

5 **METHOD AND APPARATUS FOR TOTAL ENERGY**
 FUEL CONVERSION SYSTEMS

BACKGROUND OF THE INVENTION

10 1. Field of the Invention

 This invention relates to conservatively transforming carbonaceous matter into fuels and petrochemicals for power and other purposes.

 2. Description of the Prior Art

 There have been many attempts to improve the efficiency of power generation systems
15 in order to reduce the fuel consumption/power generated ratio, and to reduce environmental pollution from combustion products. Some of those attempts include gas turbine blade cooling, combined cycle heat recovery, and the Humid Air Turbine (HAT) cycle. For example, U.S. Patent 4,829,763 discloses an intercooled, regenerative cycle with a saturator that adds considerable moisture to the compressor discharge air so that the combustor inlet
20 flow contains 20 to 40% water vapor. The water vapor adds to the turbine output while the intercooling reduces the compressor work requirement which result in higher specific power. The compressed air which is used for combustion of the fuel to drive the turbine is cooled then humidified prior to combustion in a multistage counter-current saturator with the aforementioned water vapor. Low level heat is rejected from the compressed air during
25 intercooling and prior to humidification. The HAT cycle is an improvement in thermal efficiency compared to the combined cycle, the steam injected cycle, the intercooled regenerative cycle and other humidification based processes. The HAT cycle requires very

high air pressures up to 30 atmospheres and higher turbine inlet temperatures up to 2800 F to improve overall plant thermal efficiencies.

Another system is considered to be an extension to the HAT cycle, and is called the Integrated Gasification Humid Air Turbine (IGHAT) has been described by Day and Rao as a method of coal gasification based power generation that could provide high efficiency and low emissions at least comparable to an integrated gasification combined cycle (IGCC) but without the penalty of high capital cost that is usually associated with IGCC systems. Much of the cost savings from IGHAT comes from the fact that the HAT cycle can use low level heat from gasification quench water in an efficient way via the saturator, whereas in an IGCC one must recover as much heat as possible from the raw coal gas in the form of high temperature and high pressure steam, using relatively expensive waste heat boilers. Additional cost savings occur because the cycle does not require a steam turbine condenser. Further, the large amount of water vapor mixed with combustion air is expected to reduce NO_x emissions to very low levels, assuming suitable combustion can be achieved at reduced flame temperatures.

Harvey et al., describe a process for reducing combustion irreversibility through off-gas recycling. The process has no bottoming cycle which is similar to a gas turbine with intercooling, reheating and a regenerator. The regenerator functions as a reformer wherein the fuel is cracked and partly oxidized by heat from the recycled turbine off-gases. The off-gases contain oxygen and thus are used as oxygen carriers. Before each turbine stage, air is injected into the gas stream containing reformed fuel and recycled off-gases which are thereby sequentially fired. The water vapor in the off-gases is partially liquefied in the series of water-cooled condensers after each stage; intercooling is accomplished by injection of the water. Analysis by Harvey, et. al. shows reforming for fuel conversion, but the gains presented were limited by pinch point temperature in the reformer. Harvey, et al. plan further

study of the effect of their proposed arrangement on efficiency at turbine inlet temperatures below 2300 F, which in the analysis is the approximate high limit without turbine blade cooling.

To control turbine inlet temperature within acceptable metallurgical limits (now 2600-
5 2800 F) gas turbine designers have resorted to excess combustion air, diluents such as steam as in HAT or simple steam injection, water injection or compressor intercooling. Concurrently metallurgists are working to develop ceramic components or coatings which can tolerate ever higher temperatures. This invention achieves turbine inlet temperature control by turbine exhaust recycle with consequential high system cycle efficiencies. Capital is
10 reduced by rocket engine reactor compactness and elimination of combined cycle equipment and its related efficiency reducing system infrastructure. In dealing with the exhaust from steam turbines, this invention utilizes much of the latent heat in the exhaust with consequent reduction in the cooling water load otherwise required for condensing steam for boiler feed water.

15 It is therefore an object of the present invention to provide a method of generating power from fuel with improved efficiency over prior methods, employing conventional turbine inlet temperatures without diluent injection or intercooling. Another object is to provide apparatus for generating power from fuel in a more flexible, efficient and less polluting manner than prior art methods, at reduced capital cost.

20 This invention can also be used as a pyrolysis reaction system to carry out either moderate temperature conventional pyrolysis or high temperature total pyrolysis. U.S. patents by Raniere, et al. 4,724,272 and Hertzberg, et. al. 5,300,216 teach that heating and quench in transonic flow must be accomplished at precise residence times with respect to shock type and shock location. Both hydrocarbon and steam are heated and passed through separate supersonic

nozzles before pyrolysis. Hertzberg further teaches that, after quenching, the cracked gases may be passed through a turbine for energy recovery and further cooling.

With this invention combined fuel conversion transformations and pyrolysis are also possible. U.S. patents 4,136,015 and 4,134,824 by Kamm, et. al. teach a process for thermal
5 cracking of hydrocarbons and an integrated process for partial oxidation and thermal cracking of crude oil feed stocks. Hydrogen available from heavy oil partial oxidation promotes yield selectivity. Moderate time-temperature cracking conditions are selected which result in substantial liquid product and tar yields which must be handled with difficulty within their process and in downstream processes.

10 It is therefore an object of this invention to provide a method of pyrolyzing and hydropyrolyzing carbonaceous matter either alone or in combination with fuel conversion transformations at moderate or high temperatures and pressures, achieving near total feed stock conversion, in a near total energy conservation arrangement. Another object of this invention to provide apparatus for pyrolyzing and hydropyrolyzing carbonaceous matter either alone or in
15 combination with fuel conversion transformations at moderate or high temperatures and pressures, achieving near total feed stock conversion, in a near total energy conservation arrangement.

SUMMARY OF THE INVENTION

20 These objects, and others which will become apparent from the following disclosure, are achieved by the present invention which comprises in one aspect a process of producing power comprising:

providing a turbine adapted to generate shaft work, said turbine having a combustor;
and a rocket engine having a nozzle and a compressor means;

feeding fuel and oxidant to the rocket engine and the rocket engine compressor means;

feeding carbonaceous matter and water and/or steam to the rocket engine nozzle;

processing the output of the rocket engine nozzle into fuel for the turbine;

introducing said fuel and oxidant for the turbine to the turbine combustor to produce
5 carbon dioxide and water combustion products;

passing said combustion products through the turbine;

recycling a substantial portion of the hot exhaust from the turbine to the rocket engine
compressor means;

further recycling the hot exhaust from the rocket engine compressor means to the
10 rocket engine nozzle; optionally into one or more secondary port downstream from said
nozzle; and optionally as a compressed flow for other uses.

controlling the inlet temperature to the turbine.

In another aspect, the invention comprises apparatus for generating power from fuel
comprising:

15 a turbine having a combustor;

a rocket engine having a nozzle and a compressor means;

means for adding carbonaceous matter and water and/or steam to the rocket engine
nozzle;

means for feeding fuel and oxidant to the rocket engine and to the rocket engine
20 compressor means;

means for processing the output of the rocket engine nozzle into fuel for the turbine
combustor;

means for introducing said fuel and oxidant for the turbine to the turbine combustor to
produce carbon dioxide and water combustion products;

means for recycling a substantial portion of the hot exhaust from the turbine to the rocket engine compressor means;

means for further recycling the hot exhaust from the rocket engine compressor means to the rocket engine nozzle; optionally into one or more secondary ports downstream from said nozzle; and optionally as a compressed flow for other uses; and
5 controlling the inlet temperature to the turbine;

Another aspect of the invention is an alternative process of producing power comprising:

providing a steam turbine adapted to generate shaft work; and a rocket engine having a
10 nozzle and a rocket engine compressor means;

feeding fuel and oxidant to the rocket engine;

feeding carbonaceous matter and water and/or steam to the rocket engine nozzle;

processing the output of the rocket engine nozzle into fuel for a boiler and fuel for a second rocket engine;

15 boiling water in said boiler to produce water vapor;

using the resultant water vapor to power said steam turbine;

quenching the turbine outlet steam with water; recycling the cooled steam and water mixture to the rocket engine nozzle; and

transforming the output of the second rocket engine into a fuel product.

20

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a rocket engine power source comprised of a rocket engine, a rocket engine compressor means, a conserved energy reactor and a distribution means.

FIG. 2 is a diagram of a rocket engine power source flowing to an expansion turbine whose exhaust is recompressed by a prime mover so that most of the compressor discharge is effectively recycled to a conserved energy reactor.

FIG. 3 is a diagram of a rocket engine power source flowing to an expansion turbine which is part of an existing gas turbine with productive use of its connected compressor.

FIG. 4 is a diagram depicting the rocket engine power source flowing to three expansion turbines in series interspersed with separate combustors with independent oxidant supplies from the rocket engine compressor means.

FIG. 5 is a diagram depicting a rocket engine power source in combination with a fuel cell and a second conserved energy reactor and an expansion turbine to optimize the base load and/or peak load for power delivery.

FIG. 6 is a diagram depicting a rocket engine power source integrated with a boiler and using two stage fuel transformations.

FIG. 7 is a diagram depicting a rocket engine power source and a boiler with a hot gas flow extension to further improve system efficiency.

FIG. 8 is a diagram depicting two rocket engine power sources in a combined process for pyrolysis and fuel transformation to produce ethylene and synthesis gas.

FIG. 9 is a diagram depicting the partition and distribution of the power turbine recompressed exhaust gases to optimize heat utilization within the system.

FIG. 10 is a diagram depicting a near total energy conversion arrangement for producing ethylene and other chemicals.

DETAILED DESCRIPTION OF THE INVENTION **AND THE PREFERRED EMBODIMENTS**

The process of producing power comprises:

providing a turbine adapted to generate shaft work, said turbine having a combustor;
and a rocket engine having a nozzle and a compressor means;

feeding fuel and oxidant to the rocket engine;

feeding carbonaceous matter and water and/or steam to the rocket engine nozzle;

5 processing the output of the rocket engine into fuel for the turbine combustor;

introducing said fuel for the turbine to the turbine combustor;

passing combustion products through a turbine; and

recycling a substantial part of the hot exhaust from the turbine to the rocket engine
compressor means:

10 further recycling of the exhaust from the rocket engine compressor means to the rocket
engine nozzle; optionally one or more secondary ports downstream from said nozzle; and
optionally a compressed flow for other uses; and

controlling the inlet temperature to the turbine.

Suitable gas turbines adapted to generate shaft work include standard and advanced
15 commonly available gas turbines manufactured by GE, ABB, Solar, Siemens and others.

Suitable gas turbine combustors include combustors provided with the gas turbines or
those specially designed for high steam operation.

Suitable rocket engines include jet engines manufactured by GE, Pratt & Whitney,
Rolls Royce and others; and burners made by T-Thermal, John Zink and others; and jet and
20 rocket engines made by manufacturers of propulsion systems for magnetohydrodynamic
generators up to 5000 F stagnation temperatures such as TRW.

Suitable nozzles for rocket engines include deLaval type contracting/expanding
nozzles.

Suitable fuels for the rocket engine include methane, natural gas and petroleum distillates.

Suitable oxidants for the rocket engine reactor include air and oxygen.

Suitable processing the output of the rocket engine nozzle into fuel for the turbine combustor includes one or more near-adiabatic tunnels and nozzles sized to generate one or more shock waves and produce jet propulsions to boost flow energy.

Suitable temperatures for introducing fuel for the turbine to the turbine combustor so that turbine inlet temperature is controlled within existing materials limitations, i.e., up to 2800 F for new gas turbines.

Suitable means for recycling hot exhaust from the turbine to the rocket engine compressor include gas turbines, turbochargers, diesel engines and other internal combustion engines.

Preferably the output from said rocket engine nozzle and said recycled hot exhaust gas from said turbine are transformed in a near-adiabatic atmosphere into said fuel for said turbine. By near-adiabatic atmosphere is meant that heat content of fuel gas, oxidant, carbonaceous matter and water being fed are preserved except for unavoidable radiation or other losses to the environment.

In certain embodiments, carbonaceous matter is introduced into said output of said rocket engine reactor downstream of said nozzle at velocities sufficient to transform said carbonaceous matter into said fuel for said turbine. Suitable velocities for such transformation include sub-sonic and supersonic flow up to Mach 2 and higher to complete reactions and deliver flow at turbine inlet pressure.

The carbonaceous matter is preferably methane, but can alternatively be natural gas and its components, petroleum coke, residua or distillates, biomass, coal, char or other chemicals suitable for pyrolysis or combustion. Preferably said fuel is also methane.

5 In some embodiments a portion of said hydrogen is diverted to one or more downstream uses, for example fuel cells, iron oxide reduction reactors, or chemical processes such as petroleum distillate hydrodesulfurization, hydrogenation of unsaturated hydrocarbons, ammonia and alcohol production, etc. In some embodiments, a portion of said hydrogen or other fuel is recycled by suitable means to fire rocket engine and downstream jet propulsions.

10 When the transformation occurs in a group of transformation reactors it is preferred that the pressure in said output of said rocket engine compression means conforms by suitable means with the pressure in each transformation reactor.

In certain embodiments a portion of said hot exhaust from said turbine combustor is compressed in an intermediate compressor and recycled directly to a short circuit distribution means and delivered as heat and mass additions at least matching or boosting pressure, jet-
15 like, at suitable junctures augmenting said hot exhaust.

Generally, the output of said rocket engine nozzle exits from said nozzle at transonic speeds. By transonic speeds is meant near sonic and supersonic up to Mach 2 and higher, suitable to the process reactions and maintenance of designed flow energy level.

20 When reaction severity or selectivity in the transformation reactor or series of reactors needs to be increased or when more mild operations conditions are desired, catalyst for said transformation is introduced into said output of said rocket engine nozzle. Suitable catalysts include manganese oxide and zinc titanate.

The shaft work of the turbine can be for electrical generation only, or can also include work to operate one or more compressors or pumps.

One or more turbines, one or more combustors, and one or more electrical generation means are possible.

In certain embodiments, supplemental or interstage oxidant is added to said turbine combustor(s). The oxidant can be introduced in said turbine combustor(s) to effectively
5 control turbine inlet temperature. Suitable temperatures for turbine blades and components are about 1700 F for older gas turbines up to about 2800 F for current state of the art designs.

Turbine inlet temperature can be increased consistent with improvements in materials technology for higher temperature and higher efficiency operations.

Generally one product of said transformation is hydrogen. Other products can be
10 carbon dioxide, carbon monoxide, and water vapor, for example.

Another embodiment of the invention is a process of producing power comprising: providing a steam turbine adapted to generate shaft work; and a rocket engine having a nozzle and a compressor means;

feeding carbonaceous matter and steam to the rocket engine nozzles;

15 feeding fuel and oxidant to the rocket engine;

processing the output of the rocket engine nozzle into fuel for a boiler and fuel for a second rocket engine;

boiling water in said boiler to produce water vapor;

using the resultant water vapor to power said steam turbine;

20 quenching the turbine outlet steam with water; and recycling the cooled steam and water mixture to the rocket engine nozzle; and

transforming the output of the second rocket engine into a fuel product. The fuel product generally comprises hydrogen.

In some embodiments clean water is introduced into said transformation reactor or group of transformation reactors, thereby reacting in said reactor or reactors with said output of said rocket engine. Preferably, the clean water is introduced in an approximately equal or greater weight ratio with the steam turbine exhaust.

5 Preferred embodiments of this aspect of the invention include providing a heat exchanger; a third rocket engine having a nozzle; a gas turbine having a combustor; feeding fuel and oxidant to said third rocket engine; directing the output of said third rocket engine nozzle into said heat exchanger so as to cool said output and to super-superheat steam from said boiler; and transferring the resultant super-superheated steam to said steam turbine.

10 One suitable apparatus for generating power from fuel according to the invention comprises: a gas turbine having a combustor; a rocket engine reactor having a nozzle and a compressor; means for feeding fuel and oxidant to the rocket engine;

means for processing the output of the rocket engine reactor into fuel for the turbine combustor; means for introducing said fuel for the turbine to the turbine combustor;

15 means for recycling hot exhaust from the turbine to the rocket engine compressor means;

means for further recycling the exhaust from the rocket engine compressor means to the rocket engine nozzle; optionally the secondary ports downstream from said nozzle; and optionally as a compressed flow for other uses; and for controlling the inlet temperature to the
20 gas turbine.

The high pressure high temperature gas turbines being developed may, with cost effective revisions, may be retrofitted according to this invention to increase their thermal efficiencies. Perhaps the greatest retrofit gains will redound to the many heavy-duty, low efficiency, stationary gas turbines already installed and operating in a lower temperature

range. Apart from the heat recovery via conserved recycle recompression, the implementation of the independently powered compressor can completely eliminate the work of compression from the output power expansion turbine, thereby increasing its output net work and mechanical efficiency. This same gain is accordingly obtained with a new installation.

5 This invention achieves turbine inlet temperature control by turbine exhaust recycle with consequential high system cycle efficiencies. Capital is reduced by rocket engine reactor compactness and elimination of combined cycle equipment and its related efficiency reducing system infrastructure. Nitrogen oxides normally associated with hydrogen production by steam reforming are reduced due to high steam, low air or nitrogen free reaction conditions
10 and increased thermal cycle efficiency.

