



Australian Government

IP Australia

LETTERS PATENT

STANDARD PATENT

2007229913

I, Fatima Beattie, the Commissioner of Patents, grant a Standard Patent with the following particulars:

Name and Address of Patentee(s):

The Scuderi Group, LLC
1111 Elm Street, Suite 4, West Springfield, MA, 01089, United States of America

Name of Actual Inventor(s):

Forner, Charles K.; Scuderi, Salvatore C. and Scuderi, Stephen P..

Title of Invention:

System and method for split-cycle engine waste heat recovery

Term of Letters Patent:

Twenty years from 15 March 2007

Priority Details :

<i>Number</i>	<i>Date</i>	<i>Filed with</i>
60/785,435	24 March 2006	US



Dated this 9th day of September 2010

Fatima Beattie
Commissioner of Patents

(12) STANDARD PATENT
(19) AUSTRALIAN PATENT OFFICE

(11) Application No. **AU 2007229913 B2**

(54) Title
System and method for split-cycle engine waste heat recovery

(51) International Patent Classification(s)
F01P 9/00 (2006.01)

(21) Application No: **2007229913** (22) Date of Filing: **2007.03.15**

(87) WIPO No: **WO07/111839**

(30) Priority Data
(31) Number **60/785,435** (32) Date **2006.03.24** (33) Country **US**

(43) Publication Date : **2007.10.04**

(44) Accepted Journal Date : **2010.05.27**

(71) Applicant(s)
The Scuderi Group, LLC

(72) Inventor(s)
Forner, Charles K.; Scuderi, Salvatore C.; Scuderi, Stephen P.

(74) Agent/Attorney
Davies Collison Cave, 255 Elizabeth Street, Sydney, NSW, 2000

(56) Related Art
US 5215044
US 4176630
US 6079373

(19) World Intellectual Property Organization
International Bureau



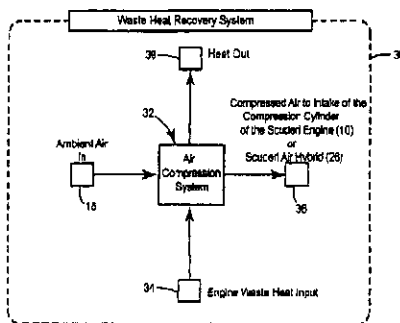
(43) International Publication Date
4 October 2007 (04.10.2007)

PCT

(10) International Publication Number
WO 2007/11839 A2

- (51) International Patent Classification:
F01P 9/00 (2006.01) F01P 11/00 (2006.01)
 - (21) International Application Number:
PCT/US2007/006459
 - (22) International Filing Date: 15 March 2007 (15.03.2007)
 - (25) Filing Language: English
 - (26) Publication Language: English
 - (30) Priority Data:
60785,435 24 March 2006 (24.03.2006) US
 - (71) Applicant (for all designated States except US): THE SCUDERI GROUP, LLC [US/US]; 1111 Elm Street, Suite 4, West Springfield, MA 01089 (US).
 - (72) Inventors; and
 - (75) Inventors/Applicants (for US only): FORNER, Charles, K. [US/US]; 1621 Corporation Street, Beaver, PA 15009 (US). SCUDERI, Salvatore, C. [US/US]; 108 Sunset Drive, Westfield, MA 01085 (US). SCUDERI, Stephen, P. [US/US]; 1023 Shaker Road, Westfield, MA 01085 (US).
 - (74) Agent: FILDES, Christopher, J.; Fildes & Outland, P.C., 20916 Mack Ave., Ste. 2, Grosse Pointe Woods, MI 48236 (US).
 - (81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
 - (84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).
- Published:**
— without international search report and to be republished upon receipt of that report
- For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

(54) Title: SYSTEM AND METHOD FOR SPLIT-CYCLE ENGINE WASTE HEAT RECOVERY



(57) Abstract: A waste heat recovery system for a split-cycle engine includes a heat exchange unit. An air compressor device is in communication with the heat exchange unit. A waste heat input receives waste heat from the engine and is in fluid communication with the heat exchange unit. An ambient air intake connected to the air compressor device draws air into the air compressor device. A compressed air outlet member on the air compressor device in fluid communication with a compression cylinder of the split-cycle engine delivers compressed air from the air compressor device to the engine. Engine waste heat is communicated to the heat exchange unit and energy from the waste heat is used to drive the air compressor device, causing the air compressor device to draw in ambient air through the ambient air intake, compress the ambient air, and deliver compressed air to the engine through the compressed air outlet.

WO 2007/11839 A2

SYSTEM AND METHOD FOR SPLIT-CYCLE ENGINE WASTE HEAT
RECOVERY

TECHNICAL FIELD

This invention relates to split-cycle engines and, more particularly, to waste heat recovery in such engines.

BACKGROUND OF THE INVENTION

The term split-cycle engine as used in the present application may not have yet received a fixed meaning commonly known to those skilled in the engine art. Accordingly, for purposes of clarity, the following definition is offered for the term split-cycle engine as may be applied to engines disclosed in the prior art and as referred to in the present application.

A split-cycle engine as referred to herein comprises:

a crankshaft rotatable about a crankshaft axis;

a power piston slidably received within a power cylinder and operatively connected to the crankshaft such that the power piston reciprocates through a power (or expansion) stroke and an exhaust stroke during a single rotation of the crankshaft;

a compression piston slidably received within a compression cylinder and operatively connected to the crankshaft such that the compression

piston reciprocates through an intake stroke and a compression stroke during a single rotation of the crankshaft; and

a gas passage interconnecting the power and
5 compression cylinders, the gas passage including an inlet valve and an outlet (or crossover) valve defining a pressure chamber therebetween.

