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(54) PROCESS AND DEVICE FOR THE RECOVERY OF ENERGY

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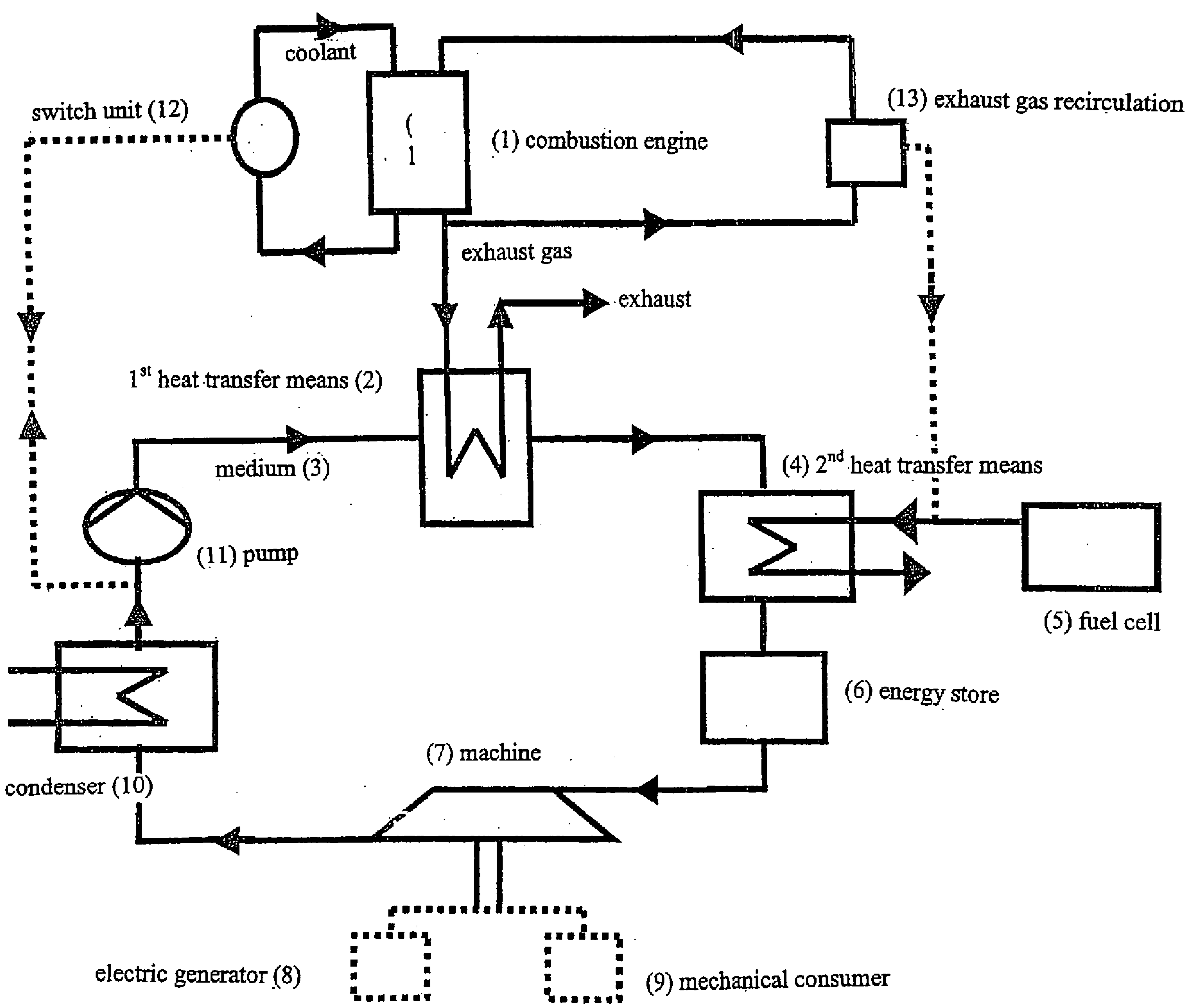
(57) ABSTRACT

The invention relates to a process and device for the recovery of energy from the waste heat of thermal or chemical processes, wherein at least a portion of said waste heat evaporates a liquid via at least one heat transfer means or heats a vapour or a gas, increasing the pressure thereof, and this pressure is transformed into mechanical energy in an engine (FIG. 1).