As mentioned, the invention comprises recycling a substantial part of the exhaust gases from an expansion power turbine; augmenting them with fuel additions and the combustion products of said fuel additions for compressing them; recompressing them in an independent heat conserving, staged jet compression process and returning them to the expansion power
15 turbine; reacting said gases in a topping compression stage with a rocket engine-driven water-gas shift hydrocarbon transforming and/or water gas shift reactor (hereinafter referred to as the conserved energy reactor), for added thermochemical conversion resulting in recyclable fuel and extra fuel for other purposes outside the expansion power cycle; and; modulating turbine inlet temperature by controlled recycling of augmented turbine exhaust flows. The
20 present invention extends the art by improving efficiency, reducing gasification capital and minimizing environmental pollution; and adds capabilities beyond the state of the art by carrying out the shift and other transforming reactions in another conserved energy reactor.

Shift reaction converts carbon monoxide to carbon dioxide and additional hydrogen. Sequential conserved energy reactor designs will further reduce capital and improve process plant and power generation economics.

Referring now to the drawings, FIG. 1 show carbonaceous matter 100 and water 99 as feeds to the secondary ports of rocket engine nozzle 120. A rocket engine 102 is fueled through line 101, preferably methane. The oxidant, preferably air, is delivered to rocket engine 102 at top pressure via line 103 from the oxidant source. Oxidant is optionally branched on line 104 to gas turbine combustor 105. Combustor 105 is also fired with fuel 106 to control the turbine inlet temperature in combination with water 107.

Hot exhaust gases from combustor 105 expand through gas turbine 108. The exhaust from the turbine in line 109 can be directed as 110 into any one or more of secondary ports to downstream nozzles via related lines 111, 112 and 113; or a portion or all of it as 114 can be branched off to join and become recoverable heat fluids carried in line 115. As an alternate to the flow in 114, the flow 116 into compressor 117 delivers the flow as 118 at system pressure to accommodate heat and mass balance for the cycle. A further branch 119 can be directed to the secondary port of nozzle 120. Transforming reactors 121, 122 and 123 respectively represent water-gas, shift, and extended residence time zones where transformation of rocket engine exhaust occurs. These zones can be programmed optionally as sequential transonic shock zones or simply as two or more residence time zones. Down-stream thrusts can be programmed by after-jet combustion by introducing oxidant through lines 124, 125 and 126 to fire with unreacted carbonaceous matter.

Un-utilized lines among 111, 112, 113, 124, 125 and 126 can be programmed to introduce other reactive matter. The extent of the uses depends on the reactivity of the compounds present. A clean reactant for conversion, methane for example, into an auxiliary

port of nozzle 120 may require no more than two reaction zones. A pre-cleaned coal or petroleum coke could require an additional zone. Solid feed stocks additionally require the separation of particulates from the flow which would take place in particle separator 127.

Another use for separator 127 can be to recover particles secondarily entrained for any one of the following functions by discharging:

1. Catalyst Particles;
2. Getter Minerals for alkali metal capture in biomass processes;
3. Sulfur Capturing Seeds like manganese oxide or zinc titanate for coal, coke and residual oils;
4. Iron Particles for Steam Iron Reactions to produce sponge iron, produce hydrogen for fuel cells and other uses, and to recycle-reduce iron oxides;
5. Other Metal Particles like tin and zinc for thermochemical reactions; and
6. Neutral Particles for heat transfer to lighter faster flowing particles, gases and vapors.

Any one or more of the above can be introduced by entrainment in a fluid that is chemically compatible to the process. Some processes may require at least one more separator 127 which may be in a cascade series manifolded so that the product gas flows totally into nozzle 128 which can serve as a back pressure for the following process uses natural gas, cleaned or pre-cleaned carbonaceous matter is converted for direct combustion for turbine expansion, or an integrated fuel cell/turbine process. One capability of the rocket engine driven reactor train is to produce a fuel gas to be used directly in combustion, as in later embodiments. Another capability of the rocket engine driven reactor train is to force the reactions to completion towards the lowest reaction end temperature by programmed, metered and controlled reactant feeds. This is useful when maximum hydrogen production is desired

for subsequent chemical use. Most conversion reactors in practice quench the reaction to preserve its final chemical composition. By contrast, when appropriate this invention fires the product gas at the end of the reaction for the stoichiometrically prescribed reaction end temperature which ends at station 129 of the conserved energy reactor distribution means.

5 On the other hand, when the reaction end temperature does not conform to still lower temperatures required by downstream processing, then the reaction must be quenched. Conversely, a process such as pyrolysis can require quenching to interrupt a reaction sequence and freeze desired intermediate chemical species. Examples would include cracking of methane to produce acetylene and ethylene; cracking of ethane to produce ethylene; and
10 cracking of propane, butane and petroleum distillates to co-produce hydrogen, ethylene, propylene, butylene, butadiene and other diolefins, and aromatic compounds.

When oxygen is the oxidant of choice and its source is available over the fence at pressure for the process, the need for a separate oxygen compressor means is eliminated. Otherwise a compressor means can serve to boost the pressure of the oxygen.

15 Line 130 shown branching off oxidant source is to provide oxygen or air to any one or more of the secondary ports to nozzle stations 120, 131, 132 and 128 for increasing the thrust in the flow by after-jet combustion. An ignition source is provided when the flow on contact is below the auto-ignition or reaction temperature. Ignition lines are not shown but are similar to line 133. The function of after jet combustion is to boost entrainment, create shock, and/or
20 make up for friction head loss to maintain pressure at station 129.

Compressor 134 is shown powered by combustor 105 and turbine 108. However compressor 134 can be powered by any prime mover, a diesel engine for example, providing preferably that its fuel composition is chemically compatible with flow in the conserved energy reactor; otherwise the exhaust must be exported for recovery uses.

Standard equilibrium plots are used as guidelines for starting and running the conversion process so as to avoid the formation of solid carbon or coke.

This process has the capability for making extra products, for example, synthesis gases for ammonia or alcohols, pyrolysis cracked gases for ethylene and petrochemicals can be produced.

Typical Baseline Reactions for the Conserved Energy Reactor

The following are the main equations which relate selectively to any embodiment incorporating the conserved energy reactor described with respect to figure 1. The basic equations are as follows:

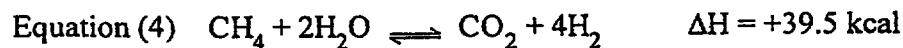
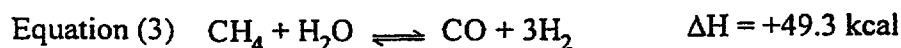
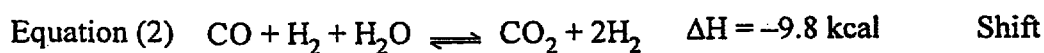
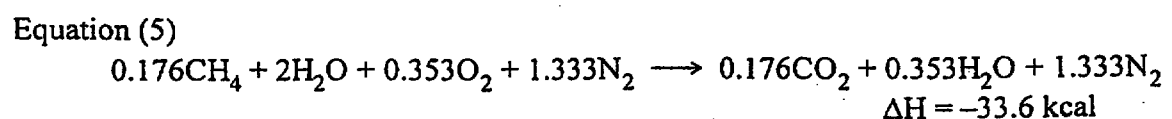
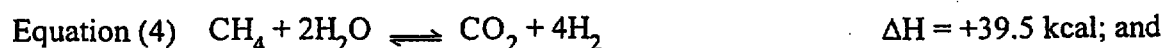
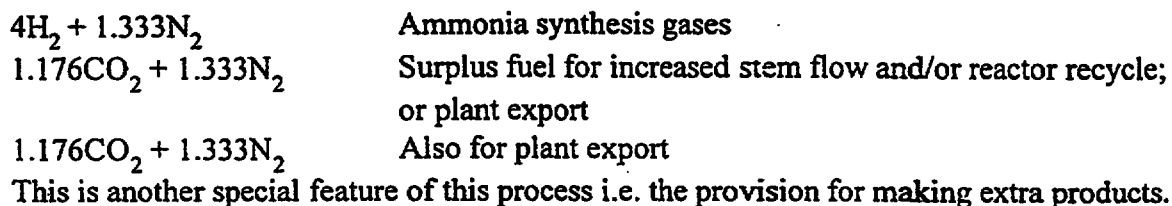


Figure 1 also shows how additional fuel can be produced in addition to increasing the efficiency of the power cycle. It shows the reactor discharging $3H_2 + N_2$ as synthesis gases for the ammonia process and additional fuel as $H_2 + 0.333N_2$ which can be used for more steam or towards fueling the rocket engine for export within the plant.

The following two equations illustrate the basic autothermal reactions taking place in the reactor to produce these gases



The sum of the reactions (4) and (5) yield the following:



The synthesis gases for ammonia can also be produced in later embodiments employing gas turbines. The water gas shift equations (1) through (4) may be applied to all the embodiments of this invention depending on the carbonaceous matter to be converted. Methane or natural gas relate to equations (3) and (4) whereas coal, petroleum coke and biomass and residual oils can be processed via the water gas shift equations (1) through (2). The water gas reaction yields $\text{H}_2 + \text{CO}$ generally from the first reactor and shown as lines 141 and 142 depending on the ultimate use as process fuel gas or synthesis gas. The significance of equilibrium in this invention is explained with respect to Equation 4 for example which produces four moles of hydrogen and one mole of carbon dioxide. For practical purposes a nearly straight line relationship holds in the positive $\log_{10} K$ scale from five to zero corresponding to temperatures respectively from 1600 K to 880 K (Wagman, et. al.), or 2400 F to 1100 F approximately. Higher temperatures of course also favor equilibrium. (Equilibrium constants by Wagman, et. al.)

In order to understand the particular significance of equilibrium with this invention is to conceptualize a very high temperature jet, say 4000 F, rich in steam progressively completing equilibrium particle by particle of interacting carbonaceous matter as they travel down the progressively decreasing $\log_{10} K$ function and corresponding temperatures down to 1100 F and lower because it is possible with pressure to do so to a minor extent in the negative $\log_{10} K$ range. Driving to low temperature is beneficial if the fuel gas must be desulfurized. It also is sometimes useful in this case to separate the carbon dioxide from the hydrogen as shown with

lines 143 and 144. A further advantage when driving a stoichiometrically specified reaction to completion at a low temperature is that less carbonaceous matter or fuel and less oxygen is required for the endothermic heat which results in less carbon dioxide in the off-gases.

On the other hand, if a pre-cleaned coal is the reactant, it can be useful to drive the
5 reaction to a higher end temperature for use in turbine combustor 129, whereby the reaction is set by firing through line 133. However, a pre-cleaned coal generated fuel gas must have its fly ash removed in separator 127 through line 145 Before being fired in combustor 129.

Flexibility for Pyrolysis

This invention can also be used as a pyrolysis reaction system as shown in FIG. 1 to
10 carry out either moderate temperature conventional pyrolysis or high temperature total pyrolysis. At moderate temperatures ethane, propane, butane and petroleum distillates may be cracked to produce ethylene and acetylene and other olefins and diolefins such as propylene, butylene, butadiene and aromatic hydrocarbon liquids. At high temperatures, methane may be cracked to produce mainly hydrogen, ethylene, and acetylene. Cracking non-methane
15 hydrocarbons at high temperatures yields virtually total conversion to yield a product distribution largely free of the normally produced cyclic compounds, aromatics and heavy aromatic oils and tars.

U.S. patents by Raniere, et al, 4,724,272 and Hertzberg, et al. 5,300,216 teach that heating and quench in transonic flow must be accomplished at precise residence times with
20 respect to shock type and shock location. Those skilled in the art know that rapid quench to a temperature about 1100-1300 F is important to preserve yields of desired products and minimize coke formation.

The rocket engine 102 and nozzle section 120 of this invention coupled to reactors 121, 122 and 123 previously described represent a facility having flexible reactor length,

capability for creating different shock characteristics along the reaction path and for quenching through ports 111, 112, 125 and 126 at different reaction time-temperature cracking severities. Many degrees of freedom are available since any one or more of said locations and including nozzle section 120 ahead of the selected quench locations can optionally be used for transonic mass inputs and heat additions to the main flow. Quenching can be total or partial and direct or indirect or a combination. Direct quench media may be water, steam, hydrocarbons and inert gases. Indirect quench is accomplished in a heat exchanger (not shown) at or near location 127 instead of the separator shown. The quenched cracked products are discharged through nozzle section 28 and distributed via line 146 to be further processed by suitable means.

Flexibility for Combined Production of Synthesis Gas and Cracked Products

U.S. patents 4,136,015 and 4,134,824 by Kamm, et. al. teach a process for thermal cracking of hydrocarbons and an integrated process for partial oxidation and thermal cracking of crude oil feed stocks. Moderate time-temperature cracking conditions are selected which result in substantial liquid product and tar yields which must be handled with difficulty within their process and in downstream processes.

With this invention, combined fuel conversion transformations and pyrolysis are also possible. High temperature operation is preferred so that complete breakdown and conversion of normally liquid or solid cracked hydrocarbon products is achieved. In combined mode synthesis gasses are first produced in one or more conserved energy reactors as previously described. Then, in a downstream conserved energy reactor, pyrolysis reactants are introduced to the high steam and high hydrogen synthesis gases flowing from the first conserved energy reactor and total pyrolysis is carried out as previously described. The presence of hydrogen in relatively large quantities during pyrolysis adds to yield selectivity

towards desired products. The presence of steam in relatively large quantities during pyrolysis reduces tendency for soot or coke formation.

To further enhance reactivity, further accelerate heating rates and further improve selectivity towards desired cracked products supplemental oxidant may be added through available secondary nozzle ports. In combined fuel transformation - pyrolysis mode direct water quenching is preferred since the steam thus produced *in situ* is useful in generating turbine power. Cracked products are passed through a turbine for further cooling by isentropic extraction of work and flow to other conventional separation processes. Either high temperature or moderate temperature pyrolysis can be practiced depending upon feed stock, desired end products and economic factors. Direct or indirect or combination reaction quenching can be practiced depending upon feed stock, desired end products and economic factors.

Figure. 8 is a diagram of a pyrolysis and fuel transformation process for ethylene and synthesis gases. The process to be described is representative in general of producing other hydrocarbons. Methane is fed through compressor 134 and is distributed to suit a high pressure in line 800 into combustor 102, line 801, nozzle section 120 and line 802 as an option for after jet combustion. A fraction of the methane is fired with oxygen in combustor 102 for the endothermic requirement of the ensuing transformation reaction in the form of



The remaining methane in combustor 102 serves to augment the mass of the jet. The synthesis gases produced in the conserved energy reactor is distributed to suit three different purposes:

1. A fraction is recycled to fuel combustor 105 of the rocket engine compressor means. The resulting exhaust from turbine 108 is recompressed by compressor 117 and is distributed along the reactor as shown;

2. A fraction is synthesis gas product; and

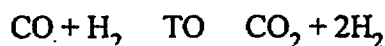
5 3. The remaining fraction is fed under pressure to a second stage rocket engine combustor and fired with oxygen to form the pyrolysis jet in the form and range of



to crack ethane for the production of ethylene as previously described.

As previously described, the combustor of the rocket engine can operate at stagnation
10 temperatures up to 5000 F and relatively unlimited stagnation pressures. The conserved energy reactor flexibility for shock location and down stream supplemental shocks were also described.

As another note, methane, carbonaceous matter such as coal and residual oil may be processed which then produce syngas in the form and range of



15 Finally, quenching to 1300 - 1000 F is required with water, steam, a hydrocarbon or inert gas at the point of optimum cracking severity in order to freeze the desired intermediate reaction products. Any fly ash is removed in the separator at location 127.

Many other transformation reactions according to the invention take place at near sonic and supersonic conditions with high relative slip velocities between reactants which break into
20 shock zones with ensuing subsonic flows. Intense reactivity is obtainable thereby with primary jet temperatures up to 5000 F (practiced in magnetohydrodynamic flows) and unlimited high pressures for practical purposes.

Turning now to pressure, increased pressure is known to favor many chemical reactions. As noted earlier, low pressures are suitable for biomass gasification. It is also well

known that biomass is much easier to gasify than coal with reactions occurring at lower temperatures and near atmospheric pressure. Coal is optimally processed at higher pressures.

This invention incorporates suitable alternatives for varying reactor pressure for conversion and at the same time conserves the rocket engine power source energy for
5 conversion by the recycle function.

The distribution of pressure is as previously described with respect to FIG. 1 whereby the flow of recoverable heat fluids from compressor 134 is branched off to line 136 to supply combustor 105. The remaining flow is divided into a branch line 137 supplying rocket engine combustor 102 and branch line 138 to supply any one or more auxiliary ports down stream of
10 power nozzle jet 120.

Flows in 137 and 138 are not necessarily fixed. Increasing the flow in 137 causes a corresponding decrease in 138. Being able to control this interchange allows more or less temperature in combustor 102 for whole or partial oxidation which can have the opposite effect from oxidant flow through branch 138, and this can be offset with more or less
15 carbonaceous feed and water through lines 100 and 99.