United States Patent Nos. 6,543,225,
10 6,609,371, and 6,952,923, all assigned to the assignee of the present invention, disclose examples of split-cycle internal combustion engines as herein defined. These patents contain an extensive list of United States and foreign patents and publications
15 cited as background in the allowance of these patents. The term "split-cycle" has been used for these engines because they literally split the four strokes of a conventional pressure/volume Otto cycle (i.e., intake, compression, power and exhaust) over
20 two dedicated cylinders: one cylinder dedicated to the high pressure compression stroke, and the other cylinder dedicated to the high pressure power stroke.

Conventionally, internal combustion engines
25 release unused energy in the form of heat into the ambient environment. Some of this heat energy, however, may be recaptured and used. Use of this heat energy can both reclaim energy that is released by the engine and also reduce fuel consumption,
30 thereby improving the efficiency of the engine.

SUMMARY OF THE INVENTION

Examples of split-cycle type engines are disclosed in United States Patent Nos. 6,543,225, 5 6,609,371, and 6,952,923 (Scuderi patents), herein incorporated by reference in their entirety.

A split-cycle engine generally includes an engine block having a first cylinder and an adjacent 10 second cylinder extending therethrough. A crankshaft is journaled in the block for rotation about a crankshaft axis. Upper ends of the cylinders are closed by a cylinder head.

15 The first and second cylinders define internal bearing surfaces in which are received for reciprocation a power piston and a compression piston, respectively. The cylinder head, the power piston, and the first cylinder define a variable volume 20 combustion chamber in the power cylinder. The cylinder head, the compression piston, and the second cylinder define a variable volume compression chamber in the compression cylinder. The cylinder head also includes an air inlet connected to the compression 25 cylinder for communicating intake gas from an intake passage into the compression cylinder.

A gas passage (or cross-over passage) interconnects the power and compression cylinders. 30 The gas passage includes an inlet and an outlet. The gas passage inlet is connected to the compression cylinder and the gas passage outlet is connected to the power cylinder.

The crankshaft includes axially displaced and angularly offset first and second crank throws, having a phase angle therebetween. The first crank
5 throw is pivotally joined by a first connecting rod to the power piston and the second crank throw is pivotally joined by a second connecting rod to the compression piston to reciprocate the pistons in their
10 cylinders in timed relation determined by the angular offset of their crank throws and the geometric relationships of the cylinders, crank, and pistons.

Alternative mechanisms for relating the motion and timing of the pistons may be utilized if
15 desired. The timing may be similar to, or varied as desired from, the disclosures of the Scuderi patents.

An internal combustion engine (ICE) mode of operation is generally the normal operating mode of a
20 split-cycle engine. The intake, compression, power and exhaust strokes of a conventional piston engine cycle are split between the compression and power cylinders of the split-cycle engine. In the ICE mode, the compression piston draws in and compresses
25 ambient inlet air for use in the power cylinder. Compressed air is admitted to the power cylinder with fuel shortly after the power piston reaches its top dead center (TDC) position at the beginning of an expansion stroke. The fuel/air mixture is then
30 ignited, burned and expanded on the same expansion stroke of the power piston, transmitting power to the crankshaft. The combustion products are discharged on the exhaust stroke.

A waste heat recovery system for a split-cycle engine having a compression cylinder, a power cylinder, and a gas passage interconnecting the compression and power cylinders in accordance with the invention includes a heat exchange unit and an air compressor device in fluid communication with the heat exchange unit. The system also includes a waste heat input in fluid communication with the heat exchange unit that receives and inputs waste heat from the engine into the heat exchange unit. An ambient air intake is connected to the air compressor device for drawing air into the air compressor device. A compressed air outlet member on the air compressor device in fluid communication with the compression cylinder of the split-cycle engine allows for delivery of compressed air from the air compressor device to the engine. Engine waste heat is communicated to the heat exchange unit and energy from the waste heat is used to drive the air compressor device, causing the air compressor device to draw in ambient air through the ambient air intake, compress the ambient air, and deliver compressed air to the engine through the compressed air outlet.

In a specific embodiment, an engine coolant subsystem may be in communication with the heat exchange unit, and engine coolant is circulated from the engine through the heat exchange unit. Further, an engine exhaust subsystem may be in communication with the heat exchange unit to pass engine exhaust gas through the heat exchange unit. The system may

also include a circulation line for circulating heat exchange medium between the heat exchange unit and the air compressor device. The heat exchange medium may be one of a refrigerant and water. A condenser
5 may be operatively connected to the circulation line. A pump may be operatively connected to the circulation line for pumping the heat exchange medium through the circulation line.

10 The split-cycle engine may also include an air storage tank, and the compressed air may be stored in the air storage tank. A first valve may control flow into the storage tank, a second valve may control flow out of the storage tank, and a third
15 valve may control flow across the gas passage, thereby allowing the compressed air to simultaneously charge the storage tank and drive the power cylinder when the first and second valves controlling flow into and out of the storage tank are open and the
20 third valve controlling flow across the gas passage is closed.

In a separate embodiment, a waste heat recovery system for a split-cycle engine having a
25 compression cylinder and a power cylinder includes a heat exchange unit for transferring thermal energy from engine waste heat to a heat exchange medium. The heat exchange unit has a waste heat side and a heat exchange medium side. The heat exchange unit
30 waste heat side includes a waste heat input that receives waste heat from the engine and inputs the received waste heat into the heat exchange unit. The heat exchange unit heat exchange medium side includes

a heat exchange medium inlet for receiving heat exchange medium. A waste heat outlet is connected to the waste heat side of the heat exchange unit, and a heat exchange medium outlet is connected to the heat exchange medium side of the heat exchange unit. The system also includes an air compressor device having a heat exchange medium inlet in communication with the heat exchange medium outlet of the heat exchange unit, a heat exchange medium outlet operatively connected in a loop fashion to the heat exchange medium inlet of the heat exchange unit, an ambient air intake for drawing in ambient air into the air compressor device, and a compressed air outlet connected to an air intake of the compression cylinder of the split-cycle engine for delivering compressed air to the engine. Energy extracted from the heat exchange medium drives the air compressor device to draw in ambient air through the ambient air intake and to output compressed air to the engine.