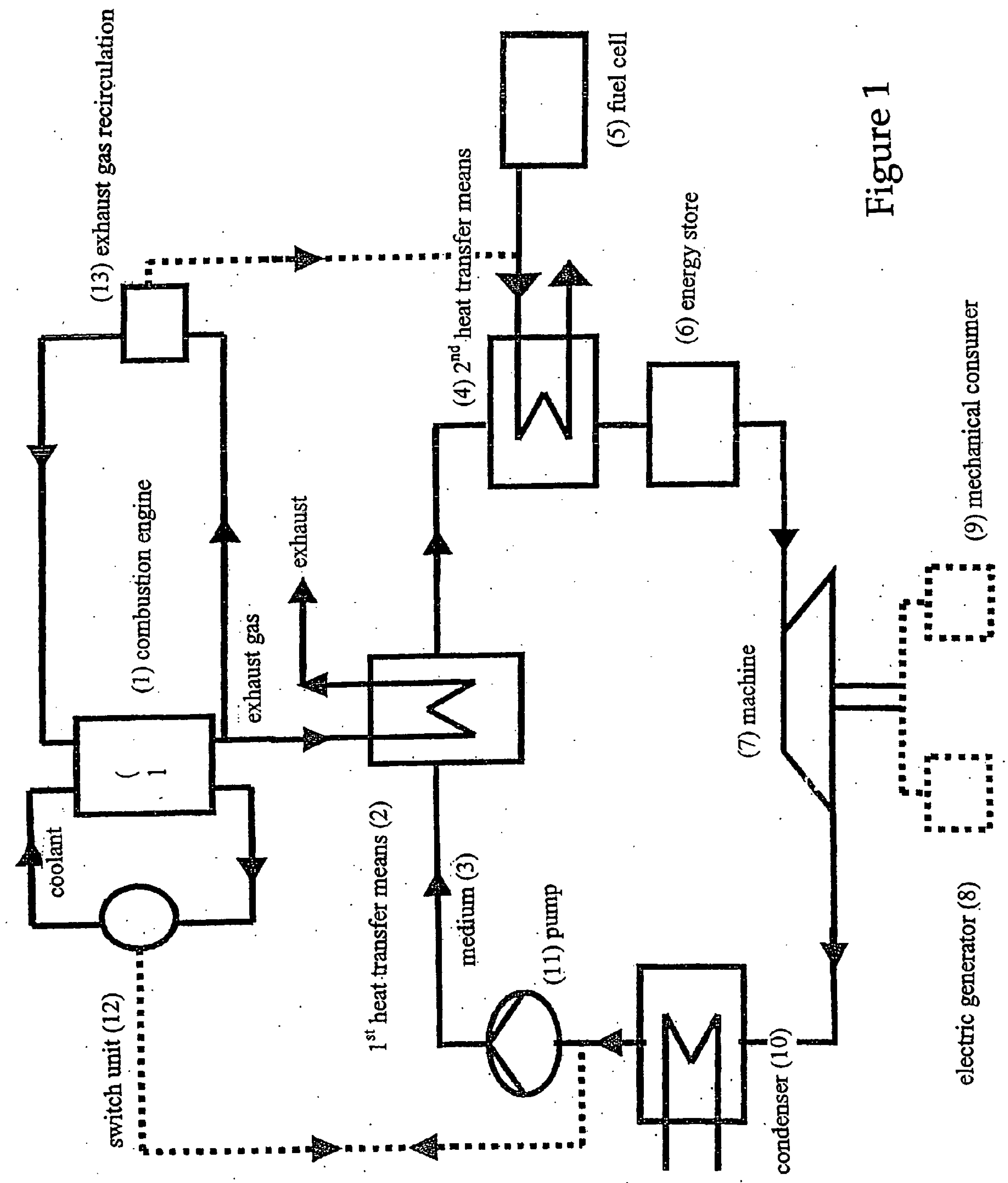

(13) exhaust gas recirculation
(5) fuel cell
(4) 2nd heat transfer means
(6) energy store
(1) combustion engine
exhaust gas
exhaust
coolant
switch unit (12)
1st heat transfer means (2)
medium (3)
(11) pump
condenser (10)
(7) machine
(9) mechanical consumer
electric generator (8)

Figure 1

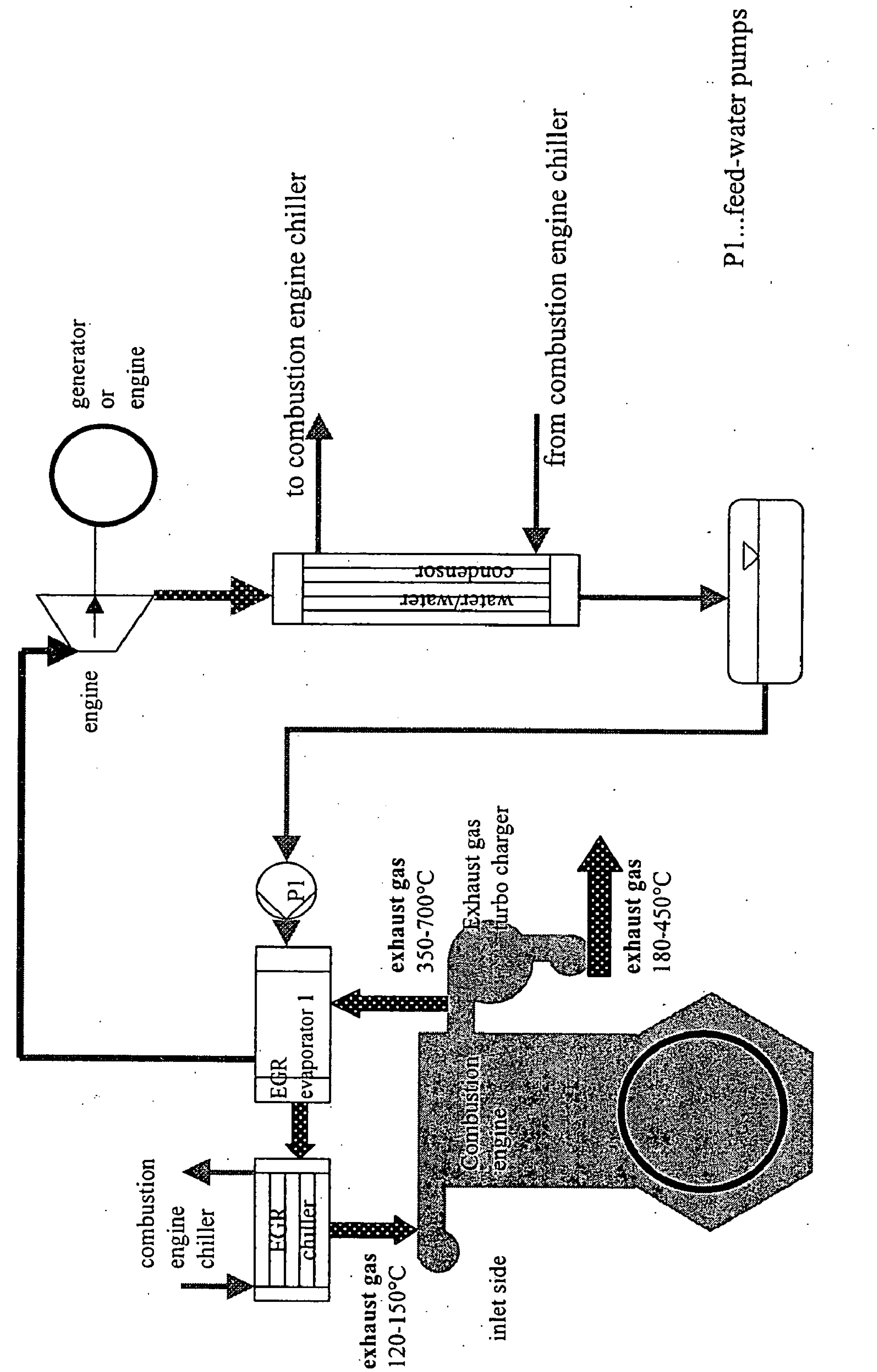

generator
or
engine
to combustion engine chiller
from combustion engine chiller
P1...feed-water pumps
engine
water/water
condensor
P1
exhaust gas
350-700°C
Exhaust gas
turbo charger
exhaust gas
180-450°C
EGR
evaporator 1
Combustion
engine
combustion
engine
chiller
EGR
chiller
exhaust gas
120-150°C
inlet side

