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(54) Title: A HYBRID ENERGY CONVERSION SYSTEM AND PROCESSES

(57) Abstract: Disclosed are flexible hybrid conversion systems that can be used with a wide spectrum of resources and feedstock. The disclosed systems can be sufficiently versatile to provide many added value products including clean energy, synthetic fuels and chemical products. Processes and system disclosed herein can produce, for example, shaft power and/or electricity from the expansion of species change of hot, hydrogen-laden syngas produced by gasification or steam reforming of inferior feedstock such as coal, bitumen, tar from sands and wastes, including biomass, municipal solid waste (MSW) sewage sludge and certain industrial wastes. This disclosure also teaches innovative system thermal integration methods of endothermic and exothermic processes and reaction enhancement approaches for the economic, clean and flexible production of synthetic gaseous and liquid fuels as well as chemicals.

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A HYBRID ENERGY CONVERSION SYSTEM AND PROCESSES

Related Applications

[0001] This application claims priority to U.S. Provisional Application Serial No. 60/759,340, which was filed on January 17, 2006.

Background

[0002] The world reliance on petroleum and natural gas has reached an era where the supply and demand as well as world political repercussions and world peace have become critical.

[0003] These circumstances make the need for innovative energy and environmental technology essential for sustainable economic development and global energy security.

[0004] It is now essential that energy conversion systems and processes be introduced and commercialized that can employ alternative sources of energy in an environmentally benign manner at economic costs.

[0005] New technology is needed in order to exploit alternative sources of energy and feedstock for sustainable economic development while maintaining a clean environment. The needed technologies must be sufficiently flexible, environmentally clean and cost effective to enable the use of the conventional inferior resources (such as coal) that are abundant as well as the use of biomass, wastes and other renewable resources for the production of clean and cost effective energy.

Summary

[0006] The present disclosure can, in one embodiment, provide efficient, feedstock flexible, environmentally clean and cost-effective alternative energy and/or chemicals production from sources other than petroleum and natural gas. Disclosed subject matter can therefore be of importance to sustainable economic development, global energy security and world peace.

[0007] Applications of the disclosed subject matter can span the use of conventional inferior fossil fuels such as, without limitation, coal, tars from tar sands and hydrocarbon liquids from oil shale. The disclosure also enables utilization of other feedstock such as wastes and renewable resources including biomass. The use of wastes to produce clean energy is an option in one preferred embodiment as this can lead to both cleaning the environment through consumption of the wastes as well as production of clean energy.

[0008] In one embodiment, the disclosure provides unprecedented level of investment security, particularly for the production of alternative liquid hydrocarbon fuels from capital intensive facilities as summarized below.

[0009] The subject of producing hydrocarbon fuels and chemicals from syngas (containing hydrogen and carbon monoxide) has been thoroughly investigated, for instance by the United States Department of Energy (DOE) in a report by the DOE National Renewable Energy Laboratory (NREL /TP-510-34929) dated December, 2003. In the executive summary of the report, it was stated that:

> "In principle, syngas (primarily consisting of CO and H2) can be produced from any hydrocarbon feedstock, including: natural gas, naphtha, residual oil, petroleum coke, coal, and biomass."

[0010] Furthermore, the report emphasized that:

> "The syngas composition, most importantly the H_2/CO ratio, varies as a function of production technology and feedstock. Steam methane reforming yield H_2/CO ratios of 3/1 while coal gasification yields ratios closer to unity or lower. Conversely, the required properties of the syngas are a function of the synthesis process. Fewer moles of product almost always occur when H_2 and CO are converted to fuels and chemicals. Consequently, syngas conversion processes are more thermodynamically favorable at higher H_2 and CO partial pressures."

[0011] Another crucial observation in the NREL report is:

> "The greatest impact on improving gas-to-liquids plant economics is to decrease capital costs associated with syngas production and improve thermal efficiency through better heat integration and utilization. Improved thermal efficiency can be obtained by combining the gas-to-liquids plant with a power generation plant to take advantage of the availability of low-pressure steam."

[0012] The low pressure steam being referred to in the above is the steam derived from the exothermic heat of the processes that converts the CO and hydrogen laden syngas to liquid fuels and chemicals.

[0013] The present disclosure provides in one embodiment for unprecedented flexibility in the feedstock (other than petroleum and natural gas) on the front end. The disclosed methods can also employ both endothermic Thermochemical conversion processes and exothermic processes and can provide unique opportunities for thermal integration, which is recognized by the NREL report as having the greatest impact on the plant economics.