20

A method of recovering waste heat from a split-cycle engine having a compression cylinder and a power cylinder includes the steps of: providing an air compression system including an air compressor device; delivering waste heat from the engine to the air compression system; utilizing energy from the waste heat to power the air compressor device to produce compressed air; and delivering waste-heat generated compressed air from the air compressor device to the compression cylinder of the split-cycle engine.

25
30

In a specific embodiment of the method, a heat exchange unit may be provided to utilize the waste heat to change a heat exchange medium from a liquid phase to a gas phase. The step of delivering
5 waste heat from the engine to the air compression system may include circulating engine coolant through the engine and the heat exchange unit. Also, the step of delivering waste heat from the engine to the air compression system may include passing engine
10 exhaust gases from the engine through the heat exchange unit. After the exhaust gases are passed through the heat exchange unit, the exhaust gases may be vented to the atmosphere through an engine exhaust system.

15

The method may further include the step of circulating the heat exchange medium through the heat exchange unit and the air compressor device. The step of circulating the heat exchange medium may
20 include pumping the heat exchange medium. A condenser may be provided downstream of the air compressor device to change the heat exchange medium from the gas phase to the liquid phase. Excess heat from the condenser may be vented to the atmosphere.
25 The air compressor device may draw in ambient air through an ambient air intake. Waste-heat generated compressed air may be delivered to the engine through a compressed air outlet operatively connected to an engine air intake. The waste-heat generated
30 compressed air also may be stored in an air storage tank of the split-cycle engine. Further, an air storage tank of the split-cycle engine may be charged with waste-heat generated compressed air from the

compression cylinder while the power cylinder is simultaneously driven with waste-heat generated compressed air from the air storage tank.

5 These and other features and advantages of the invention will be more fully understood from the following detailed description of the invention taken together with the accompanying drawings.

10 **BRIEF DESCRIPTION OF THE DRAWINGS**

In the drawings:

15 FIG. 1 is a schematic view generally illustrating a waste heat recovery system for a split-cycle engine;

20 FIG. 2 is a schematic view of the waste heat recovery system of FIG. 1 illustrating an air compression subsystem and engine waste heat subsystem in detail;

25 FIG. 3 is a schematic view of a split-cycle engine utilizing the waste heat recovery system; and

 FIG. 4 is an alternative schematic view of a split-cycle engine utilizing the waste heat recovery system.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings in detail, numeral 10 generally indicates a split-cycle engine, such as a Scuderi split-cycle engine. As shown in FIG. 3, the split-cycle engine 10 includes an engine block having at least one compression cylinder 12 and a paired adjacent power cylinder 14. The engine 10 may have any number of pairs of compression cylinders and power cylinders. A gas passage 16 (also referred to as a cross-over passage) interconnects the compression cylinder 12 and power cylinder 14 of each pair. The gas passage includes an inlet and an outlet defining a pressure chamber therebetween. The gas passage inlet is connected to the compression cylinder 12 and the gas passage outlet is connected to the power cylinder 14.

A compression piston 13 is received in the compression cylinder 12. Likewise, a power piston 15 is received in the power cylinder 14. A crankshaft rotatable about a crankshaft axis is operatively connected to the compression piston 13 and power piston 15. The compression piston 13 reciprocates through an intake stroke and a compression stroke during a single rotation of the crankshaft, and the power piston 15 reciprocates through a power (or expansion) stroke and an exhaust stroke during a single rotation of the crankshaft.

The compression cylinder 12 includes an air intake 17 for communicating intake gas such as ambient air from an intake passage 23 into the compression

cylinder 12. The power cylinder 14 includes an exhaust port 19 for releasing exhaust gases 20 from the power cylinder 14 into an exhaust passage 25.

5 An internal combustion engine (ICE) mode of operation is generally the normal operating mode of the split-cycle engine 10. The intake, compression, power and exhaust strokes of a conventional piston engine cycle are split between the compression 12 and
10 power cylinders 14 of the split-cycle engine 10. In the ICE mode, the compression piston 13 draws in and compresses ambient inlet air from intake passage 23 for use in the power cylinder 14. Compressed air and fuel communicated via fuel line 22 from fuel
15 reservoir 27 is admitted to the power cylinder 14 through the gas passage 16 shortly after the power piston 15 reaches its top dead center (TDC) position at the beginning of an expansion stroke. Alternatively, the fuel may be directly injected into
20 power cylinder 14 via fuel line 22. The fuel/air mixture is then ignited, burned and expanded on the same expansion stroke of the power piston 15, transmitting power to the crankshaft. The combustion products are discharged on the exhaust stroke through
25 exhaust passage 25.

Optionally, the engine 10 may include an air storage tank 24 and generally may be referred to as an air hybrid split-cycle engine 26. The air
30 hybrid split-cycle engine 26 includes all of the components of the split-cycle engine 10. As an air hybrid, the split-cycle engine 26 may store compressed air in the air storage tank 24 for later

use. The compressed air stored in the air storage tank 24 may be used as an intake air charge to be mixed with fuel for combustion within the power cylinder 12.