Figure 2

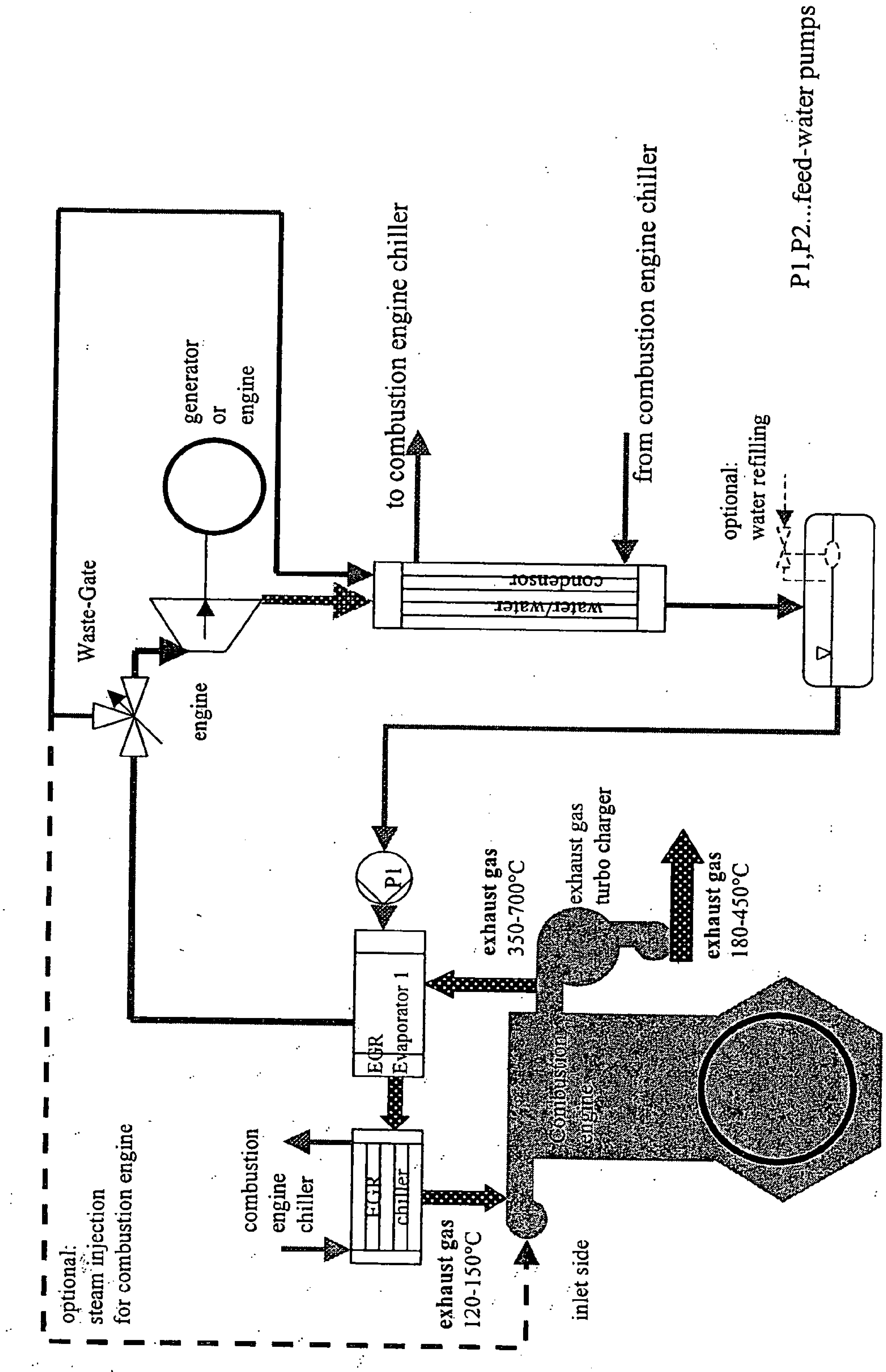

P1,P2...feed-water pumps
to combustion engine chiller
from combustion engine chiller
generator
or
engine
Waste-Gate
engine
water/water
condensor
optional:
water refilling
P1
EGR
Evaporator 1
exhaust gas
350-700°C
exhaust gas
turbo charger
exhaust gas
180-450°C
Combustion
engine
combustion
engine
chiller
EGR
chiller
exhaust gas
120-150°C
inlet side
optional:
steam injection
for combustion engine

Figure 3

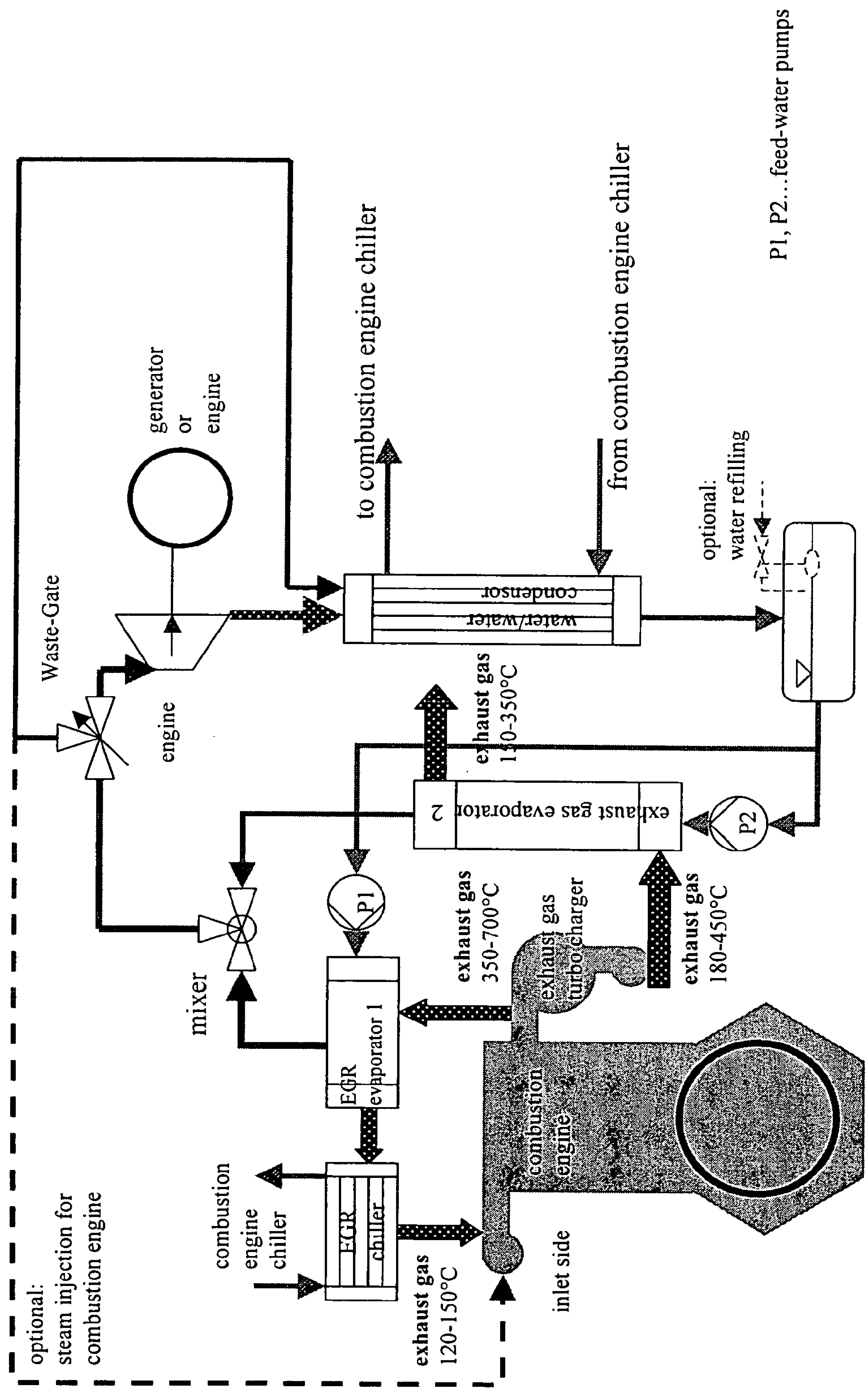

P1, P2...feed-water pumps
generator
or
engine
Waste-Gate
engine
to combustion engine chiller
from combustion engine chiller
water/water
condensor
optional:
water refilling
exhaust gas
150-350°C
exhaust gas evaporator 2
P2
P1
mixer
exhaust gas
350-700°C
exhaust gas
turbocharger
exhaust gas
180-450°C
EGR
evaporator 1
combustion
engine
combustion
engine
chiller
EGR
chiller
exhaust gas
120-150°C
inlet side
optional:
steam injection for
combustion engine