Detailed Description

[0014] Reference will now be made in detail to various embodiments of the invention, one or more examples of which are set forth below. Each embodiment is provided by way of explanation of the invention, not limitation of the invention. In fact, it will be apparent to those skilled in the art that various modifications and variations may be made in the present invention without departing from the scope or spirit of the invention. For instance, features illustrated or described as part of one embodiment, may be used in another embodiment to yield a still further embodiment.

[0015] In one embodiment, disclosed herein is a hybrid conversion system that can be flexible for the use of a wide spectrum of resources and feedstock and can be sufficiently versatile to provide many added value products including clean energy and chemical products.

[0016] In one embodiment, processes disclosed herein can produce, for example, shaft power and/or electricity from the expansion of hot, hydrogen-laden synthetic fuel gas (syngas) produced by gasification or steam reforming of inferior feedstock such as coal, bitumen, tar from sands and wastes, including biomass, municipal solid waste (MSW) sewage sludge and certain industrial wastes. This cycle can include species change to higher volume gases and vapors such as hydrogen and CO.

[0017] In traditional conversion systems such as the steam-based power (shaft power or electric power) systems, water is pressurized before the steam generation to minimize the parasitic energy consumption for attaining the required steam pressure. The pressurized water is introduced to a steam boiler operating at an appropriate pressure and converted into high-pressure steam by adding heat. In most instances, the saturated steam is further superheated to render the process more efficient before it is expanded in a steam engine (turbine or piston engine) to generate shaft power. Electricity is often the final product by using a generator driven by the shaft power particularly in large steam power plants.

[0018] In presently disclosed cycles, advantage can be taken of the fact that there is an opportunity for a phase change in the working fluid; for instance water or a hydrocarbon fluid (in the case of low temperature cycles) can become a vapor when heat is added. The phase change from liquid to superheated vapor can provide the opportunity to impart both volume and temperature to the pressurized working fluid to enable efficient generation of shaft power or electricity.

[0019] Cycles that use other working fluids that could be evaporated at lower temperatures, for example certain liquid hydrocarbons, are typically useful for generation of power from, for instance, moderate temperature geothermal resources. These cycles can employ similar principles as used in a conventional steam cycle with pressurization of the working fluid taking place while the fluid is in its liquid phase to reduce the parasitic energy needed for pressurization of the working medium.

[0020] In other popular energy conversion cycles, air is pressurized and heat is added to the pressurized air (the working medium). The hot, pressurized air is subsequently expanded to produce shaft power. There is no phase change in this case. This type of "air" or gaseous working medium cycle is found in the familiar gas turbine and piston engines, for example. In some instances steam or water is injected in the air at times after pressurization or before pressurization to achieve certain performance characteristics.

[0021] In larger gas turbine plants, a "bottoming" steam cycle is added to the system to improve the overall energy conversion efficiency. In this case the gas turbine is said to affect a topping cycle to the steam bottoming cycle.

[0022] Even with larger piston engines, a bottoming cycle may be economically viable using a lower temperature hydrocarbon vapor as a working medium to convert the heat in the exhaust into electricity The latter is generally only feasible however in cases where the local economics admit such a configuration.

[0023] The present disclosure also introduces, among other things, another topping cycle that makes use of a "species change" resulting in a larger volume working fluid. One example of such species change is found in the generation, at high pressure, of a hydrogen laden synthetic fuel gas, where the synthetic fuel itself can be employed as a working medium. In this case the change in volume at pressure and high temperature can be employed for further improvement of the overall energy conversion efficiency of a system.

[0024] For example, a species change cycle could be a topping cycle conversion device upstream of a gas turbine (or a gas reciprocating engine) that can consume the synthetic fuel. In one embodiment, the gas turbine (or the gas engine) can still have a bottoming steam cycle.

[0025] In one embodiment, a species change cycle could also be a topping cycle to a fuel cell stack (such as a molten carbonate fuel cell stack or a solid oxide fuel cell stack), with opportunities to use the heat rejected from the fuel cell stack for further improvements in the overall energy conversion process.

[0026] In another application, a species change cycle could be used as a topping cycle for certain high efficiency piston engine that consumes the synthetic gas as a bottoming cycle to further improve the overall energy conversion process. Furthermore, a hydrocarbon vapor cycle could also be used to convert the sensible heat in the engine exhaust to power.