5

Alternatively, compressed air from the air storage tank 24 may be delivered to the power cylinder 14 without being mixed with fuel such that no combustion takes place in the power cylinder. In this mode of operation, the compressed air stored in the air storage tank 24 may be used to drive the power piston 15 in the power cylinder 14. This mode of operation generally may be referred to as an air motoring mode.

15

The present invention provides a waste heat recovery system 30 for the split-cycle engine 10. The waste heat recovery system 30 as seen in FIG. 1 utilizes waste heat generated by the split-cycle engine 10 and collected by one or more waste heat inputs 34 in fluid communication with a heat exchange unit 46. The waste heat input 34 typically receives engine waste heat from a fluid such as exhaust gas or engine coolant. The energy converted from the waste heat is used to power an air compression system 32. The air compression system 32 includes an air compressor device 48, such as a pump, turbine, or other compressor device, to compress ambient air, which is drawn in through an ambient air intake 18. Compressed air is communicated through a compressed air outlet 36 on the air compressor device 48 to the compression cylinder(s) 12 of the split-cycle engine 10. The compressed air may be further compressed in

20
25
30

compression cylinder 12 for immediate use in powering the split-cycle engine 10 when the engine is operating in its ICE mode. Alternatively, the compressed air may be stored in the air storage tank 5 24 for later use in the combustion process which powers engine 10. The stored compressed air may also be used to power the engine 10 without the need for combustion in the power cylinder 14 (e.g., in the air motoring mode). The present waste heat recovery 10 system 30 thereby utilizes engine heat that otherwise would be wasted and improves the fuel efficiency of the engine 10 by reducing fuel consumption.

Referring to FIGS. 1 through 3, the waste 15 heat recovery system 30 generally includes an air compression system 32. Engine waste heat received from one or more waste heat inputs 34 in communication with a heat exchange unit 46, such as a heat exchanger, receives engine waste heat from a 20 fluid, typically engine coolant, exhaust gas, or the like, and uses the energy of the waste heat to power the air compression system 32, which compresses ambient air. Compressed air and heat are outputs from the air compression system 32. The compressed 25 air may be inputted to the compression cylinder 12 of the split-cycle engine 10 to be used by the engine or stored in the storage tank 24 for later use, as described in more detail below.

30 The engine waste heat generated by the engine 10 includes both heat in the engine coolant and heat in the engine exhaust gases. In an engine coolant subsystem 40, the engine coolant draws heat

from the engine block in order to cool the engine block as known in the art. Engine coolant in the engine coolant subsystem 40 is communicated to the air compression system 32 and returned to the engine 5 10 via engine coolant subsystem return 41. Specifically, hot engine coolant is cycled through the air compression system 32 to transfer heat energy from the hot engine coolant to a heat exchange medium, which in turn flows in a cyclic loop via 10 circulation line 44 within the air compression system 32 and cools the engine coolant. Similarly, an exhaust gas subsystem 20 receives exhaust gases generated by the combustion process in the engine 10. The exhaust gas subsystem 20 communicates exhaust 15 gases to the air compression system 32. More specifically, the hot exhaust gases in the exhaust gas subsystem 20 are passed through the air compression system 32 to transfer heat energy to the heat exchange medium, and to recover heat energy in 20 the exhaust gases prior to venting the exhaust gas to atmosphere via an exhaust outlet 42.

The engine coolant subsystem 40 and exhaust gas subsystem 20 are in fluid communication with the 25 waste heat input 34 of the heat exchange unit 46. Heat from the engine coolant and the engine exhaust gases is transferred to the heat exchange medium via heat exchange unit 46. The heat exchange unit 46 is included in the air compression system 32. The heat 30 exchange unit 46 has a waste heat side and a heat exchange medium side. The waste heat input 34 receives fluids (e.g., coolant, exhaust gases) from the engine into the waste heat side of the heat

exchange unit 46. Waste heat outlets 47 are connected to the waste heat side of the heat exchange unit 46 for communicating fluids out of the waste heat side of the heat exchange unit. The heat exchange medium side of the heat exchange unit 46 includes a heat exchange medium inlet 49 for receiving heat exchange medium into the heat exchange unit. A heat exchange medium outlet 51 is connected to the heat exchange medium side for communicating heat exchange medium out of the heat exchange unit 46.

The heat exchange unit 46 may be an evaporator, boiler, or other suitable heat exchange apparatus. The heat exchange medium may be a refrigerant, water, or other similar heat exchange medium suitable for the present air compression system 32. In the heat exchange unit 46, the heat exchange medium is heated and changes from the liquid phase to the gas phase.

While passing through the heat exchange unit 46, the heat exchange medium absorbs the engine waste heat and is evaporated and converted to the gas phase. The expanding, gaseous heat exchange medium is then communicated from the heat exchange unit 46 via outlet 51 to a heat exchange medium inlet 53 of the air compressor device 48. The gaseous heat exchange medium is utilized to power the air compressor device 48, which draws in ambient air through intake 18 and outputs compressed air through outlet 36.

The heat exchange medium exits the air compressor device 48 through heat exchange medium outlet 55 and passes to a condenser 50 where it is condensed back to a liquid phase. In the condenser 50, any excess heat retained by the heat exchange medium 44 is captured and released to the atmosphere via a heat outlet 38 such as a vent or similar. The heat exchange medium is then pumped back to the heat exchange unit 46 by a pump 52 completing the fluid's flow loop to begin its cycle over again.