Figure 4

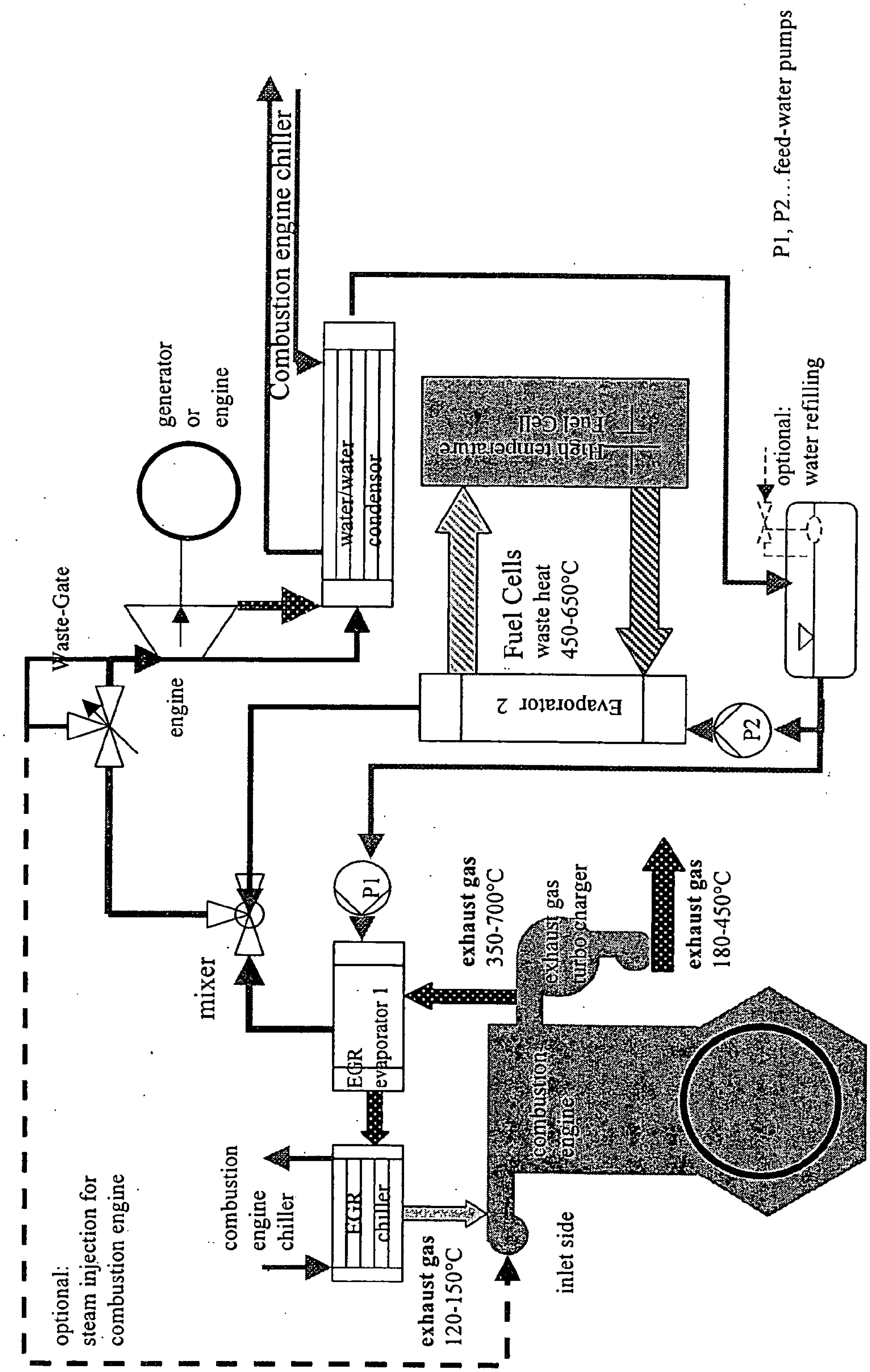
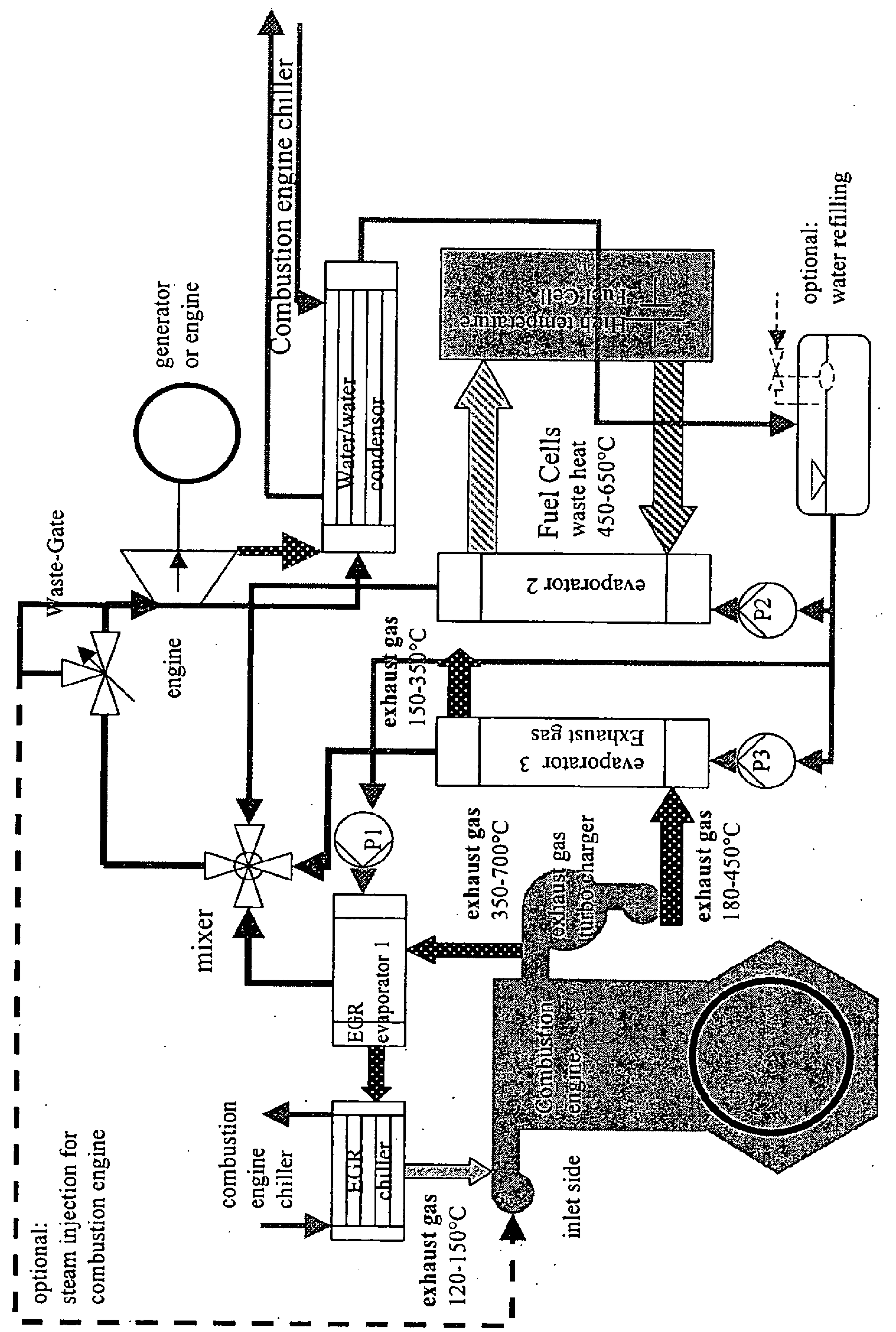