A similar branching interchange is effected from exhaust line 109 from turbine 108. This was previously explained as a routine routing. This interchange significance reported here relates to recovery of exhaust heat and mass. In relatively low pressure operations all or most of the flow through line 109 can continue through line 110 and be distributed selectively
20 along and down stream into the reactor. For process reasons or for a stronger entrainment effect the same flow can be redirected through line 119 where the combustion jet has the most entraining effect, which effect can be further amplified by increasing the temperature in combustor 102.

The need for directing the exhaust flow through line 116 to be mechanically compressed with the oxidant flow in line 139 through compressor 134 is less here because of the low pressure characteristic of the process. However, similar functions occur in later expansion turbine embodiments which operate as high as 30 atmospheres at station 129.

5 Station 129 then serves as the high pressure high temperature combustor of the turbine. In that event recoverable heat fluids line 115 are replaced by a large portion of the exhaust which is recompressed along with the flow in line 116. Then the recoverable heat fluids supply to all combustors is from another source to be later described for the respective embodiments. In every case, however, power developed by the rocket engine and its compressor means must
10 maintain in steady state recycle flow of consistent chemical composition in a near-adiabatic cycle while conserving a substantial portion of the exhaust energy for more efficiently powering an expansion turbine means which delivers mechanical power or electricity.

In this event to recover a substantial portion of the exhaust heat and mass, the flexibility afforded by the above described branching interchange options from line 109 will
15 serve to optimize the recycle system to deliver a constant and consistent mass flow to combustor 129, here powering the expansion turbine means. Most of the heat returning through the system will convert carbonaceous matter to fuel gas for the combustor at station 129. Any additional sensible heat in the flow to station 129 is conserved to flow through the gas turbine 140. To prevent buildup in recycle, the necessary export carbon dioxide, nitrogen
20 and minimal water vapor will serve to preheat fuel, recoverable heat fluids and other plant uses. These will be further described in their respective embodiments.

The invention can comprise expansion turbines; turbines with parasitic shaft work, and multiple turbine arrangements.

Case 1 - Rocket Engine Power Source for Single and Multi-Stage Turbines

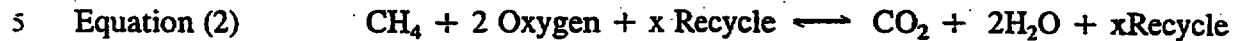
In FIG. 2 combustor 129 for the expansion turbine means 200 delivering power to generator 201. Any mechanically transmitted power load can be used. The turbine means can be a single turbine, a straight multi-stage turbine, or a multi-stage turbine with interstage heating. Preferably, the source of temperature and pressure which developed in combustor 129 is the rocket engine power source previously described with respect to FIG. 1. The rocket engine power source also includes the conserved energy reactor or transformer. Its function is not only to transform carbonaceous matter introduced through line 124 into a usable product fuel gas into combustor 129 but to convert all or most of the power expended in compressing and heating in the rocket engine compressor means, rocket engine and conserved energy reactor together into product fuel gas (and its sensible heat) flowing into combustor 129.

The encompassing function of this embodiment is to recycle a substantial portion of the exhaust part from the last turbine of said expansion means, except what must be exported from the cycle (at least for direct heat and mass transfer) to prevent build-up in the process. Accordingly, the exhaust 202 branches off at 203 and continues on as 204 after being increased in pressure through compressor 205, for interstage heating in turbine means 200. Compressor 205 to be powered by turbine 108 can be independently speed controlled by a suitable means.

It is essential that the mass and chemistry of the greater or overall cycle remain at steady state; so export mass 206 must be replaced by an equivalent mass with a conforming aggregate chemistry for continuity. For example, if CH_4 is the fuel of choice, reaction in combustor 129 is organized as follows:



where $\text{Recycle} = \text{CO}_2 + 2\text{H}_2\text{O} + 7.5\text{N}_2$ and where x is higher the lower the design turbine inlet temperature, whereby $x (\text{CO}_2 + 2\text{H}_2\text{O} + 7.5\text{N}_2)$ can substitute for any excess air firing in common practice. Equation (1) is rewritten as follows when oxygen is the preferred oxidant:



where $\text{Recycle} = \text{CO}_2 + 2\text{H}_2\text{O}$ whereby $x (\text{CO}_2 + 2\text{H}_2\text{O})$ is the substitute for the excess air. The x term can be any number or mixed number. The flow exported at 206 must equal $\text{CO}_2 + 2\text{H}_2\text{O}$ but can be fractionally larger for cycle balance as long as its equivalent chemical aggregate reenters the cycle for mass flow continuity.

10 Returning now to compressor 134 whereby the fuels for rocket engine 102 and combustor 105 are methane fractions of the design heat value, considered to be the sum of heats arriving at combustor 129 including any after-jet combustion additions. Compressor 134 receives and discharges flow 207 which is branched into 208, 209 and 210. Line 208 goes into combustor 105 and its main function by proportion is to govern the inlet temperature
 15 of combustor flow 209 into turbine 108 over suitable range for recycle balance whereby the fraction of flow 210 becoming 211 is optional on balance from zero flow to a maximum equal to that of 210. It follows then when 210 is something greater than zero on balance, it is held on zero for start-up. The compatibility of the rocket engine, or in combination with downstream after-jet combustion propulsions depends on the difference between the top
 20 pressure in combustor 102 and the design pressure for combustor 129. Combustors 102 and 129 make up more than just marginally the following head losses:

1. Rocket Engine Nozzle
2. Friction
3. Propulsion Entrainment

4. Rocket Engine Compressor Means Exhaust Distribution

In effect these losses convert to heat *in situ* between combustors 102 and 129 and thereby convert to useful fuel endothermically with some rise in sensible heat in the products flowing to combustor 129.

5 At least in the foreseeable future, advanced gas turbines are designed for temperatures up to 2800 F with blade cooling and combustor pressure up to 30 atmospheres. This invention has no practical high limit for the stagnation pressure in combustor 102, even if advanced gas turbines are planned for much higher pressures than 30 atmospheres, or higher pressure process hydrogen uses are available.

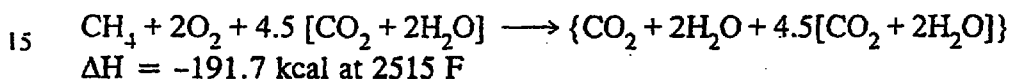
10 In view of these boundary conditions the stagnation pressure difference between combustors 102 and 129 must also be reconciled with the endothermic heat requirement for the transformation and the sensible heat content of the product fuel gas and the aerothermochemical propulsion design. This heat utilization must primarily take into account that portion of the exhaust heat from the turbine and the heat of compression that delivers it to
15 the rocket engine - conserved energy reactor sequence. For example, in applications where there is a large difference in pressure between combustors 102 and 129, it is more exergetic for the rocket engine compressor means to deliver the exhaust gases to the entrainment train toward the lower end of the pressure cascade but still above design pressure at 129.

On the other hand, when the pressure at 129 is well below the high pressure that the
20 state of the advanced art (*i.e.* 30 atmospheres) for gas turbines, like 20-25 atmospheres, then the preferred mode is to operate the flow at 212 through compressor 213 at maximum (*i.e.* equal to 210). This relates to zero flow at 211 and simplifies the cycle balance with respect to consistent chemical aggregate in mass flow.

Besides considering how varying the foregoing flow effects the design pressure at combustor 129, the main criterion is ultimately choosing a cycle balance that achieves the most net work output from the turbine means with the most recovery from recycling a related optimum of exhaust gases. This criterion requires iterating the design pressure to a value lower than 30 atmospheres, as for applications at lower pressures for retrofitting existing gas turbines operating up to 25 atmospheres. This will be covered further in the next embodiment.

Returning to the rocket engine compressor means, the fuel fraction, line 316, is sized for compressing the selected mass flow through compressor 134. Since the internal second law irreversible heats are adiabatically conserved, ideal isentropic relations can be used at least as a first approximation for determining the net work from turbine expansion.

To illustrate turbine inlet temperature control and the recycle functions of this invention, the simpler mode whereby CH_4 is fired without transformation follows:



Liberty is taken for simplicity and as a safe side analysis of the turbine work for the above, by using Keenan and Kaye Gas Tables for 200% Theoretical Air. This represents one pound mole of any gas at 2515 F and 25 atmospheres expanded to one atmosphere and 943 F:

25 atmospheres	2515 F	$h_1 = 23753 \text{ Btu/pound mole of products}$
1 atmosphere	943 F	$h_2 = 10275$
		$h_3 = 13478$

h_3 represents the ideal expansion work of the turbine.

200% theoretical air relates to a combustion product average molecular weight of 28.9

whereas the average for $5.5 [\text{CO}_2 + 2\text{H}_2\text{O}]$ is 26.7. The safe side value for determining the

Btu/pound of product is 28.9. The lower value for this follows:

$$h_3' = 13478/28.9 = 466 \text{ Btu/pound of products}$$

$$\text{Total Products Heat} = 440 \text{ pounds} \times 466 \text{ Btu/pound} = 205040 \text{ Btu}$$

$$\text{Turbine Work Efficiency} = \text{Products Heat} / \text{Heat Content of 1 mole of CH}_4$$

$$= [205040/344160] \times 100 = 59.6\%$$

or approximately 60% with respect to one mole of methane

The theoretical minimum for recovery requires the steady state fuel input to be equal in heat to the work of expansion. This is 60% for this example and relates to 13478 Btu/pound mole of products expanding through the turbine means, simply referred hereafter as the turbine.

The objective is to develop a stagnation pressure in the jet combustor that is well above the turbine inlet pressure, which is taken here as 25 atmospheres. A further objective, preferably is to arrange for a substantial part of the recycle flow to be compressed by jet propulsion in the near-adiabatic path hereinafter called the tunnel, from the jet combustor to the turbine inlet.

This is to take advantage of the 5000 F thermodynamic potential not feasible with rotating compressors. The lesser efficiency in momentum transfer is offset because the rise in sensible heat is contained for expansion so long as the stagnation pressure driving the jet is adjusted upward, and it can be, to deliver the designed turbine inlet temperature.

The foregoing operation requires two parallel compressors instead of compressor 134 shown, whereby one compressor delivers a smaller part of recycle flow at a pressure well above the turbine inlet pressure into jet combustor 102 to augment the combustion products and thereby increase the mass entraining force of the jet. The other compressor delivers the larger portion of the recycle flow into one or more secondary ports of the tunnel at pressures somewhat less

than the turbine inlet pressure to be entrained and boosted in pressure by the jet mass and further as necessary downstream by after-jet propulsion.

5 In a simpler mode, the flow from compressor 134 is divided so that the lesser flow is directed to the jet combustor and the larger flow at the same pressure can be directed just down stream from the jet into one or more secondary ports of nozzle section 121, or be further subdivided for flow into ports 111, 112 and 113 along the tunnel. In this mode, jet power is increased as necessary by increasing the stagnation temperature of the jet combustor.

10 Another alternative embodying some of either or both functions of the foregoing modes with the distinct difference that the tunnel entry pressure of the recycle flows be somewhat less than the turbine inlet pressure and that the jet combustor be independently powered by fuel and oxygen at any suitable temperature and pressure within the design limits of the rocket engine where its pressure is independently developed by one of the compressors in parallel
15 (earlier described and not shown) and consistently the pressure of the recycle flow would be independently developed by the other parallel compressor.

The foregoing modes illustrate the wide range of operations to be selectively determined and optimized by computer analysis and tunnel design based on advanced gas dynamics for jet
20 propulsion. The objective is to apportion the fuel required for the recompressor distribution with respect to:

1. The intermediate compressor means
2. The rocket engine stagnation temperature and pressure
3. Tunnel jet propulsions

all in consideration of the portion of exhaust to be recovered and recompressed within the cycle.

The following continues the previous example for the case whereby all the recompressions to 25 atmospheres take place in the intermediate compressor means and 50% of the exhaust is selected for recycle and heat recovery.

1.	Recycle 50% as 2.75 [CO ₂ + 2H ₂ O] and split same into two flows of 1.375 [CO ₂ + 2H ₂ O]		
		<u>Mass (Pounds)</u>	<u>Related CH₄ (moles)</u>
2.	Total exhaust mass 5.5 [CO ₂ + 2H ₂ O]	440	1.0
3.	½ exhaust mass 2.75 [CO ₂ + 2H ₂ O]	220	0.5
4.	¼ exhaust mass 1.375 [CO ₂ + 2H ₂ O]	110	0.25
5.	Flow (3) is compressed isentropically by compressor 134	220	0.5
6.	Flow (5) is divided equally 1.375 is delivered at 2515 F turbine inlet temperature	110	0.25
7.	The other half 1.375 is delivered to combustor 108 for turbine inlet temperature control, i.e. 1.375 [CO ₂ + 2H ₂ O]	110	
8.	along with fuel product (5) 0.500 [CO ₂ + 2H ₂ O]	80	
9.	Together equal 1.875 [CO ₂ + 2H ₂ O]	190	
10.	Exhaust (8) is recompressed by additional fuel flowing sequentially into combustor 108 for 190 / 440 = 0.43	190	0.43
11.	However 0.43 [CO ₂ + 2H ₂ O] is additionally recompressed in-situ as 34.5 pounds	34.5	0.08
12.	Total mass and fuel used for said recompressions:		
	(5)	220	0.50
	(9)	190	0.43
	(10)	34.5	0.08
		444.5	1.01
	1.01 x 440 = 444.4		

Note: Although the foregoing recompressions are shown to take place with no rocket engine recompression, the analysis nevertheless equates to the total fuel which is required no matter

how the recompressions are divided (for this example) between the rocket engine, the intermediate recompression means and down stream jet propulsions.

Although oxygen power is preferred, air is not precluded. A parallel example with respect to one mole of methane gives:



This represents a mass flow through the turbine of 580 pounds. Again using work output, h_3
 $= 13478 \text{ Btu/pound mole} / 28.9 = 466 \text{ Btu/pound.}$

Total heat flow 580 pounds x 466.4 = 270512 Btu

Turbine Work = $(270517 / 344160) \times 100 = 78.6\%$ with respect to one mole of methane.

10 The recovery procedure with air is similar to that described for oxygen. However if half the exhaust heat and related mass is conserved i.e. $21.4\% / 2 = 10.7\%$, then the work output becomes $78.6 + 10.7 = 89\%$ of the heat content of one mole of methane.

The reason the air mode in these comparisons is more efficient than the oxygen mode is because the mass flow is proportionately larger. The mass flow in each case was computed
 15 on the basis of the same turbine inlet temperature of 2515 F and 25 atmospheres whereby the heat capacity of 440 pounds of the $[\text{CO}_2 + 2\text{H}_2\text{O}]$ function is significantly greater than the $[\text{CO}_2 + 2\text{H}_2\text{O} + 7.5\text{N}_2]$ function. This points up another great advantage of the oxygen mode i.e. by increasing the mass flow of oxygen mode to that of the air mode the same work output of 78.6% would develop with the same heat recovery for a total of approximately 89% but a
 20 commensurately lower turbine inlet temperature for the same power and therefore more beneficial in turbine design.

The following can be further deduced from the foregoing analysis:

1. When a thermal efficiency somewhat less than 100% is shown for a continuous mass flow (as 440 pounds in the example), then the increased fuel and compression heat

representing 100% must redound in an increased turbine inlet temperature. So, if the designed turbine inlet temperature is at the metallurgical limit, then the recycle and recompression must be recast to comply. Otherwise the increased temperature results in more turbine output work at steady state loads.

5 2. On the other hand, as a corollary to step 1 by recycling more exhaust than exemplified, the mass flow from recompression flow additions will increase over the 440 pounds and disrupt the required continuity for steady state recycle. In this case the surplus representing surplus heat can be transformed into fuel and be bypassed to contribute to the fuel requirement for any one or more for the rocket engine via the intermediate compression
10 means, and jet propulsion operations.

3. When transformation of carbonaceous matter is introduced (which can be methane) into step 1 or 2, the result is more fuel and/or more heat which must be taken into account.

4. Except for exhaust portion which is not recycled and its heat content which can
15 be independently used, the recycle part of the exhaust and all its recompression heat and fuel additions are adiabatically contained and must be taken into account in the heat and material balance for turbine flow continuity with surplus heat and mass bypassed as converted fuel to replace a corresponding amount in the base analysis. The by-pass is necessary to preserve said continuity of turbine flow.

20 The foregoing analysis demonstrates that methane or any clean fuel can be processed according to this invention without transformation by recycle of a substantial part of the turbine exhaust, its heat recovery being adjusted for turbine inlet temperature control and continuity. Further, this invention provides for heat and pressure for turbine expansion or transforms said heat and pressure into fuel for said expansion by a staged engine operation

from which practically no shaft output work is delivered, but which converts all shaft work in-situ into heat and pressure for said expansion directly or indirectly by transforming carbonaceous matter into fuel in a near-adiabatic control volume. In other words, this is a near total energy control volume whereby all energy sources entering result in a flow with
5 heat and pressure being delivered for turbine expansion or fuel for turbine expansion.