[0027] There are a large number of embodiments of disclosed hybrid energy conversion systems and processes that are made possible by the disclosed systems.

[0028] One such an embodiment for power generation includes a fluid-bed gasifier or an indirectly heated Thermochemical conversion process that can be operated at an appropriate pressure and a moderate temperature. This can be combined with one or more of an appropriate entrained flow, higher temperature and pressure gasification system for conversion of char generated from the fluid bed device to synthetic fuel gas, in situ and/or external hot gas cleanup subsystem, a synthetic fuel gas expander, a fuel cell and/or a gas turbine, and a steam bottoming cycle. This system can, for example, augment the overall efficiency of a conventional gasification combined cycle power system and can expand the spectrum of feedstock that can be employed for the generation of clean electricity or shaft power.

[0029] In another embodiment, power can be generated from a bottoming cycle and used for indirectly heating a Thermochemical conversion process as opposed to, for example using only synthetic gas to do so in fired heaters. This can be particularly useful in a situation such as when a facility's primary products are liquid fuels produced from the synthesis gas. The pressurized hydrogen laden synthetic gas generated by the entrained gasification stage can also be employed as the working medium of the species change cycle to produce more electric power for indirectly heating the Thermochemical conversion reactor. This can further reduce or eliminate the consumption of syngas in fired indirect heater and make more of the syngas available for production of liquid fuels.

[0030] In another embodiment, tail gas from a synthesis reactor(s) used for liquid fuel production can be reheated and expanded through a turbo expander and produce shaft power and/or electricity following which this tail gas can then be utilized in a fired heater, for example in a pulsed heater, to provide indirect heat for Thermochemical conversion of the feedstock.

[0031] In another embodiment, ceramic membranes or nanofilters may be employed in one or both of a Thermochemical conversion system and a higher pressure, higher temperature char gasification system to continuously separate H2 and CO from product gases so as to enhance feedstock conversion rates and generate high value syngas for subsequent use in an expander, synthesis reactor, fuel cell, gas turbine, or the like.

[0032] In another embodiment, feedstock may be dried in a dryer and then processed in an indirectly heated, moderate temperature Thermochemical reactor. Steam and air or enriched air (optional) may be used as the fluidization medium. Membrane or nano filters can be used to continuously separate H2 and CO (optional) from the product gas. The separated H2 and CO streams can be routed through a heat recovery steam generator to cool the gases and then sent to a syngas compressor. One or more internal cyclones can capture and continuously re-circulate the relatively large char particles while the H2 and CO depleted product gas stream comprising CO2, hydrocarbon vapors, steam, and fine char particles can continuously leave the reactor. This stream can enter a pulse gasifier, which can operate auto-thermally with air or enriched air or oxygen and steam addition to effect partial oxidation and autothermal gasification reactions. The gasifier may be operated in a slagging or non-slagging/dry ash rejection mode, generally depending on the degree of the refractory or unreactive nature of the char. One or more sorbents may be added to a gasifier to promote sonic enhanced ash agglomeration and sulfur, chlorine and alkali capture as necessary. Cyclones and ceramic barrier filter (optional) can be employed to capture ash and/or spent sorbents. Hot, clean product gas can be sent to a heat exchanger (may comprise tapered tubes) for transferring heat to the Thermochemical reactor. Gases exiting from the heat exchanger may be routed through a steam superheater and a heat recovery steam generator to recover the sensible heat from the product gas. A CO2 scrubber may be employed to capture CO2 and increase the partial pressure of H2 and CO in the fuel gas stream. This stream can then be joined with the H2 and CO coming from the membrane or nano filters and compressed in a syngas compressor. The compressed syngas can be passed through a synthesis reactor and/or fuel cell and/or gas turbine to generate liquid fuel and/or electricity. A bottoming steam cycle may be employed to generate supplemental electricity and/or process steam.

[0033] The presently disclosed methods and systems can in one embodiment provide electric power, liquid fuels and/or shaft power for the electric utility, industry and transportation markets. The disclosed systems and processes can provide such in a cost effective and environmentally benign manner from a very wide spectrum of fuels including inferior fossil fuels/or and waste feedstock and can do so in a clean, environmentally responsible and cost effective manner.

[0034] Power generation and production of liquid fuels as well as the production of chemical feedstock for a variety of products is one primary objective of the disclosure. Enabling the use of the conventional and abundant inferior fuels (Coal, MSW, Peat, tar sand and oil shale, etc.) as well as biomass and wastes is believed to be essential for coping with the problems facing the world with premium fossil fuels (petroleum and Natural gas) availability and prices.