Combustion engine chiller
generator or engine
Waste-Gate
engine
water/water condensor
High temperature Fuel Cell
Fuel Cells waste heat 450-650°C
Evaporator 2
optional: water refilling
P1, P2... feed-water pumps
P2
P1
mixer
EGR evaporator 1
exhaust gas 350-700°C
exhaust gas turbo charger
exhaust gas 180-450°C
combustion engine
EGR chiller
combustion engine chiller
exhaust gas 120-150°C
inlet side
optional: steam injection for combustion engine

Figure 5



P1, P2, P3...feed-water pumps

Figure 6

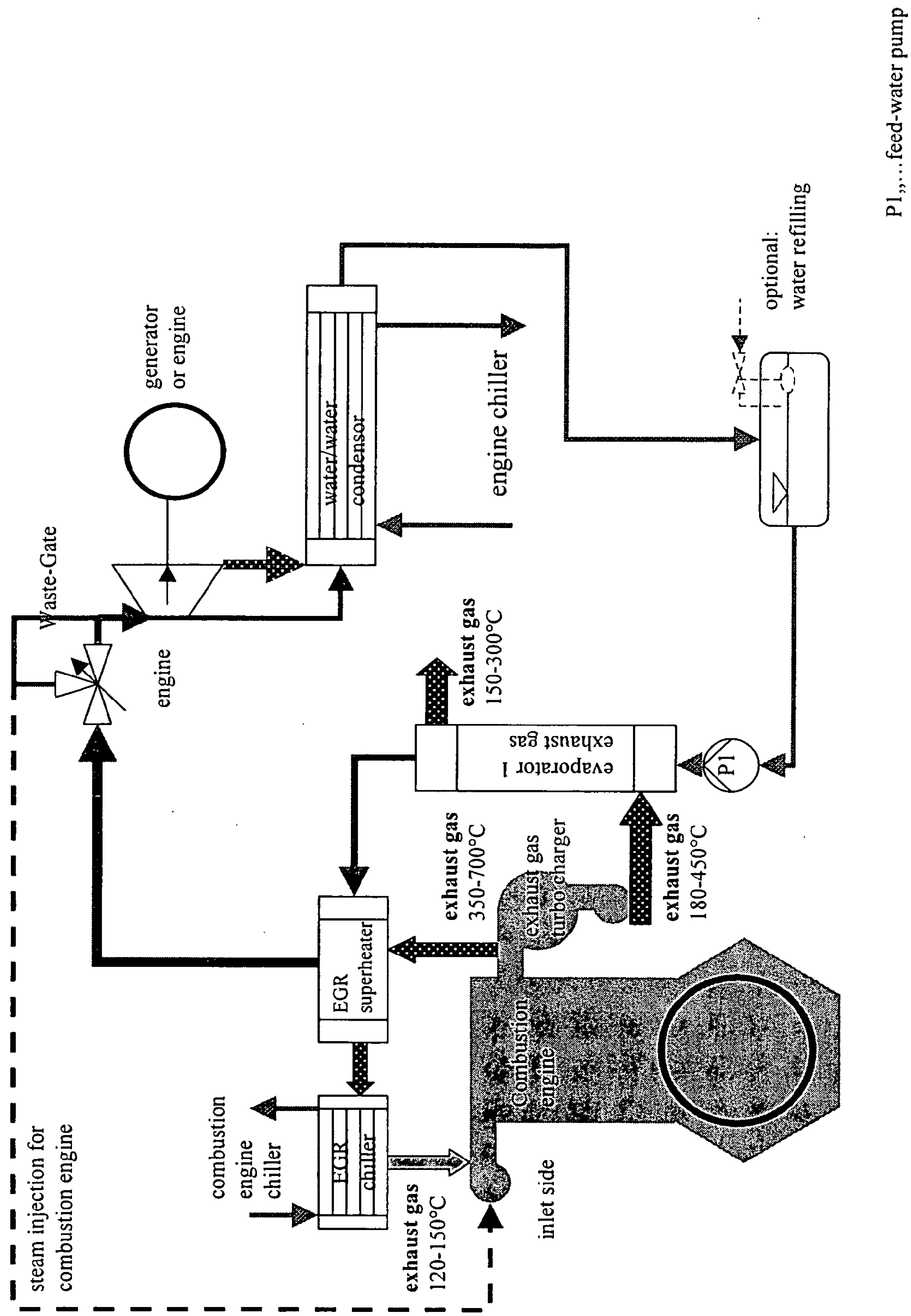

Waste-Gate
engine
generator
or engine
water/water
condensor
engine chiller
optional:
water refilling
P1,,...feed-water pump
exhaust gas
150-300°C
evaporator 1
exhaust gas
P1
exhaust gas
350-700°C
exhaust gas
turbocharger
exhaust gas
180-450°C
EGR
superheater
Combustion
engine
combustion
engine
chiller
EGR
chiller
exhaust gas
120-150°C
inlet side
steam injection for
combustion engine

Figure 7

PROCESS AND DEVICE FOR THE RECOVERY OF ENERGY

[**0001**] The invention relates to a process according to the preambles of claims **1** and **2** and in each case to a device for carrying out these processes.

[**0002**] Processes for the recovery of energy from exhaust gases in the large-scale commercial section of industrial plants are known from the prior art, wherein essentially stationary processes yield a comparatively constant exhaust gas stream, which usually flows directly back to the process via a recirculation process. The so-called cogeneration, wherein the thermal energy arising, e.g., in a steam plant is used directly for heating purposes or as process heat, is, by far, more widely used.

