (Vetrovec) 5 June 2008 (05.06.2008), para [0035], [0036].                               | 33                      |

☐ Further documents are listed in the continuation of Box C.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents  
P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-3201

Authorized officer:

Lee W. Young

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774