[0035] Expanding the feedstock spectrum available, an initial part of the disclosed systems, can provide a "front-end" of a hybrid energy conversion system and process that can accept an unprecedented spectrum of such energy bearing feedstock.

[0036] A moderate temperature fluid-bed reactor can be provided, according to one embodiment of the disclosed subject matter, for "pre-processing" and conditioning the feedstock material for further processing. One preferred embodiment for this fluid-bed reactor is an indirectly heated moderate temperature Thermochemical process. In this process, feedstock such as Refuse Derived Fuel (RDF) from Municipal Solid Wastes (MSW), Coal, Peat, Agricultural Residue (AR) and energy crops can be processed to produce carbon (char) and synthetic fuel gases and condensable hydrocarbon vapors. The condensable hydrocarbon vapors can be condensed, separated and used to form slurry with the char produced. In certain embodiments, further processing of the synthetic fuel gases and hydrocarbon vapors can be carried out using sorbents and catalysts to steam crack the hydrocarbon vapors to some extent. For example, membrane or nano filters may also be employed to separate the condensable hydrocarbons or tars from the water collected in a cold gas cleanup train.

[0037] Some or all of the synthetic fuel gases emanating from a cold gas cleanup train may be employed for firing heaters that can deliver heat to the indirectly heated Thermochemical fluid-bed reactor. Electric heaters, as may be used in some embodiments, can provide some or all of the heat needed by the fluid-bed reactor depending on the application (power generation or liquid fuels production) and the mix of products being produced. In the case of using electric heaters to reduce the consumption of such synthetic fuel by the fired heaters, the synthetic fuel saved could be used to improve liquid fuels and chemical feedstock production yield from the facility. In one embodiment, tail gas from a liquid fuel synthesis reactor or fuel cell may be employed to provide the indirect heat. This arrangement can maximize the partial pressure of the reactants (H2 and CO) for liquid fuel or electricity production but can also serve the need for maximizing the conversion efficiency in the synthesis reactor or fuel cell. The latter in turn can eliminate the need for gas recycle, multiple stages and also can reduce the equipment size as well as the capital and operating costs.

[0038] In a previous patent (United States Patent 5,059,404; Mansour, et al. October 22, 1991, which is incorporated herein), the indirectly heated Thermochemical process used to convert all of the carbon and, to the extent feasible, the entire hydrocarbon vapors to the desired synthetic fuel gas is a steam reforming process. Further laboratory and commercial scale experience with this process has revealed that the system throughput is a very strong function of the endothermic heat of reaction of the feedstock being processed. Furthermore, the process cold gas efficiency is a strong function of the ratio of the steam reforming endothermic heat of reaction to the heating value of the feedstock. The higher this ratio is, the lower the feasible cold gas efficiency. The primary reasons for this include:

[0039] 1 – Converting all the carbon generally requires higher reactor operating temperature and a higher heat load for supplying the endothermic heat of reaction per unit weight of feedstock. For example, the heat of pyrolysis is on the order of 250 to 350 BTU/LB of feedstock while the heat of reaction for steam reforming the carbon is on the order of 4,700 to 6,000 BTU/LB of Carbon.

[0040] 2 – Only a fraction of the heater-firing rate is transferred in the form of heat to the fluid bed. The higher the bed temperature, the smaller the fraction of the firing rate that is transferred to the fluid bed.

[0041] 3 – The cold gas efficiency is a strong function of the fraction of the firing rate that is transferred to the bed. The higher the fraction the higher the cold gas efficiency.

[0042] 4 – Combustion air preheat as well as flue gas recirculation can be employed to a certain extent to improve the cold gas efficiency but it does have practical limitations including reduction in pulsation in pulse heaters and maximum firing rate in the event a pulse combustor/ fired heater is employed.

[0043] 5 – The throughput of the process is lower for higher carbon conversion performance.

[0044] The moderate temperature fluid bed reactor can be a fluid bed reactor in which the exothermic heat is achieved via partial oxidation or Auto-Thermal means. In one embodiment a PAFB as described in US Patent Number 5,255,634; Mansour, October 26, 1993 (incorporated herein by reference) can be used and operated at high throughput in the sub-stoichiometric air or oxygen mode to affect this pre-processing step at a moderate temperature.