[**0003**] In U.S. Pat. No. 5,896,738, for instance, a system for the generation of steam from the exhaust gas of a gas turbine is described, wherein the superheated steam mixed with fuel is returned to the turbine. This system makes sense in large stationary plants with optimized efficiency. In a mobile use under variable load conditions, the additional water consumption would be unacceptable on the one hand and, on the other hand, the efficiency gain for the auxiliary energy would be forgone.

[**0004**] U.S. Pat. No. 4,729,225 describes a system wherein the turbo charger is designed for such an amount of excess energy that said energy can be used for auxiliary drive purposes. Such a solution has the drawback that it has a direct impact on the design of the combustion engine and, reciprocally, depends more strongly on the operating condition thereof and hence cannot be used as an independent system for the generation of auxiliary energy.

[**0005**] Document WO 02/31319 discloses a Rankine-process device for an internal combustion engine, wherein energy is recovered from the waste heat of a process. In the abstract, it is explained that a portion of the waste heat evaporates a liquid via a heat transfer means, increasing the pressure thereof, and this pressure is transformed into mechanical energy in an engine.

[**0006**] In a first stage, water is thereby preheated in a first heat exchanger in the exhaust gas. The preheated water is guided around the cylinder block to a water jacket. Thereupon, a steam turbine transforms the pressure into mechanical energy.

[**0007**] The documents U.S. Pat. Nos. 5,327,987, 5,609,029, WO 94/28298, U.S. Pat. No. 6,155,212, JP2001-132538 and U.S. Pat. No. 4,470,476 also each disclose a device and a process of a similar type.

[**0008**] The exhaust gas recirculation (EGR) is a known process in order to be able to reduce the undesired NOx-emissions in the exhaust gas of (diesel) motor vehicles or other means of transport such as ships etc. A portion of the exhaust gases is returned to the combustion air or to the fuel/air mixture, respectively, via the engine's suction system. A temperature decrease and a delay in the combustion and hence a reduction in the discharge of nitrogen oxide by approx. 40% are feasible; as a rule, the EGR is also associated with a slightly higher consumption of fuel.

[**0009**] As is known, the exhaust gases of the combustion engines of freight and passenger vehicles reach temperatures of 700 or 450° C., respectively. Those hot exhaust gases must be cooled to temperatures in the order of 150 to 200° C. so that it is possible to return those gases, which are mixed with combustion air, to the engine. A temperature decrease in the exhaust gas is feasible via the incorporation of a heat exchanger, and, in a standard design, this is indeed constructed in that way.

[**0010**] In the heat exchanger, for example the coolant which cools also the combustion engine itself can be located. The coolant then flows in a machine-cooling system-loop: First, it absorbs heat from the engine and subsequently also from the exhaust gas in order to finally release heat into the environment via a radiator. However, in this system, very high demands are made both on the heat exchanger and on the radiator (compact design, material resistance against high temperatures, corrosion and depositions) due to the increased temperatures.

[**0011**] In EP 1 091 113 A, possibilities are shown which avoid or at least minimize the problems just described. For example, the incorporation of a second high-temperature exhaust gas cooler leads to the absorption of a large portion of the heat, resulting in that the actual machine-cooling system-loop can operate as usual and that no restrictions due to the high temperatures have to be imposed. This second exhaust gas cooler is provided in a cooling loop comprising a second radiator. An altogether more effective EGR-cooling can be achieved, which, in addition, is not necessarily associated with an increase in the radiator surface.

[**0012**] In any case, thermal energy must be withdrawn from the hot exhaust gas so that it can be used in an EGR in such a way that a reduction in the discharge of nitrogen oxide will occur. By means of the known methods, the temperature of the exhaust gas can be brought to the required value, however—and that is clearly the great potential of the invention—the energy of the exhaust gas is merely discharged without being intended for any further use.

[**0013**] Therefore, the invention has the task, namely, first of all, of obtaining a reduction in the thermal load for the cooling system by coverting the thermal energy of the exhaust gas in the exhaust gas recirculation into mechanically usable energy and, secondly, of creating a use of the system in terms of a further decrease in the emissions of the combustion engine.

[**0014**] According to the invention, this task is achieved in that at least a portion of the waste heat of the recycled exhaust gas evaporates a liquid and/or heats a vapour and/or a gas, increasing the pressure thereof, and this pressure is transformed into mechanical energy in an engine. Advantageous variants thereof are illustrated in the dependent claims **3** to **15**.

[**0015**] According to a variant, in a process for the recovery of energy from the waste heat of a combustion engine, in particular of a mobile combustion engine, and of a fuel cell, at least a portion of the waste heat of the exhaust gas of the combustion engine, in particular of a recycled exhaust gas, and at least a portion of the waste heat of the fuel cell evaporate a liquid and/or heat a vapour and/or a gas, increasing the pressure thereof, and this pressure is transformed into mechanical energy in an engine. Advantageous variants are included in the dependent claims **3** to **16**.

[**0016**] Claims **17** to **32** include preferred embodiments of devices for carrying out the claimed processes.

[0017] Solutions wherein, under variable practical operating conditions, the waste heat of a combustion engine comprising an exhaust gas recirculation and/or of a fuel cell, is transformed into an energy different from thermal energy, have not been used so far. Thereby, the use as auxiliary energy for different consumers present in connection with the primary chemical or thermal process must be mentioned as particularly advantageous. Those consumers may require mechanical energy, such as, for example, a compressor for an air-conditioning system, or also electrical energy, such as, for example, servo motors in the control process, or the lighting of a vehicle. The specific advantage in terms of energy technology consists, for example, in that the use of energy produced via the primary chemical or thermal process, respectively, is always subject to the full losses of the process, i.e., any energy withdrawn productively will always produce further waste energy whereas the use of lost energy from the exhaust gas will not create any further demand for primary energy. If efficiencies of 10 to 35% are regarded as typical for an internal combustion engine which sometimes even has to be kept in operation specially for the required auxiliary energy, the energy recovered by the present invention saves, as a primary energy input, three to ten times as much.

[0018] Solutions wherein the auxiliary energy of a vehicle is generated, e.g., via a separate small diesel engine or, e.g., also via a fuel cell are likewise known from the literature. Both types of auxiliary energy sources (APU=Auxiliary Power Unit) exhibit comparatively large heat losses.

[0019] Therefore, the present invention makes use of the excess energy of waste beat arising in a vehicle driven by an internal combustion engine comprising an exhaust gas recirculation, by supplying the same via a thermal intermediate circuit, preferably involving superheated steam, to an additional engine, preferably a steam turbine, and by withdrawing mechanical energy either directly at the output of the steam turbine or transforming the same into electric current via a generator known per se. In the same manner, the waste heat of the auxiliary energy sources is used for energy utilization.