This invention is not limited to how the recovery of export mass and heat is obtained. An extraordinary recovery can be made by short circuiting a fraction of the turbine exhaust by by-passing the mass flow 203 through compressor 205, becoming hotter flow to 203. This flow is proportionately distributed so that the heat recovery between one or more stages
10 preferably, but not necessarily, equalizes the flow between stages of turbine means 200.

Further, selected mass flow 203 not only adds heat at selected interstage locations, but more significantly it admixes. boosts pressure selectively and augments parent flow 214, passing as distributed through the stages of turbine means 200. To maintain continuity, constant mass 203 branches off augmented flow 202, so that 202 then becomes flow 204
15 which sequentially becomes remnant exhaust flow 207 after flow 206 is bypassed for heat recovery indirectly within the cycle or exported for plant use. A particular advantage of the short circuiting cycle is to increase the work output without disrupting the mass flow continuity essential in the main cycle.

Case 2 - Rocket Engine Power Source for Turbines with Parasitic Shaft Work

20 FIG. 3 shows this embodiment whereby the rocket engine power source is applied to existing gas turbines and the flow from the conserved energy reactor is directed for clean-up at low pressures. Case 1 was presented, for transformations wherein the carbonaceous matter flowing into nozzle 120 via line 124 is either pre-cleaned or clean at the start. In this case, clean-up is presumed necessary and this requires that the flow from the conserved energy

reactor is discharged at whatever pressure and temperature is needed to accommodate any one of several commercially available processes.

Hot gas clean-ups operating at about 1000 F are preferred, because the cleaned gas at this temperature can then flow to the gas turbine at least retaining this level of heat. On the other hand, the advanced kinetic activity previously described for this invention can complete transformation reactions at very low temperatures without heat degradation from quenching. A further advantage for example, is that the carbon dioxide fraction in the fuel gas can be extracted at lower temperatures and pressures for other uses.

In these cases the conversion efficiency employing the rocket engine powered conserved energy reactor can be better than 90%. This reduces fuel cost compared with current practice. Further, when a low cost residual oil or petroleum coke can be substituted for natural gas, fuel cost can be reduced an additional 50 to 250% or more, depending on market prices.

It is also appropriate for this case to consider the benefits of servicing a retrofit operation with a clean or pre-cleaned fuel. This brings into play much of the process described in Case 1.

FIG. 3 illustrates a process wherein all or most of the load of standard compressor 300 is relieved so that in effect standard gas turbine 200 is transformed into a free-power turbine whereby the former load of turbine 200 now becomes additional power output at 201.

Accordingly, the compressor 300, only as a matter of convenience, can be used for low pressure oxidant flows into the conserved energy reactor through line 301.

Case 3 - Multiple Turbine Arrangements

FIG. 4 shows a multiple turbine embodiment whereby recycle for turbine inlet temperature control is optimized. The use of oxygen is also effective when applied to multi-stage turbines by this invention.

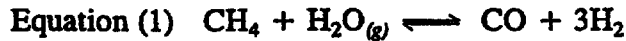
Several process modes are described:

- 5 A. First consider partial oxidation of methane by thermochemical transformation for direct interchange with recycle turbine exhaust gases. Some methane is fired in combustor 102 through line 401; the remainder is fired through line 124. The recycled exhaust gases are compressed at 134 and first proportioned so that compatible flow 208 is sized for the turbine inlet temperature of turbine 108. Accordingly, compatible exhaust 210 is largely compressed
10 in 215 and delivered at high pressure along the conserved energy reactor. The remaining lesser flows 402 and 403 can be optionally applied or turned off.

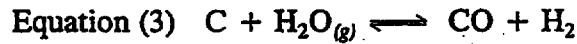
The remaining large part of compressor discharge 404 is then divided to suit the temperature and pressure interaction between combustor 102 and jet entrainment nozzle 120. The reaction zones can be applied as needed. Separator 405 is omitted. Nozzle 406 provides the back
15 pressure for the flow on to top combustor 407. The partially oxidized gas continues on through combustors 408 and 409 to exhaust from bottom turbine 410 in complete combustion to exhaust in line 202. Oxygen is supplied through line 411 and controlled for flow content and pressure (not shown) into lines 412, 413 and 414. The control is for maintaining preferably equal temperatures at each interstage to match the temperature in combustor 407.

- 20 B. Methane can also be fired with a shortage of oxygen resulting in gas flow that is partially oxidized and be treated as explained in A above.

C. The thermochemical activity between methane and steam can vary depending on temperature and pressure. Either of the following reactions can be obtained over a wide temperature range:



However the reactivity with coal/carbon can be applied to the process:



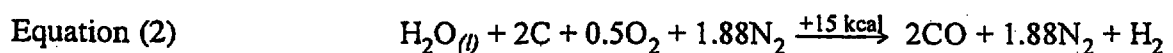
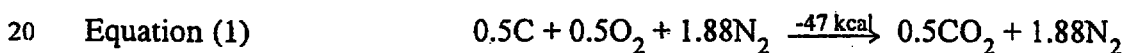
All the foregoing reactions are endothermic and operate within the heat and reactant content of the recycle part. In this way the cycle first yields the endothermic heat and reactant steam for the transformation and then regains it when the product fuel gas is fired downstream. The reaction equilibrium is well served by the abundant water vapor content of
10 the recycle part.

FIG. 5 shows an embodiment whereby the production of hydrogen is preferably accomplished via steam - iron reactions. Either of the following three ways are described for their different physical effects in reaction equilibrium and kinetics with respect to how the iron product can be later stored and used:

- 15
- A. Reduction of Fe_3O_4 to FeO for Hydrogen
 - B. Reduction of Fe_3O_4 to Fe (sponge iron) for Hydrogen
 - C. Carburization of Fe to Fe_3C (iron carbide)

A - Reduction of Fe_3O_4 to FeO for Hydrogen

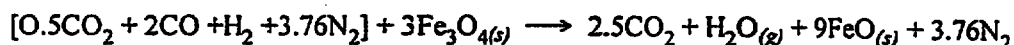
Heat Source for and Production of the Reducing Gas



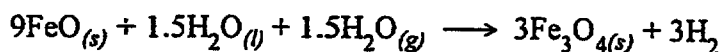
Net $\Delta H = -32 \text{ kcal}$

Reduction

Equation (3)

Oxidation

Equation (4)

5 $\Delta G = -93 \text{ kcal}$

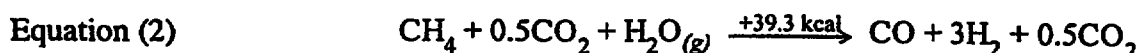
FeO particles, derived from fairly sizable Fe_3O_4 particles (probably from a pellet source), offer a unique characteristic whereby the particles can lumber along forward from drag forces created by the high velocity, reacting steam exerting slip velocities up to transonic speeds. As a recycle process only the product hydrogen has to be discharged at the end of the reaction zone. It does not matter if solids recycling are a mixture of Fe and FeO particles so long as suitable means are provided to preclude agglomeration in recycle. The orientation of the reactor by this invention can assume any angle with horizontal that sustains the solid particles in flight.

An alternative mode relates to a very fine Fe particle in the 50 to 200 micron range. At the lower end close to dust in size they must be conveyed by a neutral gas, nitrogen for example, in a sealed conduit to preclude spontaneous combustion. Because of this characteristic they can be expected to develop very high reaction rates just by mixing with steam. Further comments will ensue after examining the following reactions for producing hydrogen from sponge iron, Fe:

20 B. Reduction of Fe_2O_3 to Fe (sponge iron) for HydrogenHeat Source

Equation (1)

Reforming

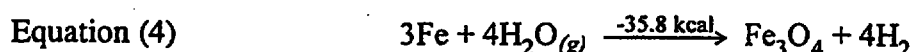


Net ΔH for (1) and (2) = -56.5 kcal

Reduction



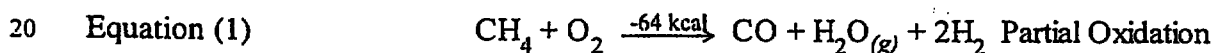
5 Oxidation



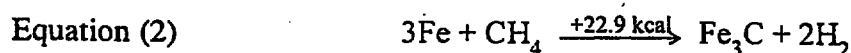
according to Gahimer et al (IGT experiments 1976) Equation (4) has a favorable free energy change almost linearly from $\Delta G = -20$ kcal at 125 C to about -3 kcal at 925 C. The free energy changes for reactions "A" were computed from Thermochemical Properties of Inorganic Substances by I. Barin and O. Knacke. In view of Gahimer, the favorable free energy changes for the "A" reactions support both processes as achievable for hydrogen production by the rocket engine power source and the conserved energy reactor. This is not to preclude running larger particle sizes in "B" reactions while still striving for an all-Fe or sponge iron production for other uses while producing hydrogen for fuel cells and gas turbines. Such a use is sponge iron for steel mills presented next as "C."

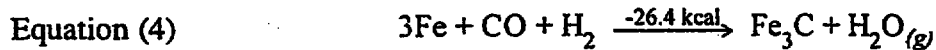
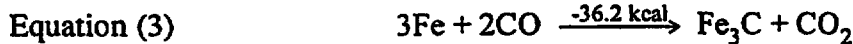
C. Carburization of Fe to Fe₃C (Iron Carbide)

The production of sponge iron is basically the direct reduction of iron oxides as described above and its use in steel is primarily to form iron carbide (Fe₃C). With methane, as a major constituent of natural gas, the chemical environment is described by equation (1):



The following are the driving carburization reactions:





5 The foregoing illustrates the expansive applicability of the rocket engine power source of relatively unlimited high pressure range and a 5000 F ceiling for the rocket engine combustor as a facility for high productivity in steel mills with a coordinated process which also produces power. The combination for this is next described with respect to reactions "B" above and FIG. 5.

10 The sequence now is to generate for example, six moles of hydrogen independently from the above equations by transforming methane in the rocket engine power source. The hydrogen flow is divided equally into three tracks:

Track 1 delivers two moles to fuel cell 500 (preferably solid oxide fuel cells) delivering power and high pressure steam into combustor 501 which empowers turbine 502,
15 as shown.

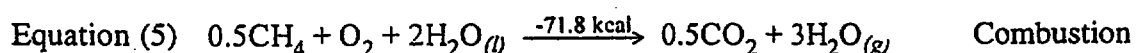
Track 2 delivers two moles of hydrogen directly to combustor 501

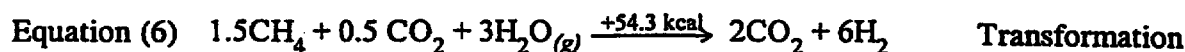
Track 3 delivers two moles of hydrogen to reduce 0.5 Fe₃O₄.

What follows next are the potential reactions in the first and second stage operations.

The first stage produces all the hydrogen and is a pressure cascade. It empowers the second
20 stage for the reduction of Fe₃O₄. The pressure developed in rocket engine 503 also delivers the off-gases in track 3 from reactor 504 into the combustor 501 for maximum heat utilization.

The reactions occurring in stage 1 are:





Reaction 5 takes place at top pressure inside combustor 503 so that the combustion nozzle develops a jet as needed up to transonic velocities thereby activating reaction (6) which occurs when 1.5 moles of methane are metered to react with the jet, accordingly producing in this example six moles of hydrogen equally distributed as above described to the three tracks. The carbon dioxide is separated from the hydrogen by suitable advanced means for retaining pressure and heat and directed from reactor 505 from said separation and on to empower the second stage sequence 506 and 504 for reducing the magnetite Fe_3O_4 .

Accordingly, carbon dioxide and hydrogen flowing into jet pump 506 extend the back pressure from stage 1 through a transonic nozzle to interact with Fe_3O_4 particles being metered downstream of the carbon dioxide and hydrogen jet according to the following reaction (7):



The foregoing reactions are approximately in heat balance so that additional heat may be added as necessary for process purposes. This is simply an example of the versatility of this invention to facilitate a two stage reaction process. The jet pump 506 can readily be organized for combustion by introducing oxygen to fire a fraction of the hydrogen, and this can be the case when the carbon dioxide must be separated by a conventional solvent absorber-stripper or pressure swing adsorption system.

The exhaust from turbine 502 comprises water vapor and carbon dioxide. The flows in the process would be iterated (not done for the purpose of this example) as described in previous embodiments whereby a substantial fraction in line 507 would continue on in line

508 into rocket engine compressor means 509 and the difference in line 510 bypassed for other uses.

Returning now to the production of iron carbide and using endothermic reaction (2) for example, sponge iron and methane react with heat to yield iron carbide $[\text{Fe}_3\text{C}]$ and hydrogen.

5 As an option, this is depicted in FIG. 5 as a third stage process whereby the methane is partially oxidized in the rocket engine combustor 511. Methane may be metered in excess into the nozzle section of combustor 511 or metered down stream into nozzle sections of sponge iron reactor 512. The jet from combustor 511 accordingly supplies the endothermic heat of reaction to produce iron carbide and hydrogen. In alternate modes the hydrogen
10 produced from reactor 512 can be recycled to the nozzle sections of combustor 506 and reactor 504 to reduce Fe_3O_4 and/or FeO to sponge iron thereby minimizing carbon dioxide production.

In conclusion for this embodiment two further points are made. Firstly, a full power plant or peak load requires operating tracks 1 and 2 together. In this way the turbine can be
15 organized to handle the base load on track 2 alone. Secondly, sponge iron can be commercially made into pellets or briquettes which can be conveniently ground into powder form. The reactivity of fine iron particles with steam can produce Fe_3O_4 and pure hydrogen. This can be more suited for small fuel cells for residences, for example. Polymer electrolyte membrane fuel cells are commercially being developed for this purpose as well as somewhat
20 larger units for commercial buildings or mobile power sources. This class of fuel cell minimizes high temperature components in dwellings and confined spaces. This invention can produce the sponge iron for these or other fuel cell types with relatively small reactors for portability and security as well as the aforementioned larger scale operations.

We next describe the rocket engine power source applied in two ways for boilers and steam turbines.

The Steam Turbine Power Cycle - General Considerations

Refer to Figures 6 and 7 which are later described in detail. Typically steam turbines in boilers are without connected compressors. As an example, a steam turbine generator producing 50 MW would be powered by a boiler delivering approximately 346,000 pounds of steam per hour at 600 psia and 1000 F with an exhaust from the turbine at 250 F and 30 psia as dry saturated steam containing 1517 Btu per pound. Entropy is approximately 1.7 Btu/pound R.

At constant entropy, the theoretical efficiency, neglecting pump work, is calculated as follows:

$$E = \{ [1517 - 1164] / [1517 - 218] \} \times 100 = 27.2\%$$

The efficiency represented sets the point of departure between existing or new installations planned on the Rankine Cycle and this invention. The objective here is to recover most of the heat into the conserved energy reactor for converting and developing all the fuel, retaining recovered heat for firing the boiler. In completing the cycle, the efficiencies of the boiler and of the transmission of power between the turbine and generator will remain substantially unchanged. However, the inner cycle gain in entropy increasing the exhaust enthalpy will be recovered in the conserved energy reactor which will receive the exhaust steam directly as the major companion reactant with carbon and hydrocarbon compounds.

The latent heat in the turbine exhaust represents the largest part of the waste energy. At least 50% of it is recoverable by inter-mixing an additional flow of water with the turbine exhaust steam on a one to one basis. If all the latent heat is recoverable at this point in the process then the usual boiler efficiency of about 90% (100% for simplicity) would also hold

as the overall thermal efficiency for the advanced operation. However the 27.2% efficiency shown above also represents the overall thermal efficiency of a current operation. The lost energy is 72.8%, which for practical purposes is the latent heat loss to cooling water.

By recovering 50% this, as above described "E" becomes:

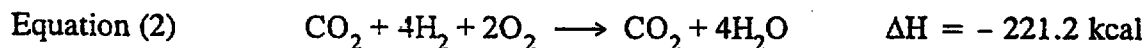
$$5 \quad E = 27.2 + 36.4 = 63.6\%$$

The net work is nominally unchanged as 50 MW or 27.2% of the heat flow to the turbine. The fuel economy is greatly increased so that 36.4% less fuel is needed to produce the same net work. Further, the cooling water requirement is cut in half and the additional water, 50% saturated after intermixing is next used as the major water vapor reactant as $2H_2O$ into the
 10 conserved energy reactor shown for example, with CH_4 by



For this analysis and in general two moles of steam can represent all the steam that the boiler supplies as 100% and all for the turbine. It is therefore consistent to recover as much heat from two moles of turbine exhaust by the inter-mix flow transfer, above described, by
 15 relating to two moles for continuity of mass whereby two moles of exhaust continue on to the condenser and two additional moles with half of the latent heat go into the reactor which supplies the fuel to the boiler. The added water must at least be as pure as the turbine exhaust so as not to contaminate the flow to the condenser.

The two moles of water vapor are thereby converted to fuel in the power source. The
 20 fuel is next fired to provide 100% of the heat to the boiler by



whereby the combustion products $CO_2 + 4H_2O$ are stack gases (for cleanup as necessary) to become the heat source in near adiabatic flow for a second stage power source which can provide additional fuel at any pressure for any purpose for immediate use and part of which

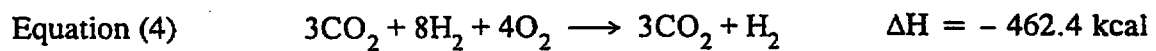
can be recycled to power the rocket engine and or rocket engine compressor means for either or both first and second stage reactors.