The air compression system 32 is coupled to a dedicated compression cylinder(s) 12 of the split-cycle engine 10. The compressed air from the air compression system 32 is fed to the compression cylinder 12 through the intake passage 23 of the compression cylinder. Ambient air may also be drawn into the compression cylinder 12 through the air intake 17 for compression in the compression cylinder. The compressed air may then travel to the power cylinder 14 through the gas passage 16. Alternatively, the compressed air may be stored in the air storage tank 24 for later use by the engine 10. The compressed air may enter the air storage tank 24 through a port 54 that branches off the gas passage 16.

Fuel may be directly injected into the power cylinder 14 for mixing with the compressed air 36 to form a combustible mixture that is ignited in the power cylinder to create power. Alternatively, the fuel may be port fuel injected into the gas passage 16 downstream of the branch port 54 to mix

with the compressed air prior to entering the power cylinder 14.

Combustion in the power cylinder 14
5 generates hot exhaust gases that are fed to the air
compression system 32 via the exhaust gas subsystem
20 as described above. Further, combustion in the
engine 10 heats the engine block. Engine coolant in
the engine coolant subsystem 40 is cycled through the
10 engine block to and from the air compression system
32 by a pump 56 to cool the engine block as described
above.

In the air motoring mode of operation, the
15 split-cycle engine 10 may use the compressed air
generated by the air compression system 32 and stored
in the air storage tank 24 to drive the power piston
15 in the power cylinder 14. After the compressed
air has expanded in the power cylinder 14, the air
20 may be exhausted through the exhaust passage 25. In
this mode, the compression cylinder 12 is idled and
no combustion takes place in the power cylinder 14.

Referring now to FIG. 4, in an alternative
25 embodiment of the air hybrid split-cycle engine 126,
compressed ambient air from the compression cylinder
112 enters the storage tank 124 through input passage
158, which is connected to port 154. The stored air
exits the air storage tank 124 through outlet passage
30 160, which is connected to port 162. Valves 164 and
166 control flow into and out of the tank 124, while
valve 168 controls flow across the gas passage 116.
With control valves 164 and 166 open and valve 168

closed, waste-heat generated compressed air may simultaneously charge the tank 124 through input passage 158 while driving the power cylinder 114 via output passage 160. Moreover, in this configuration, 5 valves 164, 166, and 168 may be utilized to provide additional flow control between the air tank 124 and either compression cylinder 112 or power cylinder 114. In other remaining aspects, the split-cycle air hybrid engine 126 has the same features as the split- 10 cycle air hybrid 26, and similar reference numerals indicate similar features.

Although the invention has been described by reference to a specific embodiment, it should be 15 understood that numerous changes may be made within the spirit and scope of the inventive concepts described. Accordingly, it is intended that the invention not be limited to the described embodiment, but that it have the full scope defined by the 20 language of the following claims.

2007229913 05 May 2010

- 19 -

Throughout this specification and the claims which follow, unless the context requires otherwise, the word "comprise", and variations such as "comprises" or "comprising", will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

The reference in this specification to any prior publication (or information derived from it), or to any matter which is known, is not, and should not be taken as, an acknowledgement or admission or any form of suggestion that that prior publication (or information derived from it) or known matter forms part of the common general knowledge in the field of endeavour to which this specification relates.

2007229913 05 May 2010

- 20 -

The claims defining the invention are as follows:

1. A waste heat recovery system for a split-cycle engine, the split-cycle engine including an engine block having a compression cylinder for receiving air and a power cylinder for receiving air and fuel disposed therein, a gas passage interconnecting the compression cylinder and the power cylinder, and an engine coolant subsystem including a pump for pumping liquid engine coolant through the engine block to remove engine waste heat therefrom, the waste heat recovery system comprising:
 - 5 a heat exchange unit having a waste heat input for receiving the liquid engine coolant pumped from the engine, a waste heat outlet for returning the liquid engine coolant to the engine, a heat exchange medium inlet and a heat exchange medium outlet;
 - 10 a heat exchange medium circulation loop connected to the heat exchange medium inlet and heat exchange medium outlet of the heat exchange unit;
 - 15 a heat exchange medium circulating within the heat exchange medium circulation loop, wherein the heat exchange medium enters the heat exchange unit through the heat exchange medium inlet in a liquid phase, absorbs the engine waste heat from the engine coolant while passing through the heat exchange unit, and exits the heat exchange unit in a gas phase through the heat exchange medium outlet;
 - 20 an air compressor device having a heat exchange medium inlet connected to the heat exchange medium outlet of the heat exchange unit, a heat exchange medium outlet connected to the heat exchange medium circulation loop, an ambient air intake for drawing in ambient air and a compressed air outlet connected directly to the compression cylinder of the engine;
 - 25 wherein the gaseous heat exchange medium enters the heat exchange medium inlet of the air compressor device and exits the heat exchange medium outlet of the air compressor device to power the air compressor device with the engine waste heat from the engine coolant;
 - 30 wherein the air compressor device draws in ambient air through the ambient air intake, transfers engine waste heat energy from the gaseous heat exchange

2007229913 05 May 2010

medium to the ambient air to produce waste-heat generated compressed air, and delivers the waste-heat generated compressed air directly to the compression cylinder of the engine through the compressed air outlet to recover the waste heat energy from the engine coolant.

5

2. The waste heat recovery system of claim 1, wherein the split-cycle engine includes an exhaust gas subsystem for removing exhaust gases from the engine through an exhaust port of the power cylinder, and the waste heat input of the heat exchange unit receives the exhaust gases from the exhaust gas subsystem and the waste heat outlet of the heat exchange unit vents the exhaust gases to atmosphere via an exhaust outlet, wherein the heat exchange medium absorbs engine waste heat from the engine exhaust gases while passing through the heat exchange unit.

10 3. The waste heat recovery system of claim 1, wherein the heat exchange medium is one of a refrigerant and water.