[0020] Depending on the process and design of the thermal or chemical process, respectively, temperatures of 300° C. to 1000° C. can be used for the recovery of energy. In combustion engines, particularly the exhaust gas is usable and is generally available at 300 to 600° C. Similarly, fuel cells, if designed as high-temperature fuel cells, also have high exhaust gas and coolant temperatures, which can reach up to 1000° C. High-temperature fuel cells are also used because they have a slightly higher efficiency and are more tolerant in terms of the supplied fuel. However, as a guide value, it can also be assumed that approx. 50% of the supplied energy will go into the exhaust gas or is available from the cooling process.

[0021] In the thermal intermediate circuit, a medium, optionally pressurized, circulates, which, via heat transfer means, absorbs the thermal energy from the exhaust gas and/or the cooling circuit of the thermal or chemical process and subsequently releases the same in the additional engine. Such a medium can be any liquid suitable for a cooling or heating circuit, or a vapour or a gas. Since a mobile plant occasionally also has to be operated at temperatures below 0° C., the medium is chosen such that it does not solidify at ambient temperatures normal for vehicles. A simple and proven example thereof is water mixed with antifreeze. A particularly favourable embodiment provides that the thermal intermediate circuit is connected directly to the coolant circuit of the internal combustion engine, the same medium is used and the through-flow between the two circuits can be controlled via, e.g., a valve. In this way, on the one hand, the medium cooled after the engine can contribute to the cooling of the internal combustion engine, and, on the other hands the medium preheated by the internal combustion engine can reach a higher temperature after the heat transfer means from the exhaust gas. This means that, in addition, another portion of the thermal energy flowing into the cooling circuit of the internal combustion engine is recovered. Reciprocally, the energy recovered from the exhaust gas of the auxiliary energy source, for instance of a fuel cell, can also be used for preheating the internal combustion engine prior to the start. This guarantees a reduced exhaust-gas discharge during the cold start and, optionally, also a preheating of the passenger compartment via the conventional beating of the vehicle.

[0022] In a further advantageous embodiment, the medium of the thermal intermediate circuit is heated in at least two stages. The waste heat of the combustion engine is used for preheating in a first stage, and the waste heat of a second thermal or chemical process, for example of the auxiliary energy source, heats the medium in a second stage to the higher final value for the supply to the additional engine. By means of this design comprising at least two stages, the efficiency of the device for the recovery of energy from the exhaust gas can be increased substantially, since the inlet temperature into the engine is higher.

[0023] In the normal case, the heating of the medium is performed via heat exchangers in one of the usual designs. A particularly advantageous embodiment of a heat exchanger consists in that the ratio of surface to volume is maximized via extremely fine metal structures. In doing so, the gas flow control is chosen such that laminar streams, which reduce the heat transfer, are prevented from occurring. Heat exchangers have the effect that the temperature of the medium in the intermediate circuit is always cooler than the waste heat used for the heat transfer. Thus, if the internal combustion engine has an exhaust gas temperature of, e.g., 300° C. at the location where the exhaust gas can be guided into the heat exchanger without negative repercussions on the combustion process, the medium in the intermediate circuit can reach only about 260-280° C. In one embodiment of the invention it is therefore suggested that a heat pump is used as a heat transfer means either instead of or in addition to a heat exchanger. Thereby, the temperature of the medium and the heat content thereof can be increased clearly beyond those of the exhaust gas of the internal combustion engine. This allows, in turn, an improved efficiency of the engine, preferably the steam turbine.

[0024] A preferred embodiment of the invention is described below.

[0025] According to **FIG. 1**, after the possibly provided turbo charger, the exhaust gas of a combustion engine **1** is guided through a first heat transfer means **2**, prior to proceeding to the further exhaust gas aftertreatment and to the exhaust. In the heat transfer means **2**, it thus heats a medium **3**, preferably the condensate of a water/antifreeze mixture, which thereby forms superheated steam. The medium **3** is passed on to a possible second heat transfer means **4**, which is charged on the primary side, e.g., by the exhaust gas or the coolant of a fuel cell **5**, thus producing an additional overheating of the medium **3**.

[**0026**] Alternatively or additionally, the heat from an exhaust gas recirculation **13** of the combustion engine **1** can also be supplied to a heat transfer means, preferably to the second one **4**—optionally also to another one.

[**0027**] In the steam cycle, an energy store **6** makes sure that a variable occurrence of power as well as a variable demand can be compensated for. After the energy store, the medium **3** drives an engine **7**, preferably a steam turbine, which transfers its energy via the output shaft to an electric generator **8** and/or to a mechanical consumer **9**. The medium is returned to the liquid state via a condenser **10** and is re-pressurized by a pump **11** and again returned to the circuit.

[**0028**] In an advantageous advanced embodiment, the medium **3** is charged directly from the cooling circuit of the combustion engine **1** via a switch unit **12**. In normal operation, the medium circulates in a closed circuit. Under certain operating conditions, such as, e.g., in a cold start, the two circuits can be interconnected so that the warmer one preheats the other one.

[**0029**] In another embodiment according to the invention, the engine **7** is a piston engine, either a reciprocating piston engine or a rotating piston engine, or a gas turbine.

[**0030**] In a further embodiment according to the invention, the heat transfer means **2** can be a heat pump for increasing the temperature level of the medium **3** beyond that of the waste heat from the thermal process of the combustion engine **1**.

[**0031**] According to the invention and according to **FIG. 2**, the heat of the exhaust gas, which must be cooled for the EGR, is used such that it evaporates the liquid agent flowing through the first heat exchanger (EGR evaporator **1**). The energy contained in the vapour can be used for another energy utilization, before the reliquified vapour again passes through the circuit. The energy rendered usable for mechanical purposes is not necessarily discharged via the engine heat exchanger (chiller, radiator). Thus, said heat exchanger can either be designed smaller or can yield the required cooling capacity for correspondingly higher exhaust gas recirculation rates—involving a corresponding benefit in terms of a decrease in the emissions of nitrogen oxide.

[**0032**] Since engines operating on the expansion of steam exhibit a narrow optimal operating range, in a special embodiment, the mass flow and the pressure applied on the engine are limited by a waste-gate. In said embodiment, the surplus portion of the vapour generated in the process is added to the combustion air. This is a process known per se which also serves for the purpose of reducing the amount of nitrogen oxide. A direct coupling of those measures is advantageous, since the operating ranges which exhibit high recoverable thermal energy flows (full load) are also those ranges in which the discharge of nitrogen oxide emissions reaches its peak. However, in this operating mode, the vapour is used up so that it becomes necessary to refill the system (**FIG. 3**).

[**0033**] The vapour can be mixed with a vapour generated otherwise in order to increase, in this manner, the volume rather than the temperature (**FIG. 4, 5, 6**). An increased vapour volume can be used for efficiency purposes in analogy to a vapour compressed by pressure. The vapour generated otherwise can originate both from energy sources of a heat engine and from a fuel cell. The coupling of all heat sources is also provided according to the invention (**FIG. 6**).