It is preferable that in the foregoing staged operations the engines are fired with a clean fuel like methane and that at least in stage one the carbonaceous matter is also methane or an
5 equally clean and compatible fuel.

The following reaction(s) demonstrate the escalating benefit of stage two:



The effect of firing is shown by:



10 By comparing the combustion heat releases from Equations (2) and (4) with the endothermic requirements of Equations (1) and (3) it is fairly obvious that there is abundant fuel available apart from exhaust heat recovery both as latent and sensible heat from turbine exhaust and stack gases to further supply hydrogen recycle for the rocket engine and compressor combustors. The carbon dioxide part may be retained or separated and by-passed by suitable
15 means.

A yield of eight moles of hydrogen is considered a maximum and the yield may be considerably reduced by lowering the flow of stack gases for the second stage reactor and directing the difference to low grade heat uses. On the other hand this mode, without or with less use of a second stage power source, can apply the first stage in the use of other
20 carbonaceous less costly and/or less clean feeds which depend on in-situ boiler or stack clean-up.

Case 5 - Rocket Engine Power Source Integrated With Boiler

FIG. 6 is now described in compliance with the foregoing operations. FIG. 6 shows this embodiment in which a rocket engine power source is integrated with a boiler utilizing the two stage fuel transformation. Steam exhaust from turbine 600 via line 601 flow into mixer 602 for direct heat interchange with clean water, through line 603, which is metered and pumped (not shown) to boost as necessary the flow through the mixer 602. The mixed flow 604 divides into flows 605 and 606 so that flows 601 and 606 are mass-matched (control not shown) to preserve boiler feed water continuity through condenser 607 at a controlled low pressure which also boosts the mixed flow 604 through the mixer 602. As a consequence bypass flow 606 matches the mass content of clean water inflow 603. Mixer steam flow 608 from boiler 609 joins the mixed flows 601 and 603 to bring the clean water flow 603 at least up to the point of vaporization. The minor steam quantity for this purpose becomes part of and increases bypass flow 606 over said mass-matched condition, which now as a partly saturated vapor is directed into a downstream port of rocket engine nozzle section 120 (not shown). Increased flow 606 accordingly becomes the major H₂O reactant with carbonaceous matter 610 in the first stage power source. The fuel 611 can be any fuel but clean fuels such as methane or natural gas are preferred for two stage operation. The oxidant 612 is preferably oxygen for the first stage of a two stage operation. The power source discharges fuel product 613 through distribution means 614 which can be the fire box of boiler 609 or simply deliver the fuel product to the boiler's fire box away from said means.

The boiler delivers steam 615 which supplies minor bleed 608 (previously described) and which can be further divided into a steam flow 616 which directly powers turbine 600 and discharges optional flow 617 which is divided into flows 618 and 619 to suit make-up steam requirements. The optional flow 617 of course requires additional fuel supply 613 over what is necessary for turbine power.

There is a second more dominant option for flow 618 whereby the compressor means is eliminated and combustion is precluded inside of jet combustor 102 shown in FIG. 1 and flow 618 (up to full boiler pressure) empowers the jet so that the rocket engine is replaced by a powerful steam jet pump. However, combustion is not precluded downstream of the jet and
5 can be applied for increasing the temperature and thrust of the downstream flow. This feature, though not shown, can be applied to the second stage power source in this embodiment and likewise in the FIG. 7 embodiment.

Continuing now with FIG. 6, steam rich stack gases 620 pre-cleaned as necessary inside boiler 609 or outside (not shown), can be divided into flows 621 and 622. Flow 621 is
10 directed into a port of nozzle section 120 (shown in FIG. 1) just down stream of the jet. Flows 621 and 622 are adjusted to suit the reactivity with flow 622 being directed accordingly into the conserved energy reactor. Other aspects of the second stage reactor are similar to those of stage one and generally of the power source described in FIG. 1.

Case 6 - Hot Flow Extensions of Boiler Embodiment

15 FIG. 7 shows this embodiment whereby a boiler arrangement is used with a hot flow extension to further improve system efficiency. The hot flow engine gasifier is powered by a standard industrial supercharger available over a wide flow range, for large industrial diesel engines. In this application, the turbine and compressor part are interspersed with a custom
built combustor designed to be fueled so that combustion products are chemically compatible
20 and can flow adiabatically under power, practically without heat loss, except for minimal radiation for increasing the efficiency of the Boiler 609.

The turbocharger engine described is a simple cycle gas turbine and can be started by any suitable means. The turbocharger - gas turbine is preferred to an expensive conventional

gas turbine (which is not precluded) because the pressures anticipated are generally predicted to be under four atmospheres.

Referring to FIG. 7 the hot flow unit compressor 700 receives air from line 701 and delivers part to combustor 702 from line 703 at top pressure. The remaining air is delivered
5 at the same pressure to combustor 704. Combustors 702 and 704 are separately fueled by lines 705 and 706 respectively by any compatible fuel, but preferably hydrogen in the ration of 4 to 1 with carbon dioxide, which can be supplied by the second stage rocket engine power source. The products accordingly have high emissive potential for radiant heat transfer. The products from combustor 704 discharge through a sonic nozzle in conjunction with secondary
10 ports which comprise nozzle entrainment unit 707. The nozzle is integral with the combustor and the secondary entrainment ports which separately receive ambient air 708 and exhaust gases 709 from turbine 710.

Extremely hot gases (2000 F and higher) emanate as mixed flow comprised of combustion products from 704, ambient air 708 and turbine exhaust 709 coming together in
15 channel by suitable means and continue as flow 711 through heat exchanger 712 which further super-superheats the boiler steam 713 to 1600 F and higher. The exit flow 714 can be deployed for further recovery by conventional heat transfer means to suit various boiler needs.

The foregoing completes the hot flow cycle which for practical purposes is 100% heat utilization efficient except for minimal radiation and whereby the turbocharger - gas turbine
20 power, converting to heat in-situ, becoming intrinsically part of the total heat, comprises a total energy conversion adjunct to Boiler 609.

The hot flow velocities are planned to be very high so as to greatly increase the heat transfer rate in exchanger 712. This is a total energy system whereby the turbocharger gas turbine's power heat equivalent is totally conserved, resulting in extremely high heat transfer

rates because the power for generating the necessarily very high velocities is conserved. As a consequence the ultimate benefit is a relatively smaller heat exchanger. Flow velocity, the essential factor, requires power which rises as the cube of the velocity. Power here is not a cost factor because it is conserved, as already explained. Accordingly, by combining this
5 intense heat transfer by convection with the previously described highly emissive radiation, heat fluxes up to 90,000 Btu per square foot per hour and higher can be obtained.

The hot flow extensions to the conserved energy reactor described above effectively create a total water and energy recovery system. Investment costs are minimized by the very high heat fluxes thereby greatly reducing the surface area in exchanger 712. Water and its
10 contained energy is internally recycled; the turbocharger gas turbine's power heat equivalent is totally conserved; the energy required for high velocity heat transfer (which rises as the cube of the velocity) is not a factor here because it is conserved, as already explained. The principle advantage of increasing the steam temperature to about 1600 F and higher is that this substantially increases the turbine output while still retaining the conserved energy benefits of
15 the two stage system and the flexibility of being able to transform considerably less costly fuels into more useful products. Of course it is also possible to add the hot flow extension to the fuel cell arrangements described in FIG. 5.

Referring back to and extending the 50 MW example, the following demonstrates the Hot Flow gain from just a 400 degree rise to 1400 F, based on a nominal specific heat of 0.5
20 Btu/ pound F:

$$E' = [(1717 - 1164) / (1717 - 218)] \times 100 = 36.9\% \text{ for 68 MW}$$

compared with 27.2 % for 50 MW. The numbers speak for themselves. Every dollar for fuel heat energy spent in this way is reflected in equivalent electrical energy without loss.

Turning now to Figure 9 which is an extension of Figure 4 and introduces three options with respect to flow 212 shown in Figure 2 as the recompressed exhaust from turbine 108. Both Figure 2 and Figure 9 show this recompressed exhaust delivered into the Conserved Energy Reactor and this is also one of the options shown on Figure 9 as flow 916.

5 The other two options are:

1. flow 917 as an indirect heat transfer source for interstage heating, and
2. flow 918 as a direct heat transfer source for interstage heating.

Parent flow 212 may be apportioned to flow 916 and to flow 917 and 918. Controlled metering and throttling of these flow options (not shown) are preferred. Also when two
10 options are selected to apportion the exhaust flow from turbine 108, then each flow can be provided with a separate and additional compressor (not shown). This would allow one flow to be a significantly different in pressure.

The main advantages of the flexibility provided by these options are:

1. They facilitate establishing and maintaining the continuity of the main cycle as
15 to chemistry and mass flow;

2. While continuity is indigenous with a prescribed heat capacity, flow 918 and particularly flow 917 provide additional heat capacity that translates to additional expansion power. The additional mass into the cycle by flow 918 is compensated for by programming the discharge at flow 206 to include an equivalent mass. Indirect heat flow is exhausted from
20 the cycle as flow 919 to be applied for further recovery; and,

3. Deploying all or much of the exhaust away from the Conserved Energy Reactor and the main recycle flow, the more parent exhaust mass and heat can be delivered through line 207 for recovery within the main cycle, thereby minimizing external heat additions for completing the cycle.

Recovery flexibility is also enhanced by provision of separate compressors 920 and 134. These are shown on the same shaft schematically for simplicity. The main requirement is that they are independently controlled and powered by the same turbine 108 or any prime mover so long as the compressor 213 is also powered by the same prime mover and its
5 exhaust is recompressed by compressor 213.

Returning again to compressors 920 and 134, these are shown to receive flows 915 and 209 respectively which are selectively apportioned from exhaust flow part 207. One objective is for each compressor to be capable of delivering up to the highest pressure required by the cycle which is a relatively unlimited high pressure specified for rocket engine combustor 102.
10 The second objective, accordingly, is to deliver the least mass into combustor 102 from line 922, and the remainder at a selected lower pressure from 404 which may further be selectively sub-divided for delivery into one or more secondary ports, via line 923, to the rocket engine nozzle section 120; or via line 924 into selective ports of the Conserved Energy Reactor.

The main objective of the foregoing alternatives is to take full thermodynamic
15 advantage of the 5000 F upper limit and top pressure capability of the rocket engine combustor to support the prescribed overall cycle requirement for the least pressure requirement from compressor 134 which is delivering the greater part of the mass into the cycle and thereby reduce the power otherwise required by turbine 108. This power may be further reduced by down stream jet propulsion previously described. The thrust force
20 produced thereby increases the entrainment capability and the power of the flow for delivery into the power output turbines.

As was earlier discussed in conjunction with the bench mark analysis for cycle optimization, the foregoing description with respect to Figure 9 further exemplifies the

increased flexibility afforded by the two compressors for selectively dividing that portion of the turbine exhaust, chosen for recovery within the cycle.

Returning again to the production of ethylene, further concepts relate to several functions for optionally arresting the chemical reactions for its production.

- 5 This is complementary to the various ways previously discussed for this invention for setting chemical reactions to a prescribed product resolution. These mainly, with the exception of products involving products resulting in non-equilibrium mixtures such as olefins, principally ethylene, were treated with respect to equilibrium related reactions in the production of synthetic fuels.

10

What follows further extends the treatment of ethylene. Transonic flow is extended over a significantly greater length in series sections as a better control of the millisecond character of the pyrolysis residence time and a further increase in selective length down stream in order to continue to accelerate the flow

- 15 1. Supersonically after shock and a brief interval of increased pressure to ensure flow through at least one sequent transonic nozzle;
2. Alternatively, the flow through the next or last de Laval nozzle can be adequately fast for some reactions if only slightly subsonic.
3. This mode can also be appropriate when all flows and related nozzles are designed to
- 20 operate at slightly sub-sonic but increasing in velocity down stream, so that acceleration after pyrolysis would be considerably greater to enhance setting the reaction
4. Still another option is to program a shock after the pyrolysis zone which still continues to accelerate flow after a slight increase in pressure and a slight deceleration.

The main objective of the foregoing described accelerations particularly after pyrolysis is to set or "freeze" the planned reaction by causing the temperature of the reaction to drop by converging the contour of the channel or tube thereby changing the pressure head to kinetic energy. According to Raniere, a slight increase in pressure just after the last shock zone, functions to offset the endothermic reaction by the related increase in temperature. This is true providing an accelerating flow and a decrease in temperature follows.

Other variations with respect to the foregoing options can be practiced by those knowledgeable in fluid mechanics and/or gas dynamics within the context of this invention, so long as the objective for accelerations is practiced as an in-situ cooling function, to set the pyrolysis reaction. In this way, the need for a water mist quench is either eliminated or minimized. If used, its preferred function thereafter is to expand the flow through a turbine in order to continue to drop the temperature.

The following comments are in support of the foregoing to employ shock waves for pyrolysis. The advanced concepts of Hertzberg, Kamm, Raniere and others who teach various forms of shock activity may be compared or contrasted with the art of Millisecond Furnaces which, though capital intensive, have operated for years successfully in the marketplace and challenge competitive efforts to devise a simpler, more compact, much less capital intensive technology.

The other simple fact from a purely fluid mechanic standpoint is that the flow in the tubes of a Millisecond Furnace accomplishes the pyrolysis without shock waves. While furnaces differ with respect to tube shapes between manifold entry and quench sections, consider an M. W. Kellogg furnace as described by Ennis, et al in their paper entitled "Olefin Manufacture via

Millisecond Pyrolysis" (Chemtech Magazine November, 1975). The tubes are straight, approximately one inch inside diameter and approximately 36 feet long. For substantial ethylene yields, the residence time is 0.03 to 0.1 second. With an outlet temperature range of 870-925 C. Accordingly, the average velocity in 36 feet, ranges from 360 to 1200 feet per second.

The velocity of sound $a = (g k R T/m)^{0.5}$ which as given for steam at 925 C is 2700 feet per second (Keenan and Kay Gas Tables). So with gRT constant, Mach 1 for products would vary as k/m where $k = C_p/C_v$ and m is the molecular weight.

With this frame of reference the flow in this invention, in the shock wave mode, can by starting with Mach number of 3 or higher, cascade down to a lower Mach number selectively to suit the pyrolysis zone at the end then allowing a slight deceleration of the flow before a relatively steep acceleration to the turbine entrance. Accordingly, pyrolysis can be considered to take place, selectively in the last shock zone as a "bottle" shock or compression shock conforming to the L/D ratios recommended by Ascher H. Shapiro in his text "The Dynamic and Thermodynamics of Compressible Fluid Flow" under the heading of "Normal Shocks in Ducts" pp. 135-137 and 1153-1156 (Ronald Press) 1954.

Supersonic zones can also be provided in series to promote mixing first for steam generation in-situ- and next to mix the feed with steam whereby the feed is metered in at a substantially low velocity, but fast enough for tube cleanliness, whereby the steam-hydrogen mix is flowing at supersonic velocity. The boundary layer in ducts is impacted from successive shocks, in a "bottle shock" zone. When feed stocks are metered in peripherally this action can be

expected to assist its diffusion into the main stream and can minimize the growth of the boundary layer by entering with some kinetic energy into a low pressure zone, but still as a relatively low velocity compared with the supersonic entraining stream. However, when feed is directed into a low pressure zone, its velocity can be selectively increased in order for the feed to penetrate deeper into the flow to further enhance mixing, particularly in advance of or into a shock zone. An alternate mode of pyrolysis, as stated previously, can function at very high subsonic velocities by this invention.

Further, it is to consensus that ascending heat rates increase conversion for coal. See Von Rosenberg, U. S. Patent 4278446. With respect to a temperature difference of 1500 K for a well dispersed coal particle, he purports to attain a high heating rate of 106 K/sec. Reaction rates range from 0.6 to 2.4 milliseconds in a supersonic diffuser approximately 2 meters long.

In his report to the U. S. Department of Energy (DE-AC 21-85 MC 22058, March, 1987), the team achieved coal conversion rates up to 70% in about 50 milliseconds. The reactor length down stream of the DeLaval nozzle was 80" long to the quench station. Pressures up to about 4 ATM, and temperatures up to 4000 C were tried. The flows enter the supersonic diffuser at Mach 2.27 and leave at Mach 2+.

It's of interest now to apply a heating rate of 105 K/sec to an ethane fed steam pyrolysis reactor of Hertzberg's U. S. Patent No. 5,300,216. This is to estimate the reaction length portion devoted to achieve the 573 C temperature rise given and shown on Figure 2B of the patent. The peak temperature 1000 C is shown as a normal shock rise from 427 C as the mixed ethane and steam temperature. The pyrolysis temperature is given an 863 C. The

drop from 1000 C to 863 C is shown on the drawing as a cusp down to the horizontal at 863 C. This is over a pressure and Mach change of 9 bars and Mach 0.44 to 10 bars and Mach 0.12 just before quenching. At 1000 C and 26.7 bars steam mixes with ethane at 381 C for a final temperature after mixing, as above stated, of 427 C. The Mach number at this
5 temperature is 2.8.