4. The waste heat recovery system of claim 1, including a condenser operatively connected to the heat exchange medium circulation loop.

20 5. The waste heat recovery system of claim 1, including a pump operatively connected to the heat exchange medium circulation loop for pumping the heat exchange medium through the heat exchange medium circulation loop.

25 6. The waste heat recovery system of claim 1, wherein the split-cycle engine includes an air storage tank connected to the gas passage, and the waste-heat generated compressed air delivered to the compression cylinder is stored in the air storage tank.

30 7. The waste heat recovery system of claim 6, including a first valve for controlling flow into the air storage tank, a second valve for controlling flow out of the air storage tank, and a third valve for controlling flow across the gas passage, wherein the waste-heat generated compressed air simultaneously charges the air storage tank and drives the power

2007229913 05 May 2010

- 22 -

cylinder when the first and second valves controlling flow into and out of the air storage tank are open and the third valve controlling flow across the gas passage is closed.

8. A method of recovering waste heat in a split-cycle engine, the method comprising:
- 5 providing a split-cycle engine including an engine block having a compression cylinder and a power cylinder disposed therein, a gas passage interconnecting the compression cylinder for receiving air and the power cylinder for receiving fuel and air, a crankshaft rotating about a crankshaft axis of the engine, a compression piston slidably received within the compression cylinder and operatively connected to the crankshaft such that the
- 10 compression piston reciprocates through an intake stroke and a compression stroke during a single rotation of the crankshaft, a power piston slidably received within the power cylinder and operatively connected to the crankshaft such that the power piston reciprocates through an expansion stroke and an exhaust stroke during the same rotation of the crankshaft, and an engine coolant subsystem including a pump for pumping liquid
- 15 engine coolant through the engine block to remove engine waste heat therefrom;
- receiving the liquid engine coolant pumped from the engine into a waste heat input of a heat exchange unit, and returning the liquid engine coolant to the engine through a waste heat outlet of the heat exchange unit;
- 20 circulating a heat exchange medium within a heat exchange medium circulation loop connected to a heat exchange medium inlet and a heat exchange medium outlet of the heat exchange unit, wherein the heat exchange medium enters the heat exchange unit through the heat exchange medium inlet in a liquid phase, absorbs the engine waste heat from the engine coolant while passing through the heat exchange unit, and exits the heat
- 25 exchange unit in a gas phase through the heat exchange medium outlet;
- delivering the heat exchange medium to an air compression device having a heat exchange medium inlet connected to the heat exchange medium outlet of the heat exchange unit, a heat exchange medium outlet connected to the heat exchange medium circulation loop, an ambient air intake for drawing in ambient air and a compressed air outlet connected to the compression
- 30 cylinder of the engine, wherein gaseous heat exchange medium enters the

2007229913 05 May 2010

heat exchange medium inlet of the air compressor device and exits the heat exchange medium outlet of the air compressor device;
utilizing engine waste heat energy from the engine coolant to power the air compressor device by drawing ambient air into the air compressor device through the ambient air intake, transferring engine waste heat energy from the gaseous heat exchange medium to the ambient air to produce waste-heat generated compressed air; and
delivering the waste-heat generated compressed air directly to the compression cylinder of the split-cycle engine through the compressed air outlet to recover the waste heat energy from the engine coolant.

9. The method of claim 8, including the step of:
communicating exhaust gases from the engine through an exhaust port of the power cylinder to the waste heat input of the heat exchange unit, and passing the exhaust gases through the heat exchange unit to transfer waste heat energy from the exhaust gases to the heat exchange medium.

10. The method of claim 9, including the step of:
venting the engine exhaust gases to the atmosphere after the engine exhaust gases are passed through the heat exchange unit.

11. The method of claim 8, wherein the step of circulating the heat exchange medium includes:
pumping the heat exchange medium.

12. The method of claim 8, including the step of:
providing a condenser connected to the heat exchange medium circulation loop downstream from the air compressor device for changing the heat exchange medium from the gas phase to the liquid phase.

13. The method of claim 12, including the step of:

2007229913 05 May 2010

venting excess heat from the condenser to the atmosphere.

14. The method of claim 8, including the step of:
storing waste-heat generated compressed air that is delivered to the compression
5 cylinder in an air storage tank of the split-cycle engine that is connected to
the gas passage, and
driving the power piston with waste-heat generated compressed air from the air storage
tank.
- 10 15. A waste heat recovery system for a split-cycle engine, substantially as hereinbefore
described with reference to the accompanying figures.
16. A method of recovering waste heat in a split-cycle engine, substantially as
hereinbefore described with reference to the accompanying figures.