[**0034**] However, due to the higher temperature of the exhaust gas in the exhaust gas recirculation circuit, the energy from the EGR can also be used for superheating a vapour already generated otherwise (**FIG. 7**), which then can drive, e.g., an engine connected to a generator and/or mechanical consumers via a drive shaft.

[**0035**] The individual evaporators according to **FIGS. 4, 5** and **6** are operated in feedback with the evaporator output so that equal pressure conditions prevail in the evaporator circuits and it becomes possible to mix the vapour generated in the evaporator connected in parallel. This is achieved by means of output-controlled pumps P**1**, P**2** and P**3**.

[**0036**] However, according to **FIG. 7**, two evaporators connected in series are provided.

1. A process for the recovery of energy from the waste heat of a combustion engine comprising an exhaust gas recirculation, in particular of a mobile combustion engine, characterized in that at least a portion of the waste heat of the recycled exhaust gas evaporates a liquid and/or heats a vapour and/or a gas, increasing the pressure thereof, and this pressure is transformed into mechanical energy in an engine.

2. A process for the recovery of energy from the waste heat of a combustion engine, in particular of a mobile combustion engine, and of a fuel cell, characterized in that at least a portion of the waste heat of the exhaust gas of the combustion engine, in particular of a recycled exhaust gas, and at least a portion of the waste heat of the fuel cell evaporate a liquid and/or heat a vapour and/or a gas, increasing the pressure thereof, and this pressure is transformed into mechanical energy in an engine.

3. A process according to claim 1, characterized in that the vapour or gas is evaporated or heated, respectively, in two or more stages.

4. A process according to claim 1, characterized in that the conversion into mechanical energy is carried out via a steam turbine.

5. A process according to claim 1, characterized in that the conversion into mechanical energy is carried out via a gas turbine.

6. A process according claim 1, characterized in that the conversion into mechanical energy is carried out via a piston engine.

7. A process according to claim 1, characterized in that at least one heat transfer stage is a heat pump.

8. A process according to claim 1 characterized in that, in front of the engine, energy is stored in an energy store.

9. A process according to claim 1, characterized in that the mechanical energy is used as an auxiliary energy for the combustion engine and/or for the fuel cell and/or as an auxiliary energy in means of transport such as vehicles, preferably for driving a coolant pump and/or a hydraulic unit and/or a compressor for an air-conditioning system.

10. A process according to claim 1, characterized in that the mechanical energy is transformed into electrical energy.

11. A process according to claim 10, characterized in that the electrical energy is used as an auxiliary energy for the combustion engine and/or for the fuel cell and/or as an auxiliary energy in vehicles, preferably for driving a coolant pump and/or a hydraulic unit and/or a compressor for an air-conditioning system.

12. A process according to claim 1, characterized by an exhaust gas turbine of the combustion engine, wherein exhaust gas to be recycled is branched off before the exhaust gas is introduced into the exhaust gas turbine.

13. A process according to claim 12, characterized in that at least a portion of the waste heat of the exhaust gas expanded in the exhaust gas turbine evaporates a liquid and/or heats a vapour and/or a gas, increasing the pressure thereof, and this pressure is transformed into mechanical energy in an engine.

14. A process according to claim 12, characterized in that the liquid or the vapour or the gas, respectively, heated by the expanded exhaust gas, is heated further, in particular superheated, by the exhaust gas to be recycled.

15. A process according to claim 12, characterized in that the liquid or the vapour or the gas, respectively, heated by the expanded exhaust gas, is mixed with the liquid or the vapour or the gas, respectively, heated by the recycled exhaust gas.

16. A process according to claim 2, characterized in that a liquid or a vapour or a gas, respectively, heated by the waste heat of the fuel cell is mixed with a liquid or a vapour or a gas, respectively, heated by the exhaust gas of the combustion engine.

17. A device for the recovery of energy from the waste heat of a combustion engine comprising an exhaust gas recirculation, in particular of a mobile combustion engine, characterized by the combination of the following features:

at least one heat transfer means for transferring the thermal energy of the recycled exhaust gas to a heat carrier medium,

a device for increasing the pressure of the heat carrier medium,

an engine, preferably a steam turbine, which transforms the energy stored in the heat carrier medium into mechanical energy.

18. A device for the recovery of energy from the waste heat of a combustion engine, in particular of a mobile combustion engine, and of a fuel cell, characterized by the combination of the following features:

at least one heat transfer means for transferring the thermal energy of the exhaust gas of the combustion engine to a heat carrier medium,

at least one heat transfer means for transferring the thermal energy of the fuel cell to a heat carrier medium,

a device for increasing the pressure of the heat carrier medium,

an engine, preferably a steam turbine, which transforms the energy stored in the heat carrier medium into mechanical energy.

19. A device according to claim 17, characterized by two or more heat transfer means which gradually heat the heat carrier medium.

20. A device according to claim 17, characterized in that the heat carrier medium is identical with the cooling medium for the combustion engine and/or the fuel cell.

21. A device according to claim 17, characterized in that at least one heat transfer means is a heat pump.

22. A device according to claim 17, characterized in that an energy store is arranged in front of the engine.

23. A device according to claim 17, characterized in that the engine is coupled with at least one drive for at least one auxiliary power unit for the thermal or chemical process, preferably cooling or lubricant pumps.

24. A device according to claim 17, characterized in that the engine is coupled with at least one drive for at least one auxiliary power unit for a vehicle, preferably with the drive of a hydraulic unit and/or a compressor for an air-conditioning system

25. A device according to claim 17, comprising an electric power generator, preferably a generator, which is drivable by the engine and transforms at least a portion of the mechanical energy into electrical energy.

26. A device according to claim 25, characterized in that the electrical energy is provided for the operation of auxiliary power units for the combustion engine and/or the fuel cell, preferably of cooling or lubricant pumps.

27. A device according to claim 25, characterized in that the electrical energy is provided for the operation of auxiliary power units for a vehicle, preferably of a hydraulic unit and/or a compressor for an air-conditioning system.

28. A device according to claim 17, characterized by an exhaust gas turbine of the combustion engine, wherein an exhaust-gas branch duct for exhaust gas to be recycled, which branches off—in the flow direction of the exhaust gas—from the exhaust gas duct in front of the exhaust gas turbine, runs into a heat transfer means.

29. A device according to claim 28, characterized in that a heat transfer means for exhaust gas expanded in the exhaust gas turbine is arranged downstream of the exhaust gas turbine.

30. A device according to claim 28, characterized in that a heat carrier medium duct runs from the heat transfer means arranged downstream of the exhaust gas turbine to the heat transfer means for the exhaust gas to be recycled.

31. A device according to claim 28, characterized in that a mixing device for the heat carrier medium heated by the exhaust gas to be recycled and the heat carrier medium heated by the remaining exhaust gas is provided.

32. A device according to claim 28, characterized in that a heat carrier medium heated by the fuel cell can be supplied via a duct to a mixing device for mixing with a heat carrier medium heated by the exhaust gas of the combustion engine.

* * * * *