The above description is easily followed by seeing the patent drawings. The point is to show that the rise to 1000 C could not take place over the span of a shock wave. Accordingly, a prospective heat rate of 105 K/sec is used to determine the time for the rise from 427 C to
10 1000 C and the related distance to the shock line shown in Fig. 2B. The shock line symbolizes a shock wave which Shapiro (p. 134) gives at 10-5 inches or less in thickness for shocks just above Mach 1.

The thickness is also related to the mean free path between molecules. The ratio of the
15 thickness to mean free path is 2 for shocks in the Mach 2 range and higher. To bring the 105 C/sec in perspective, the time for the rise is determined:

$$t = 573 \text{ C} / 105 \text{ C per sec} = 0.0006 \text{ sec or } .06 \text{ ms, approximately}$$

20 For an order of magnitude approximation, the mixture at 427 C is considered steam at 1300 R. From Keenan & Kaye Table, the velocity of sound for steam is given as 2100 fps

$$\text{Mach } 2.8 \times 2100 \text{ fps} = 5880 \text{ or } 6000 \text{ fps}$$

Related reactor length is

$$6000 \text{ fps} \times 0.0006 \text{ sec} = 3.6 \text{ feet}$$

- 5 This length is in the same order of magnitude as the work of Von Rosenberg for the Department of Energy. However, this rate pales with respect to the rate that would be required for a 573 C rise in temperature if it had to take place in a distance of 10-5 inches.

This is not to question the rise, but the space-time relationship in which it occurred.

- 10 Presumably, the temperature started to rise in the so-called mixing zone of Figures 1 and 2B.

In this context, it is noteworthy to compare the work of Raniere, U. S. Patent 4,724,272. He clearly illustrates pyrolysis in the multiple shock zone, as does Von Rosenberg. Raniere's Figure 1b shows a steadily rising temperature there, corresponding to a linear deceleration in
15 velocity. Raniere maintains a supersonic velocity above Mach 2 through most of the reactor where multiple shock or "bottle shocks" start to occur. The flow goes subsonic before entering a converging subsonic diffuser. His reactor processed 1500 tons per day of methane yielding 43 TPD of ethylene while recycling methane and hydrogen. He develops a Mach 2 flow at about 3 atmospheres powering the jet and operates the pyrolysis at 500 to 2000 C.

20

These operating details are mentioned because they are widely different than Hertzberg's.

They point up the plausibility of a process according to this invention, which provides a wide range of flexibility and control with the further benefit for facilitating scale-up which does not preclude the use of shocks, but presents an alternate embodiment of a reactor designed for

accelerating high subsonic flows which can employ shocks selectively for mixing and/or pyrolysis, but which, on the other hand can operate by the further embodiment without shocks at all.

- 5 In keeping with the total energy aspect of this invention and here with respect to the production of ethylene (but which also can be practiced in the production of synthesis gases) is the generation of steam in-situ, in the combustor of the rocket engine. When necessary, additional steam can be generated just down stream from the rocket engine nozzle where additional heat can be added as needed.

10

- The preferred fuel for the rocket engine is hydrogen. So if more space is needed for steam generation, the heat for this can be provided from firing the related additional hydrogen either flowing (preferably) as part of the jet or added secondarily just down stream of the jet. The hydrogen is provided by an independent rocket engine power source as a first stage operation
- 15 to the foregoing ethylene cracker embodiments described. Other fuels can be used so long as the combustion products are free of oxygen and are also chemically compatible with the pyrolysis function. A jet slightly rich in hydrogen is also compatible in some pyrolysis operations. Its richness is of course increased for after-jet combustion when additional steam is required downstream of the jet.

20

Specification of the Invention - In the pyrolysis of olefins with respect to sonic and/or transonic flow Figure 10 is a diagram of a near-total energy steam pyrolysis closed cycle for producing olefins in the rocket engine powered transonic mode.

The alternative mode whereby the flow is near-sonic and continuously sub-sonic throughout is not configured.

Of course combinations of the two modes are still in the context of this invention as readily
5 understood by those knowledgeable in the field of gas dynamics, particularly when there is a transition from gas dynamics in-situ to sub-sonic flow of the venturi type in fluid mechanics.

Turning now to Figure 10:

10 1001 is a rocket engine combustor designed for temperatures up to 5000 F and relatively unlimited pressures. 1002 is a DeLaval nozzle designed in the range of Mach 0.8 to 5.

Steam is generated in 1001 in-situ by injecting water into the Rocket engine combustor.

When additional steam from water is required in the process, this takes place in diffuser 1003
15 which, in this case, is powered and served by DeLaval nozzle in the Mach 0.8 to 0.9+ range whereby the combination of 1002 and 1003 comprise a venturi wherein additional water is metered in for steam generation.

When additional steam is not required, the nozzles 1002 and 1003 are designed for super-
20 sonic flow in the range of Mach 1+ to 5.

In either case, nozzle 1004 and diffuser 1005 are transonic for delivering super-sonic flows into duct 1006, which is preferably constant in cross-section (although a slightly diverging duct is permissible). In either case, the design and related process flow is preferably

programmed to emerge from 1006 in sub-sonic flow which can be increased in pressure by a slight divergence in the extension (not shown) of duct 1006 before converging severely in 1007 into close-coupled expansion turbine 1008 which exports power P, which may be optionally applied to turbo-charging or in the generation of electricity, AC or DC, to be used
5 preferably within the process.

Accordingly, what is being described is a quasi-closed loop for near total energy conversion where the principle source of power (in keeping with this invention and that of the many previous embodiments) is the rocket engine power source 1001 as a pressure-temperature
10 cascade whereby the turbine 1008 converts part of said power into export power P which can be returned to the cycle without specificity as practically applied by one versed in conventional process engineering.

Continuing now in the loop, the flow passes into condenser 1009. The cooling water (not
15 numbered) indicated by arrows, is preferably deployed and further heated as the source of steam to be fed into a first stage rocket engine power source and conserved energy reactor which supplies hydrogen or hydrogen containing fuel gas into combustor 1001 through line 1022 of the second stage rocket engine..

20 The oxygen requirement for firing combustor 1001 can come in on line at system pressure, or be compressed by the efficient power source of previous embodiments. For this mode the oxidant is represented on Figure 10 as oxygen. An alternative mode using air would require a similar compressor means.

A further process can involve additional hydrogen 1015 down stream and distributed to the pyrolysis reaction in zone 1 via 1003 with the feed stock and/or as 1016 into zone 2 via 1004 and/or zone 3 via 1005. In each case the flows are to be controlled and metered by suitable means, as with all flows in the process in order to govern the prescribed stoichiometry.

5

The alternative functions of duct 103 are: to produce more steam as needed, to generate high subsonic flows or to produce high supersonic flows with respect to jet 1002. Each mode, each design and coordinated flow specification are tailored to meet a programmed process.

These functions have been previously described as an interrelated series of ducts 1002, 1003, 1004, 1005, 1006 and 1007.

10

This series is further described as functions in zones 1 through 4, particularly with regard to the right and left hand end of duct section 1003. Accordingly it converges to the right for any one of the following functions for:

15

A. Accelerating high subsonic flows to and through its right hand nozzle extremity from an overall venturi action from jet 1002 on the left;

20

B. Building up an adequately high static head at duct 1003's largest intermediate cross section so as to produce a transonic jet at its right end nozzle, thereby producing a high supersonic flow from zone 1 to zone 2; and continuing in supersonic flow to selectively produce "bottle" shocks or a normal shock in zone 3.

C. Developing an adequately high Mach number (up to mach 5 or higher) as needed at jet 1002, so that in producing a transition shock as the flow enters the right hand or converging contour of duct 1003 enough static head is retained to selectively produce a high subsonic velocity or a lower supersonic velocity at the right hand nozzle of zone 1.

Although the cascading Mach sequence just described effects a decelerating flow through zone 1, the cascade can be governed by selecting a stagnation pressure in the rocket engine combustor 1001 in coordination with jet 1002, so that the flow, as sated above, through the right hand end of zone 1 is either a high subsonic or an adequate supersonic flow. Notwithstanding the deceleration, the ducts 1006 and 1007 (relating to zones 3 and 4) are further correlated and are thereby contoured to accelerate the flow as earlier described. In this way the flows through zones 3 and 4 for cases $A < B$ and C are similarly accelerated. Furthermore, for all cases the foregoing functions for flows through zone 1 will hold irrespective of steam generation therein.

A main objective of this invention is to accommodate a wide range of feed stocks and production resulting in a wide range of flows, as well as to facilitate scale-up from prototypes. It is therefore by no means limited to 4 zones, provided the functions of zones 3 and 4 become 5 and 6 for example. In this event zone 1 would repeat as zones 1 and 2 with zones 2 and 3 becoming 3 and 4.

On the other hand for some processes a shorter series can be applied. Accordingly, intermediate zone 2 can become the right hand of zone 1, thereby discarding the right hand end of zone 1, and so forth.

The condensed steam and product gas from condenser 1009 are separated in 1010. The product gases, largely olefins, are exported for further processing and use. The warm water separated is pumped by 1011 to become the water 1013 for regenerating the pyrolysis steam in

nozzle diffuser 1002-1003 after by-passing excess water at station 1012. Return water flow 1013 is shown divided into flow 1017 for high pressure injection into combustor 1001 and/or as high or low pressure flow just down stream of the jet. Water 1014 at low pressure from an outside source is intended to mainly for startup and as a trimming function for later
5 adjustments for steady state flow.

As an added function, steam 1014 is bled and by-passed through control valve D for minimizing or largely eliminating the boundary layer developed by "bottle shocks" which develop boundary layers in constant area ducts. This steam can be jetted in at the beginning
10 of or through the boundary layer region, through perforations, slits or forced through porous media.

Another embodiment employs steam 1021 as a trimming function and alternatively to effectively replace all or most of the in-situ steam generation. It does this while still retaining
15 the quasi total energy objective of this invention as well as the fluid and gas dynamic functions above described.

Steam feed 1021 can also be provided with dirty steam which is available in some plants. Clean steam can be supplied by a separately heated steam generator or boiler which is
20 integrated with the pyrolysis cycle. Accordingly, condensate 1013 instead of flowing for distribution into the rocket engine complex as shown in Figure 10, now is directed through a purification process before being returned to the boiler.

The advantage of the boiler embodiment is that it minimizes the quantity of hydrogen for the pyrolysis cycle. In the preferred embodiment, the boiler is provided with its own rocket engine power source which delivers fuel for the boiler as previously described for the other boiler embodiments of this invention.

5

When the boiler is specified exclusively for the pyrolysis cycle, the preferred fuel gas is delivered by its rocket engine power is hydrogen and carbon dioxide because it can be produced in excess, so that the excess is bypassed to fire the complimentary rocket engine powering the pyrolysis train. This firing is programmed to adjust or increase the temperature of steam from the boiler entering the same rocket engine combustor at a common controlled pressure. The carbon dioxide accordingly compliments and augments boiler steam as the pyrolysis medium. When air is the oxidant, the pyrolysis medium becomes steam, carbon dioxide and nitrogen.

10

15 This boiler can also be designed to produce an additional quantity of steam for powering a steam turbine, as a compliment to turbine 1008, thereby providing adjustment toward the total power for the process. Another advantage of the boiler embodiment is that it minimizes the oxygen or air requirement and accordingly the mechanical compression required for powering the rocket engine for the pyrolysis train.

20

The pyrolysis train can also be a small process addition to a large steam generating plant. Accordingly, all the previously described functions and combinations are similarly applied.

Returning again to the non-boiler embodiment, the preferred fuel gas to be provided for the rocket engine powering the pyrolysis train is hydrogen and carbon dioxide. The hydrogen is fired to produce steam in-situ from water. Accordingly, less steam and less hydrogen is required, because of the carbon dioxide compliment; and , of course, still less is required if
5 the hydrogen is fired with air, because of the nitrogen compliment for the pyrolysis medium as described for the boiler embodiment.

The main source of power for the cycle is the cascading temperature and pressure developed in the rocket engine combustor. The controlling parameters for the cycle are the prescribed
10 temperature and pressure to developed for the pyrolysis reaction wherever it is programmed to occur. To the extent that the pyrolysis pressure can be favorably increased for the desired chemical reaction, it is preferable to build up pressure so as to increase the turbine export power toward approaching the pumping power required at 1011. In low pressure reactions, the balance of power is approached by increasing the flow in line 1018 while controlling the
15 flow in line 1017 toward zero. The balance is further improved when enough power is generated for driving the compressor 1020 which delivers the cracked gases through line 1014.

Not previously mentioned, some condensate can be recycled and applied as a quench medium
20 just prior to converging duct 1007 to assist when necessary as an additional way to reduce the temperature of the flow after pyrolysis in order to set the olefin reaction. The increase in mass flow through the turbine serves to offset to some extent , the loss in power due to related decrease in turbine inlet temperature.

In summary, two principle embodiments have been presented with respect to a second or common final stage reactor train as shown in Figure 10. In the first case, the first stage comprises a cascading rocket engine source of fuel gas and power for the final stage, and steam is generated in-situ. In the second case, the first stage comprises a boiler rocket engine complex whereby the boiler provides the steam and pressure largely for the second stage; and the rocket power source provides the fuel for the boiler and a prescribed fuel gas excess for the second stage.

Each two stage complex represents a quasi-total energy reactor cycle for equilibrium and non-equilibrium chemical processes whereby practically all of the mechanical compressive energy inside the loop converts first to heat and then to chemical energy and sensible heat in the product chemicals.

Further, it can be readily deduced by those familiar with states of the art in fluid and gas dynamics, as well as the production of steam, that finally the rocket engine source of power and fuel described from the onset of this invention, including the boiler variations, can also be applied for kinetic control in equilibrium reactions as described with respect to Figure 10 for pyrolysis reactions relating to the production of olefins and diolefins.

In conclusion the disclosure of this invention involves dispensing power in a cascade to one or more prime movers, expansion turbines for example so that the ultimate delivery is electricity or mechanical work. Within the cascade action, hydrocarbon fuels or other carbonaceous matter are subjected to an aerothermochemical driving force, a relatively unlimited stagnation pressure and combustion temperatures up to 5000 F for delivering jets of

compatible formulation to bombard and/or entrain carbonaceous matter introduced downstream. The consequence is the production of a fuel gas that is more economical and more physiochemically suitable for the prime mover. The exhaust from the prime mover is then suitable to a cycle whereby it is recompressed and delivered at top pressure to the top of the cascade. The part of the exhaust that is bypassed for export can be used to preheat the oxidant and fuel entering the cycle for the recompression of the exhaust. The fuel for recompression provides a substantial part of the top combustion pressure requirement. Similarly accounted fuel can also be applied for jet propulsion entrainment at one or more locations downstream of the top jet; that is, between the top jet and the head of the turbine or other prime mover where the fuel gas is fired at the design temperature and pressure.

The reactor can transform and provide reactant products for any purpose, with or without producing electricity. Further, waste heat can be applied to an endothermic heat requirement for many reactions similar to those described in this invention. Hydrogen and synthesis gases are provided for ammonia, methanol and other petrochemicals. Ethylene, acetylene and other cracked pyrolysis products are provided for downstream refining and petrochemical operations. Mixed reactions with solids such as iron oxides and sponge iron for steel mills and fuel cells also produce exceptional results with this invention. Finally, temperature and pressure largely are depended upon to drive reactions to completion through one or more transonic zones. By metered and controlled stoichiometry, with reactions taking place in milliseconds and with the intense gas dynamic action described, kinetic control in process operations can be developed over relatively short time spans. Metered and staged stoichiometry in a kinetically controlled reaction environment results in autothermal quenching. If desired, conventional quenching to freeze intermediate reaction species may be

employed. Also, catalysts may additionally be employed to promote reaction at less severe operating conditions and achieve concurrent removal of sulfur and other pollutants.

Applying the power source described in this invention to a whole variety of electric power, chemical and other process uses can fill a great need in industry and the world.