15

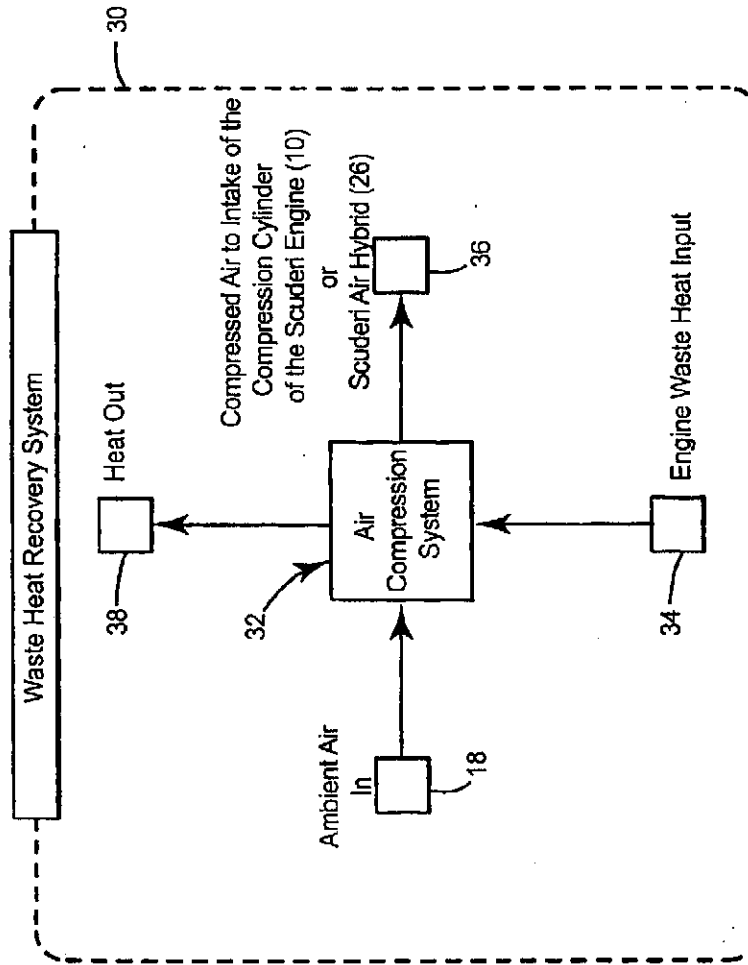
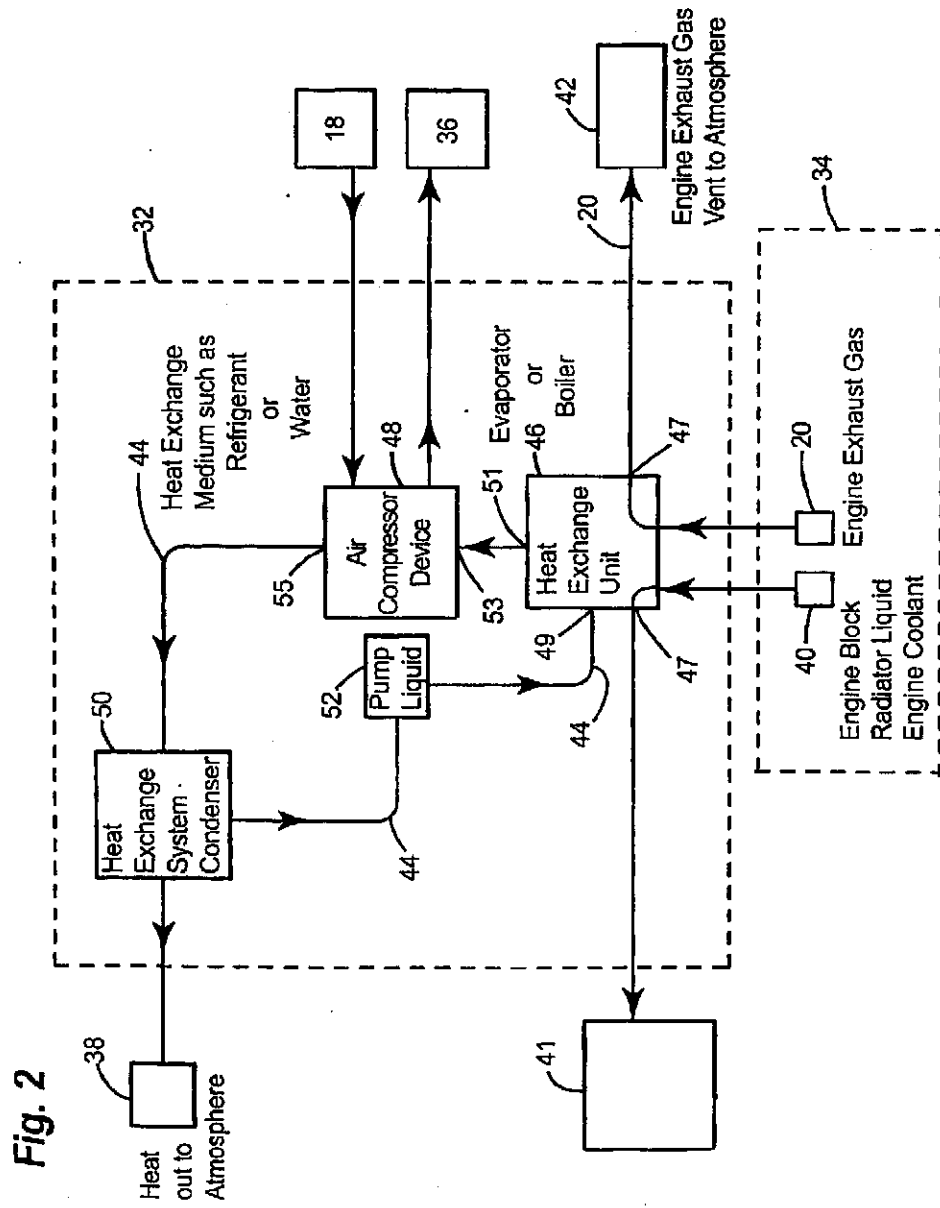