CLAIMS

What is claimed is:

1. A selective energy conversion source of synthetic fuels, hydrogen and/or
5 related combustion power comprising a rocket engine topping stage provided with fuel and
oxidant capable of firing up to 5000 F and higher with relatively unlimited stagnation
pressures whereby said engine powers a jet substantially rich in steam to admit and propel one
or more fluids in a near adiabatic tunnel, whereby said fluids are first pressurized by at least
one prime mover for delivering said fluids at conforming pressures into the nozzle section of
10 said rocket engine and/or downstream nozzle sections in said tunnel and further whereby all
the mass and substantially all the heat and energy delivered by said prime mover, including
recompressed exhaust from said prime mover, are conserved and come together in said tunnel
as a unified fluid at a controlled temperature and pressure at the end of said tunnel as a source
of said fuels, hydrogen and power;
- 15 2. The process according to claim 1 whereby a substantial portion of said fuels
and/or hydrogen are recycled to substantially fuel said rocket engine and/or at least one said
prime mover;
3. A source according to claim 1 whereby said fuels and hydrogen are clean fuels;
4. The process according to claim 2 whereby said fuels are fired to power gas
20 turbines and expansion turbines;
5. A source according to claim 1 whereby synthetic fuels are produced by said
transformation reactions occurring in any one or more reactors interspersed between said
nozzle sections;



This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

6. The process according to claim 4 whereby said fuels are fired for generating steam in a boiler which can power a steam expansion turbine, whereby a portion of said steam and/or a portion of the exhaust from said turbine recycles into the nozzle section of said rocket engine and/or the nozzle sections of said tunnel for providing said fuels;

5 7. A source according to claim 5 whereby said fuels are produced in excess to the requirements for said boiler and/or said turbine for other uses;

8. A source according to claim 1 whereby hydrogen is produced by said transformation reactions occurring in any two or more reactors interspersed between said nozzle sections;

10 9. The process according to claim 4 and claim 7 whereby said fuels and/or hydrogen are produced by transforming hydrogen containing matter, water and/or steam which are introduced into any one of said nozzle sections to react with said steam rich jet;

10. The process according to claim 8 whereby said synthetic fuels and/or hydrogen are fired to power gas turbines and expansion turbines;

15 11. The process according to claim 3, claim 4 and claim 7 whereby said gas turbine is relieved from any in-cycle compression load and said expansion turbines are precluded from any in-cycle compression load;

12. The process according to claim 1 whereby said prime mover also recompresses additional recoverable material for delivering same in conforming pressures into said nozzle
20 section of said rocket engine and/or said down stream nozzle sections in order to augment the mass flow of the rocket engine;

13. The process according to claim 11 whereby said additional recoverable material is a substantial portion of the exhaust from said gas turbines and/or expansion turbines.

This Sheet Has Been Replaced





14. A source according to claim 4 and claim 7 whereby nitrogen and hydrogen are provided for ammonia synthesis;

15. A source according to claim 13 whereby said hydrogen is provided for other use;

5 16. The process according to claim 1 whereby said fuels and hydrogen containing matter are not acceptably clean when delivered at the end of said tunnel, so then are purified by acceptable means before being used in said gas turbines, expansion turbines and other prime movers.

10 17. The process as in claim 13 whereby said portion, in recycle, of said exhaust significantly exceeds the mass balance for continuity and the heat balance with respect to the power exported by said turbines then the excess heat and mass which is adiabatically contained is transformable, in part, to fuel which can replace, by external recycle, a substantial amount of the fuel required by said rocket engine and/or said prime mover.

15 18. The process according to claim 4 for producing ammonia synthesis gas in one stage with methane or natural gas as feed stock whereby a fraction of said feed is fired at a suitable pressure with air and water to produce a jet rich in steam from the rocket engine whereby the constituents of said jet react autothermally with a prescribed quantity of said feed stock metered into the nozzle section of said engine and/or into the nozzle sections inside of
20 said tunnel and down stream of said engine so that reactivity is enhanced with jet flows up to transonic velocities which then produce shock waves as necessary to deliver ammonia synthesis gas with carbon dioxide from said tunnel for separation and purification.

19. The process according to claim 4 whereby two rocket engine stages are used with the first stage providing carbon dioxide and hydrogen which are fed into the nozzle

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

section of the second rocket engine and/or the nozzle sections in the tunnel coupled to said rocket engine, whereby a fraction of the feed methane or natural gas is fired with air and water in each staged combustor to produce heat and jets rich in steam and any unreacted oxygen for subsequent complete oxidation ultimately producing hydrogen and nitrogen in the right ratio autothermally for ammonia and carbon dioxide to be delivered from said tunnel for separation and purification.

20. The process according to claim 18 and claim 19 whereby additional fuel is produced which is recycled to make up for a substantial portion of the fuel required for said prime mover.

10 21. The process according to claim 18 and claim 19 whereby said reactions produced autothermally are enhanced by catalysts.

22. A process comprising an expansion turbine whereby the turbine output is substantially free for useful shaft work with the substantial portion of the fluids expanding through said turbine, producing said work, which results from recompression in stages by at least two independently powered compressors which create pressure for delivering said output and further whereby practically all the energy provided for said recompression is conserved in an adiabatic tunnel including

A. the heat and mass and total energy of said flow, and

B. the heat and mass of the fuel fired

20 23. The process according to claim 22 whereby said expansion turbine is a combustion turbine and said heats and masses and total energy coming together are conserved in said tunnel and are driven into the head of said turbine in a pressure cascade;

24 The process according to claim 22 whereby said expansion turbine is a steam turbine;

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

25. The process according to claim 23 whereby the fuel for said combustion is fired with oxygen;

26. The process according to claim 23 whereby the fuel for said combustion is fired with air;

5 27. The process according to claim 23 when the mass of combustion products expanding through said turbine is equal in mass to the mass when air is used, the work output is equal but a lower turbine inlet temperature is obtained than when using the equivalent mass flow for said air;

28. The process according to claim 27 whereby the temperature with respect to
10 oxygen is increased to match temperature with respect to air for equal mass flows, then the output with respect to oxygen is significantly greater than for air;

29. The process according to claim 23 whereby the heat capacity for the mass flow through said turbine can be adjusted by controlled recycling and with respect to firing with oxygen control flexibility is considerably greater than said control flexibility than when firing
15 with air, and which for the same mass, results in lower turbine inlet temperature.

30. In a gas turbine process whereby the output of the turbine is substantially reduced by reducing the load of its combustion air compressor on the same shaft, whereby said load is substantially eliminated by a system of at least two independently powered and staged compression operations recompressing the greater portion of the exhaust from said
20 turbine whereby the heats and masses and total energy from said operations come together near totally conserved in a near adiabatic tunnel and are driven thereby in a pressure cascade into the head of said turbine.

31. A process of producing power comprising:

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED



providing a turbine adapted to generate shaft work, said turbine having a combustor;
and a rocket engine having a nozzle and a compressor means;

feeding fuel and oxidant to the rocket engine and the rocket engine compressor means;

feeding carbonaceous matter and water and/or steam to the rocket engine nozzle;

5 processing the output of the rocket engine nozzle into fuel for the turbine;

introducing said fuel and oxidant for the turbine to the turbine combustor;

passing the combustion products through a turbine;

recycling a substantial portion of the hot exhaust from the turbine to the rocket engine
compressor means; and

10 controlling the inlet temperature to the turbine.

32. The process according to claim 31 wherein said output from said rocket engine
nozzle and said recycled hot exhaust gas from said turbine are transformed in a near-adiabatic
tunnel into said fuel for said turbine.

33. The process according to claim 32 wherein said transformation in a near-
15 adiabatic tunnel into said fuel for said turbine comprises introducing carbonaceous matter and
water and/or steam into said output of said rocket engine nozzle downstream of said nozzle at
speeds sufficient to transform said carbonaceous matter into said fuel for said turbine.

34. The process according to claim 33 wherein said carbonaceous matter and said
fuel are selected from the group consisting of crude oil, petroleum fractions, coal, char,
20 biomass, natural gas liquids and methane.

35. The process according to claim 31 wherein said transformation occurs in one
transformation reactor or a group of transformation reactors.

36. The process according to claim 35 wherein water and/or steam is introduced
into said transformation reactor or group of transformation reactors, thereby reacting in said



reactor or reactors with said output of said rocket engine nozzle and recycled output of said compressor means to form hydrogen.

37. The process according to claim 36 wherein at least a portion of said hydrogen is diverted to one or more downstream uses selected from the group consisting of fuel cells,
5 iron oxide reduction reactors, other turbines, and chemical processes.

38. The process according to claim 31 wherein said transformation occurs in a group of transformation reactors and the pressure in said output of said rocket engine compressor means is controlled to conform with the pressure in each transformation reactor.

39. The process according to claim 31 wherein a portion of said hot exhaust from
10 said turbine combustor is compressed in an intermediate compressor for interstage heat additions between two or more stages of said turbine.

40. The process according to claim 31 wherein said output of said rocket engine nozzle exits from said nozzle at transonic speeds.

41. The process according to claim 31 wherein catalyst for said transformation is
15 introduced into said output of said rocket engine nozzle.

42. The process according to claim 31 wherein said shaft work is for electrical generation.

43. The process according to claim 31 having more than one turbine and more than one combustor and more than one electrical generation means.

20 44. The process according to claim 31 wherein supplemental or interstage oxidant is added to said turbine combustor(s).

45. The process according to claim 31 wherein oxidant is introduced in said expansion turbines at controlled temperatures.

This Sheet Has Been Replaced



* C L M S *

THIS SHEET HAS BEEN
REPLACED

46. The process according to claim 31 wherein one product of said transformation is hydrogen.

47. A process of producing power comprising:

providing a steam turbine adapted to generate shaft work; and a rocket engine having a
5 nozzle and a rocket engine compressor means;

feeding fuel and oxidant to the rocket engine;

feeding carbonaceous matter and water, and steam or a water-steam mixture to the
rocket engine nozzle;

processing the output of the rocket engine nozzle into a heat source for a boiler;

10 boiling water in said boiler to produce water vapor;

using the resultant water vapor to power said steam turbine.

48. The process according to claim 47 wherein said clean water is introduced in an
approximately equal weight ratio or more with hot exhaust from said steam turbine.

49. The process according to claim 48 further providing a heat source for a second
15 rocket engine power source transforming the output of said second power source into a fuel
product.

50. The process according to claim 47 wherein said fuel product comprises
hydrogen.

51. The process according to claim 50 further including providing
20 a heat exchanger;

a third rocket engine having a nozzle;

a turbine having a combustor;

feeding fuel and oxidant to said third rocket engine;



This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

directing the output of said third rocket engine nozzle into said heat exchanger so as to cool said output and to superheat steam from said boiler; and

transferring the resultant superheated steam to said steam turbine.

52. Apparatus for generating power from fuel comprising:

5 a gas turbine having a combustor;

a rocket engine having a nozzle and a compressor means;

means for feeding fuel and oxidant to the rocket engine and to the rocket engine compressor means;

10 means for feeding carbonaceous matter and water, steam, or a mixture of water and steam, to the rocket engine nozzle;

means for processing the output of the rocket engine nozzle into fuel for the turbine combustor;

means for introducing said fuel and oxidant for the turbine to the turbine combustor;

means for recycling hot exhaust from the turbine to the rocket engine compressor

15 means and controlling the inlet temperature to the turbine.

53. The process according to claim 1 whereby said cycle as a first stage power source provides for the production of hydrogen by a reaction of water vapor with any one of the following reacting carbonaceous materials in the conserved energy reacting system by order of preference:

- 20
1. methane
 2. natural gas
 3. coal carbon
 4. biomass
 5. char

This Sheet Has Been Replaced



6. any hydrocarbon

whereby said reacting system which is activated by up to a transonic flow of the combustion products and additional entrained combustion products, whereby the energies for both said combustion products are developed by firing oxygen and any fuel that is compatible with said reaction and whereby the energy of said additional products provide the compression energy for said transonic flow so that the hydrogen produced accordingly can now be divided into three tracks for three interrelated processes whereby

1. the hydrogen in track one empowers a fuel cell operation and the resulting water vapor exhaust in a pressure cascade from said first stage power source flows on to fire with oxygen as the combustion energy for developing power by expanding the combustion products of said energy;
2. the hydrogen in track two is directly applied in combustion for developing additional power which combines with that of track one by expanding its combustion products; and
3. the hydrogen of track three combines with the carbon dioxide (which is produced and separated from hydrogen before the hydrogen is divided into said three tracks) whereby both are now empowered by the commanding pressure of the first stage to develop a second stage pressurized jet, without combustion, which in turn activates a second stage conserved energy reactor in which said track three hydrogen reduces iron oxide, Fe_3O_4 , injected into said reactor just downstream of said jet so accordingly the following result in:

A. Sponge iron (Fe) is produced



This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED



B. Carbon dioxide and water vapor still under pressure supplies additional heat under said pressure to flow to and combine with other combustion products in expanding to develop said power

54. The process according to claim 53 whereby any one of said tracks can operate
5 alone and independently.

55. The process according to claim 53 whereby track one and track three are shut down and track two provides the power for off peak loads.

56. The process according to claim 53 whereby any one of the said three track uses of hydrogen can be independently processed.

10 57. The process according to claim 53 for the third track when the carbon dioxide from the first stage power source is low pressure or by-passed, whereby a portion of hydrogen from said stage is fired with oxygen in the rocket engine combustor of the second stage and the remaining hydrogen is metered into the nozzle section of said rocket engine combustor to admix metered in at least stoichiometric proportion with the iron oxide metered into said
15 nozzle section and/or additional nozzle sections down stream of in the reactor section to produce sponge iron.

58. The process according to claim 57 whereby the sponge iron is delivered into the rocket engine nozzle section and/or down stream nozzle sections in a third stage operation whereby the sponge iron reacts with methane, which is partially oxidized in the combustor of
20 said engine, so that the resulting jet with excess methane in suitable proportions reacts with said sponge iron to produce iron carbide and hydrogen.

59. The process according to claim 1 for the production of iron carbide in at least two
steps whereby methane is partially oxidized in a last stage rocket engine combustor

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

providing a jet with an excess methane fraction or methane is metered into down stream
nozzle sections in suitable proportions for reacting with sponge iron delivered into the
nozzle section of said engine and/or down stream nozzle sections producing said iron
carbide and hydrogen whereby said hydrogen is then recycled into a suitable previous rocket
5 engine reactor to reduce the iron oxide thereby producing a substantial amount of sponge iron.

60. The pyrolysis process according to claim 1 for cracking methane and largely
paraffin feed stocks to largely olefin and diolefin mixtures, methane to ethylene/acetylene and
ethane to ethylene for example, whereby a largely steam source is developed in a rocket
engine combustor to discharge a transonic jet to interact with feed stock metered into the
10 nozzle section of said engine and/or down stream nozzle sections with said jet accordingly
cracking to discharge ethylene and steam for suitable separation.

61.. The process according to claim 60 whereby stagnation temperatures up to 5000
F and higher and relatively unlimited stagnation pressures can be developed in said
combustor.

15 62.. The process according to claim 60 and claim 61 where the downstream reactor
comprises at least three optional cracking zones for flexibility locating precise shock zones
under various flow velocities and shock related pressure differences for a substantial range
offered by said relatively unlimited stagnation pressure in said rocket engine combustor.

20 63.. The process according to claim 62 whereby each of said cracking zones is
preceded by a nozzle section for additional reactants and supersonic flows.

64. The process according to claim 62 and claim 63 whereby additional shock
flows can be symmetrically oriented around the central flow at critically strategic positions as
sought by adjusting the synchronization of said shocks by selectively precise control of said
flows.

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

65. The process according to claim 64 whereby hydrogen is introduced in conjunction with said additional shock flows and said control.

66. The process according to claim 60 for producing ethylene whereby synthesis gas co-produced is the pyrolysis gas in a first stage supply in addition to producing some
5 synthesis gas for export and an additional amount is provided in recycling as a substantial source of fuel for said rocket engine and/or said prime mover so that by difference of the total synthesis gas flow, sufficient synthesis gas is provided for the production of ethylene according to the following procedure whereby synthesis gas at high pressure is delivered in prescribed quantity into the combustor of a second stage rocket engine and fired therein to
10 produce a suitable pyrolysis jet for cracking methane metered into the nozzle section of the rocket engine and/or one or more nozzle sections down stream of the nozzle to said last stage rocket engine ;

67. The process according to claim 66 whereby said cracking occurs at one or more shock waves

15 68. The process according to claim 67 whereby supplementary shocks occur and as a consequence of compatible matter as supersonic flows are directed into one or more nozzle sections down stream of said jet;

69. The process according to claim 68 whereby said supersonic flows are organized as one or more symmetrical pairs angling into and fairing into and along the main flow
20 produced by said engine jet as admixed with a prescribed amount of ethane directed into said engine nozzle section and/or one or more said nozzle sections down stream;

70. the process according to claim 67 and claim 68 whereby the shock waves produced by said engine jet and/or those produced by secondary supersonic flows are suitably

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

coordinated with respect to plausible cracking time ranges and the velocity of the main stream to take place in any one or more locations designated for the entry of said supersonic flows;

71. The process according to claim 70 whereby suitable arrangements are made to at least partially quench the product flow by use of the ports at the next nozzle section location from said cracking location thereby delivering said ethylene and some steam for further quenching and separation beyond this process;

72. The process according to claim 70 whereby carbonaceous matter is also produced in the first stage for producing the synthesis gas required for pyrolytic cracking in the production of ethylene and other petrochemicals.

73. A process for a cracking reaction or other chemical reaction, whereby a largely steam source is developed in a rocket engine combustor to discharge through a transonic nozzle to interact with feed stock metered into the nozzle section of said engine and/or into one or more down stream nozzle sections whereby said cracking or other chemical reaction is programmed at least at one reactor station between said nozzle sections over a range of flow velocities and steam-to-feed ratios thereby respectively resulting in the products of said cracking or other chemical reaction;

74. The process according to claim 73 whereby said feedstock is optionally directed into the high pressure side or low pressure side of said transonic nozzle and/or into the high pressure side or the low pressure side of said downstream nozzle sections;

75. The process according to Claims 73 and 74 whereby said reactor stations comprise optional shock zones for flexibility in locating more precise cracking over said range of flow velocities for various flows and relative pressure differences for a substantial range offered by said relatively unlimited stagnation pressure in said rocket engine combustor;

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

76. The process according to Claims 74 and 75 whereby said feedstocks entering into said nozzle sections are accelerated to transonic velocities by the parent jet from said rocket engine which is programmable up to Mach 5 and higher;

77. The process according to Claim 76 whereby hydrogen is introduced in
5 conjunction with said steam and/or into said down stream nozzle sections;

78. The process according to Claim 77 whereby suitable arrangements are made to at least partially quench the product flow by use of the ports at the next nozzle section location for respectively setting said cracking reaction or other chemical reaction thereby delivering said reaction products and some steam for further quenching and separation beyond this
10 process;

79. The process according to Claim 73 whereby steam is generated in situ by water being metered into said combustor and/or into an additional section just down stream of said nozzle and before said reactor station whereby said steam is generated by direct heat transfer from the hot jet emanating from said nozzle at a selected temperature up to 5000 F;

15 80. The process according to Claim 79 whereby said water is recycled condensate from said steam;

81. The process according to Claim 79 whereby a substantial part of the energy for recycling said condensate is derived by expanding the flow after the setting of said cracking reaction or other chemical reaction respectively in a turbine after said flow comprises cracking
20 products;

82. The process according to Claim 79 whereby said products are first sprayed with water to set said cracking reactions and said other chemical reactions in order to amplify and expand said flow;

This Sheet Has Been Replaced



* C L N S *

THIS SHEET HAS BEEN
REPLACED

83. The process according to Claim 79 whereby the relatively high velocity through the reaction zone is selected to suit steam - to - feed ratios with the temperatures of said steam up to 5000 F;

84. A process for developing a source of compressed hot gases expanded in a turbine for export power whereby a substantial portion of the exhaust from said turbine is independently compressed and delivered into a quasi adiabatic continuum for ultimate delivery of said gas along with gases also independently compressed to make up the difference with respect to said exhaust and likewise delivered into said continuum which together at the end of said continuum, comprise a hot flow at a prescribed temperature and pressure for said export power.

85. The process according to Claim 84 whereby at least a portion of said compressed gas is first delivered to the combustor of a rocket engine at the head of said continuum at a pressure substantially higher than said prescribed pressure so that the difference between said pressure is substantially converted to heat from friction losses and the intermingling of said gases between said combustor and the entry to said turbine;

86. The process according to Claim 85 whereby said pressure for said combustor is sufficiently high to additionally produce at least one shock wave in said continuum;

87. The process according to Claims 86 whereby said independent compression is provided by any prime mover and further whereby the exhaust of said prime mover is also recompressed by said prime mover and delivered into said continuum as a constituent of said gases;

88. The process according to Claim 87 whereby the fuel and its oxidant fired in said combustor make up the difference for continuity in completing the mass flow for said prescribed temperature and pressure and said export power;

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

89. The process according to Claim 88 whereby the fuel is hydrogen produced in a separate transformation process which at least utilizes some of the remaining part of said exhaust which was not delivered into said continuum;

90. The process according to Claim 89 whereby water is provided into any part of said continuum, including said combustor, which becomes steam in situ as part of said mass flow for said continuity;

91. The process according to Claim 90 whereby water is metered in down stream in said continuum becomes steam to augment the flow and increase the thrust of flow into said turbine;

92. The process according to Claim 88 whereby the fuel is methane or any clean hydrocarbon which is transformable in situ into synthesis gas by utilizing at least some of the remaining part of said exhaust which is not delivered into said continuum;

93. The process according to Claim 88 whereby the flow down stream of said combustor includes unreacted oxygen which supports as after-burning thrust by fuel metered into a junction in said continuum chosen to maximize the thrust of the increased mass flow thereby into said turbine.

94. A process for eliminating the compressor load in the Brayton Cycle by an independent compression system whereby quasi all the energy for producing said system is conserved in a flow of hot gases at a prescribed temperature and pressure for expanding in a turbine which exports all its power from said process.

95. The process according to Claim 94 whereby a substantial portion of the exhaust from said turbine is recompressed by said system to become part of said flow;



This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

96. The process according to Claim 95 whereby the exhaust from the prime mover for recompressing said portion is also recompressed by said prime mover to become part of said flow.

97. A rocket engine firing in a continuum to power one or more expansion
5 turbines whereby a substantial portion of the exhaust is separated into a minimal stream and a maximal stream to be separately recompressed by preferably a single independent prime mover whereby said minimal stream is selected in size and compressed for delivery at top pressure into the combustor of said rocket engine and said maximal stream in cooperation with
10 said size is compressed to a substantially lower pressure than said minimal stream into one or more secondary ports downstream of the jet developed by said rocket engine so that said jet provides enough momentum for propelling said maximal stream in mixing with the constituents of said jet to the design pressure for delivering said power for said expansion turbines.

98. The process according to Claim 97 whereby additional independently powered
15 jet propulsions are introduced further down stream in said continuum to boost momentum from said engine;

99. The process according to Claims 97 and 98 whereby the exhaust from said prime mover is also recompressed by same said prime mover for delivery into said continuum and/or for delivery as a direct and/or indirect heat transfer media to the interstages of said
20 expansion turbines;

100. The process according to Claim 99 whereby the application of said direct heat transfer provides a means after said heat transfer for discharging from the cycle the products of combustion from said rocket engine and said prime mover along with a substantial portion

This Sheet Has Been Replaced



* C L N S *

THIS SHEET HAS BEEN
REPLACED



of the products of combustion from said rocket engine and said propulsion down stream in said continuum;

101. The process according to Claim 99 whereby said rocket engine and said continuum conform in stream line to replace gas turbine combustors in retrofit gas turbines;

5 102. The process according to Claims 100 and 101 for independently increasing the efficiency of said cycle whereby the fuel fired in said engine as a minimal part is selected in cooperation with the maximal part of the same fuel whereby said maximal part is delivered into one or more secondary ports of said engine to admix and react with the water vapor contained in said exhaust in said continuum thereby transforming into a fuel gas which fires
10 by auto ignition and/or is ignited towards the said continuum for entry into said turbines.

103. A cycle comprising an expansion turbine means and an independent prime mover for recompressing a substantial portion of said exhaust from said turbine means whereby said portion is admixed from the exhaust from said prime mover which is also recompressed by the same said prime mover and conforming thereafter in a near adiabatic
15 continuum at the design pressure for powering said turbine means and further whereby the deficiency in mass flow for said cycle is made up by additionally firing a fuel of consistent chemistry with oxidant at said pressure in said continuum to also admix with the compressed products from said prime mover in said continuum and into said turbine means.

104. The process according to Claim 103 whereby the mixing in said continuum is
20 enhanced by firing said make-up fuel to produce up to transonic flows.

105. A rocket engine powered steam-complemented jet flow is directed to selectively activate equilibrium and non-equilibrium chemical reactions whereby said flow derives from a fuel gas whereby its hydrogen component largely converts to steam, when fired with a any oxidant in the combustor of said engine, and then said flow proceeds down stream through

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

two or more interconnected adiabatically shielded ducts in series to bombard and transfer heat thereby to reactive carbonaceous feed stock selectively injected into one or more locations in said ducts which are selectively interspersed with nozzles for provisionally accelerating subsonic flows and decelerating cascading subsonically shock-interrupted supersonic flows and
5 further whereby said ducts are contoured to conform to and interconnected with said nozzles in further conformation for the principal functions of said flow which is to activate said equilibrium and non-equilibrium chemical reactions;

106. A process according to claim 105 whereby steam is generated by injecting water into said combustor which is heated by mixing with the firing of said hydrogen;

10 107. A process according to claims 105 and 106 whereby additional steam is generated in-situ by directing water into the low press zone of said flow just down stream of said jet;

108. A process according to claims 105 and 106 whereby the pre-mixing of said flow with said feed stock can take place in said ducts before the activation of chemical
15 reactions;

109. A process according to claim 108 whereby said pre-mixing takes place in a transition zone from supersonic flow to shock;

110. A process according to claims 105 and 106 whereby the mixing of said flow and feed stock can take place as a quasi-simultaneous function with chemical reactivity
20 through one or two ducts;

111. A process according to claim 110 whereby said simultaneous function occurs in said ducts for the reacting mixed flow in decelerating from supersonic flow through a shock wave;

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

112. A process according to claims 110 and 111 whereby said chemical reactions are set by suitable means which cause the temperature of resulting flow to drop significantly;

113. A process whereby high subsonic or supersonic steam or steam-complemented jet flow is directed to selectively activate equilibrium and non-equilibrium chemical reactions
5 down stream of said jet through two or more interconnected, adiabatically shielded ducts in series wherein said flow proceeds to pyrolyze and transfer heat to reactive carbonaceous feed stock selectively injected into one or more locations into said ducts which are interspersed with nozzles for provisionally accelerating subsonic flows and decelerating subsonically-shock-interrupted supersonic flows and further whereby said ducts and said nozzles are
10 contoured to conform with respect to said reactions and in addition to comply with the following functions:

A. To set said reactions by causing the reaction temperatures to drop by at least accelerating the product flow in the last duct;

B. To separate the product gases by condensing the remaining steam;

15 C. To return said remaining steam condensate to largely become the source of steam in said jet thereby substantially closing the cycle of said process;

114. A process according to claim 113 whereby said steam is generated in the combustor of a rocket engine wherein water is injected becoming steam in mixing with the products of combustion of said engine;

20 115. A process according to claim 114 whereby the fuel gas of said products of combustion is provided by a top or first stage rocket engine power source which is provisionally hydrogen, or hydrogen or carbon dioxide, or hydrogen carbon dioxide and nitrogen depending on firing with oxygen or air or on the chemical requirement for pyrolyzing with steam alone;

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

116. A process according to claim 113 whereby said steam is generated in a boiler which is the top or first stage source of pressure for said jet flow;

117. A process according to claim 116 whereby the fuel gas for said boiler is provided with an independent rocket engine power source;

5 118. A process according to claim 117 whereby said fuel gas is provided in excess, whereby said excess is delivered to the combustor of the second or last stage rocket engine which also receives the steam from said boiler and which can provisionally have its temperature increased by firing said excess fuel with oxygen or air;

119. A process according to claims 118, 116, and 114 whereby additional steam is 10 provisionally generated in the duct just down stream of said jet by injecting water therein which mixes with the products of combustion resulting downstream from firing a portion of said carbonaceous matter;

120. A process according to claim 113 whereby said supersonic flows derived from coordinating rocket engine combustor and nozzle relationship with respect to stagnation 15 temperature and pressure to deliver said flow through said nozzle up to Mach 5 and higher;

121. A process according to claim 120 whereby said up-to-Mach 5 flow transcends to subsonic flow from shock with enough kinetic and pressure energy to deliver a flow of with a lower supersonic Mach number through a coordinated sequent nozzle;

122. A process according to claim 113 whereby said feed stock is introduced into a 20 provisionally selected shock zone, in any down stream duct wherein said flow is culminating from one or more supersonic decelerations;

123. A process according to claim 122 whereby said flow after said mixing reacts chemically at the consequent sonic or supersonic velocities and then are at least accelerated in order to continue to reduce the temperature of said flow in-situ;

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

124. A process according to claim 123 whereby said accelerated flow is then expanded through a turbine for a further drop in temperature before condensing the remaining steam in said flows;

125. A process according to claim 124 whereby at least a part of the cooling water
5 for condensing said steam is introduced as spray or mist at the head of said accelerated flow.

126. A rocket engine powered process for producing olefins and diolefins, mainly ethylene and acetylene, whereby steam, applied for the pyrolysis or thermal cracking of a wide range of hydrocarbons including ethane, liquefied petroleum gases, petroleum fractions, petroleum coke and coal, is sequentially recycled as condensate after separation from said
10 olefins by being pumped into the combustor of said engine whereby said condensate becomes steam by direct heat exchange with the products of combustion in said engine in preparation for and providing said products are compatible with said pyrolysis;

127. A process according to claim 126 which provides for independently heated or cooled pyrolysis zones.

128. A process according to claims 126 and 127 whereby said products of
15 combustion derive from firing oxygen and hydrogen.

129. A process according to claims 126 and 127 whereby said products of combustion derive from firing air and hydrogen.

130. A process according to claims 126, 127, 128 and 129 whereby additional steam
20 is provided by firing a fuel-rich mixture in said combustor, so that an extended firing can take place in the steam-rich flow in a first duct section of said cycle just down stream from the jet of said engine to intermix with a complimentary portion of said condensate in direct heat exchange in order to provide said additional steam.



This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

131. A process according to claim 126 whereby complete generation of steam in said combustor takes place in the first duct section of said cycle so that the second duct section in continuous flow is the place where active intermixing between the feedstock of said hydrocarbons and said steam is provided by suitable means.

5 132. A process according to claim 130 whereby the second duct section in continuous flow is the place where active intermixing between the feedstock of said hydrocarbons and said steam is provided by suitable means.

133. A process according to claim 131 and 132 whereby said cracking can take place in said second duct section during the completion of said intermixing.

10 134. A process according to claim 133 whereby said intermixing is enhanced by selective transonic flow by providing "bottle shocks" and/or a focused normal shock in said second duct sections.

135. A process as in claims 131 and 132 which is provided with a third duct section of substantially constant cross section wherein said thermal cracking is provided in-situ by
15 suitable means.

136. A process as in claim 135 wherein said thermal cracking is enhanced by transonic flow by providing bottle shocks and/or a focused normal shock in said third duct section.

137. A process as in claim 136 whereby the third duct section is followed in close
20 proximity by a fourth duct section delivering the product flow also in close proximity to an expansion turbine.

138. A process as in claims 126 and 130 provided with all the duct sections through duct section 4 with optionally a fifth duct section, and on to the expansion turbine whereby all

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

the flows throughout take place at selective very high subsonic velocities just close to speed of sound with thermal cracking selectively to take place in the third or fourth duct section.

139. A process according to claims 134 and 136 provided with said "bottle shocks" whereby the boundary layer developed by said shocks is dispersed selectively by suitable application of steam injection through perforations, slits in the wall of said duct, or through duct walls of porous media.

140. A process according to claims 134 and 137 provided with said "bottle shocks" whereby the boundary layer developed by said shocks is dispersed selectively by suitable application of combustible gases and steam through perforations, slits in the wall of said duct, or through duct walls of porous media to cause continuous supplementation of heat and mass along the duct.

141. A rocket engine powered quasi-adiabatic process for producing olefins and diolefins, mainly ethylene and acetylene, whereby steam or a substantially steam complemented pyrolysis medium, applied for the thermal cracking of a wide range of hydrocarbons including ethane, liquefied petroleum gases, petroleum fractions, petroleum coke and coal, is generated by injecting water into the combustion of said engine.

142. A process as in claim 141 whereby the fuel for said engine is hydrogen fired with oxygen whereby said hydrogen is provided by a first stage rocket engine power source and a separate conserved energy reactor which converts carbonaceous matter and steam via the water-gas/shift reaction.

143. A process as in claim 141 whereby the fuel for said engine is hydrogen fired with air whereby said hydrogen is provided by a first stage rocket engine power and a separate conserved energy reactor which converts carbonaceous matter and steam via the water-gas/shift reaction.

This Sheet Has Been Replaced





144. A process as in claims 141 and 142 whereby the flow down stream of the jet from said engine is in a continuum including four or five duct sections, the last of which said duct sections is located in close proximity and connected to an expansion turbine and whereby other duct sections in said continuum starting from said jet are used selectively first
5 for generating more steam in-situ and next for mixing said streams with feed stocks before pyrolysis which is completed in the next duct section just before said flow accelerates into said turbine.

145. A process as in claim 144 whereby all the flows throughout take place at selective very high subsonic velocities just close to the speed of sound, that is up to Mach
10 0.9+, with thermal cracking taking place in the third and/or fourth duct sections.

146. A process according to claim 144 whereby all the flows are transonic, with some pyrolysis taking place at supersonic speeds after downstream steam generation preferably taking place at high subsonic velocities.

15 147. A process according to claim 146 which employs "bottle shocks" in zones of relatively constant cross section where boundary layers prevail is provided with a suitable application of steam injection, for dispersing said boundary layers, through perforations, slits in the wall of said duct or through walls of porous media.

148. A process according to claims 117 and 118 whereby the flow down
20 stream of the jet from said engine is in a non-adiabatic continuum including four or five duct sections, the last of which said duct sections is located in close proximity and connected to an expansion turbine and whereby other duct sections in said continuum starting from said jet are used selectively first for generating more steam in-situ and next for mixing said streams with feed stocks before pyrolysis which takes place in the next duct section just before said flow



accelerates into said turbine which provides for independently heated or cooled pyrolysis zones.

149. A process according to claim 148 whereby the flow down stream of the jet is cooled by indirect heat exchange with a lower temperature medium.

5 150. A process according to claim 148 whereby the flow down stream of the jet is heated by fuel gas and oxidant introduced

This Sheet Has Been Replaced



* C L M S *