Fig. 1



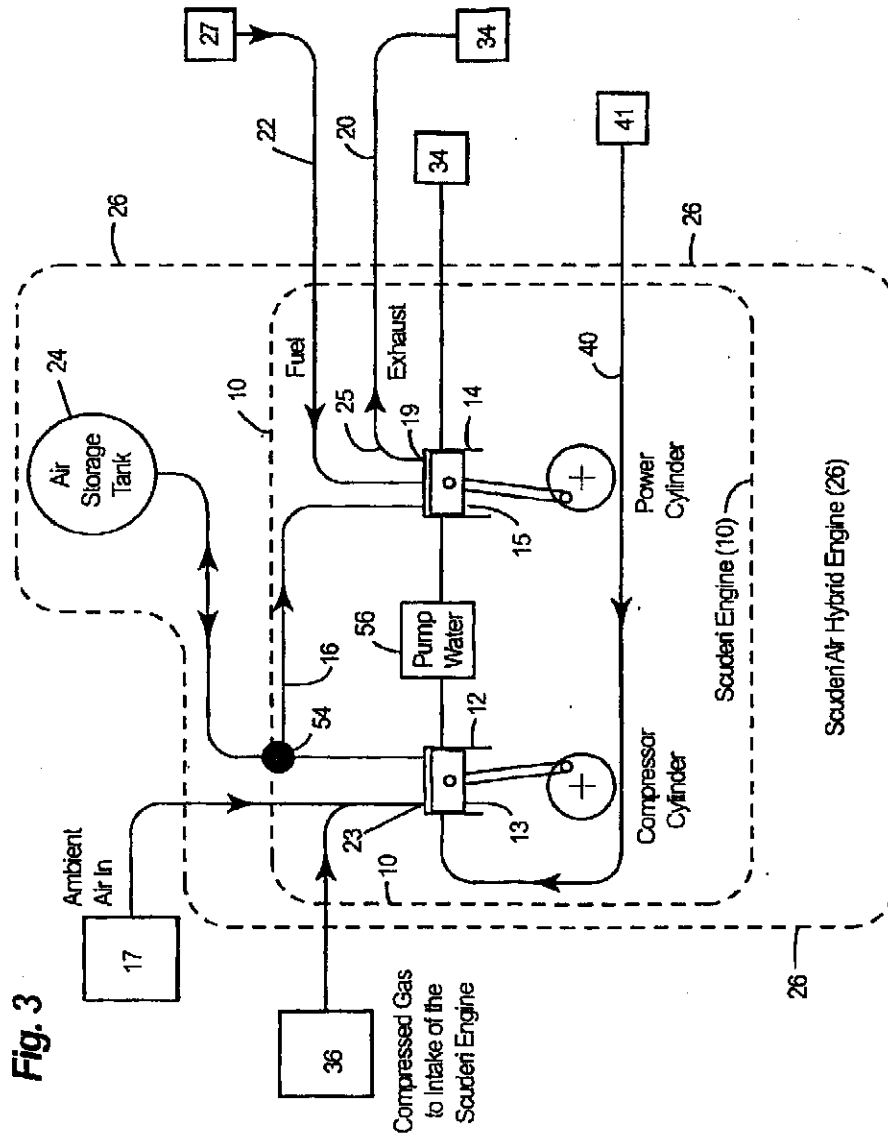


Fig. 3

Compressed Gas to Intake of the Scuderi Engine

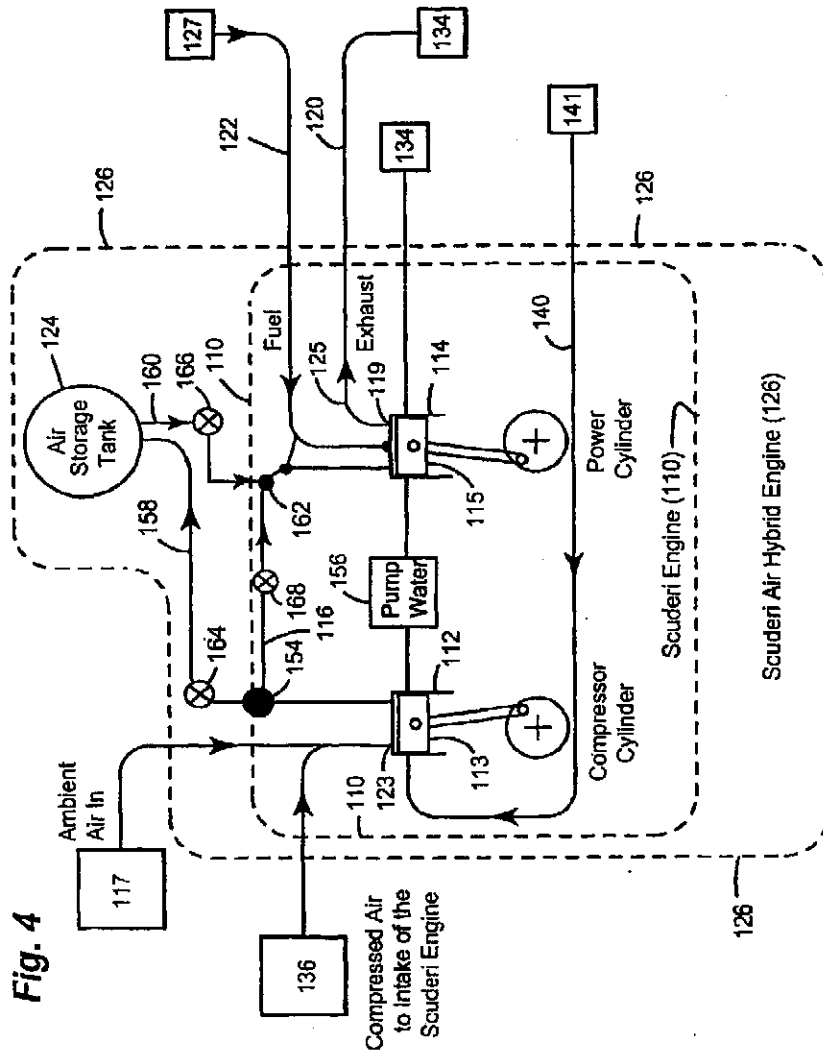


Fig. 4

Compressed Air to intake of the Scuderi Engine