[0045] In one embodiment of the present disclosure, an indirectly heated Thermochemical reactor is the preferred embodiment to reduce dilution of the products with effluents from exothermic partial oxidation and autothermal processes, but it is not essential. The use of a pulsating combustor for the fired heaters is also not essential. In one embodiment, the present disclosure introduces the use of tapered cross-section heat exchanger tubes as another option to affect uniform heat flux in the heat exchanger tubes. The latter has, however, a small pressure drop penalty that can be overcome by the use of combustion air fans. Nevertheless, the use of tapered cross-section heat exchanger tubes can make it more feasible to reduce the number of fired combustion chambers and the associated burner management subsystems.

[0046] In the course of the development of a process of making ethanol from a variety of biomass feedstock, it appeared beneficial to seek approaches for both increasing the CO/hydrogen ratio in the product gas, as well as reducing the capital cost. As a result, an embodiment was developed in which not all of the carbon need be converted in the indirectly heated steam reformer, and a carbon converter can be used to convert carbon in the char remaining from the process.

[0047] This embodiment triggered in part a direction of thought that lead to the development of a feedstock flexible, hybrid conversion process. This in turn led to an opportunity to expand the syngas from a pressurized carbon converter in an expansion turbine making use of the effect of the species change on the volume of the synthetic gas.

[0048] An embodiment using a moderate temperature pre-processing step, together with a tapered cross-section heat exchanger tubes, a pressurized carbon converter, and syngas expansion, led to lower overall capital and operating cost (particularly maintenance costs), higher efficiency and a very broad spectrum of feedstock being made feasible thus expanding the resources that can be employed in various embodiments of the disclosed systems.

[0049] In fluid-bed reactors, solids circulation as well as bed fluidization flow patterns can both be important variables. Typically, the particles that are elutriated from the dense fluid bed can be captured in one or more stages of solid separation devices that can remove the solids from the product gas and vapors emanating from the process. The particles that are captured by the solids separation device are often returned to the fluid bed from the first stage solids separators, the first stage and the second stage solids separators, or, in some embodiments, from all stages of solids separators.

[0050] This can allow the residence time of solids in the reactor to be prolonged and more reactions to take place before the product gas and the remaining elutriated solids enter a gas clean-up subsystem.

[0051] For example, cyclones or multi-clones can be employed as solids separators. In some instances, a porous metal or ceramic filter (or a barrier filters) can be used to capture the fine particles leaving the fluid bed with the product gas and vapors. Some such filters need to be high temperature devices in some of the embodiments.

[0052] The approaches employed for solids circulation can be an integral part of the process and can have significant effect on the process performance in general and the conversion of energy from solids in particular, with implications to system throughput as well as the energy conversion efficiency.

[0053] Similarly there are embodiments that can provide for product gas and vapors recirculation as well, for instance as hot gas and vapors re-circulation with similar results including enhanced quality of the product gases and vapors and control of steam to carbon ratio.

[0054] Often times the bulk density of the captured fine particles is lower than the expanded fluid bed-density in the dense bed. This can limit the feasible depth to which the fines could be returned into the dense bed. For example, the depth at which the fines could be discharged in a fluid-bed by gravity drain of a dip leg from a cyclone, multi-clone or barrier filters, could be limited because of the density differences.

[0055] Since the solids circulation can be an important variable in the process performance and since reliability is generally also important, in one embodiment of the present disclosure, a dynamic coupling means to enable deep injection of the returning captured solids is provided.

[0056] This embodiment involves providing for down comer conduit(s) and regions for downward solid flow pattern in the fluid bed. This can entrain fines returned to the fluid bed at higher elevations in the bed down to near the bottom of the dense bed. Entraining fines to near the bottom of the dense bed can increase the residence time of the fines in the dense bed before they are re-elutriated again to the free board of the fluid-bed reactor.

[0057] This can provide a reliable, passive means (no special motive force) for re-circulation patterns in the bed for achieving the desired process performance, particularly in moderate-temperature fluid bed reactors. Examples include FCC and steam reforming or mild gasification fluid-bed reactors.

[0058] In some instances, subsonic or supersonic jet nozzles can be provided to enhance the solids flow re-circulation patterns. Jet nozzles can also serve as attrition mills.

[0059] In one embodiment, a carbon converter can be a pressurized entrained flow partial oxidation/Auto-Thermal Gasifier. One preferred embodiment for the carbon converter is a pulse gasifier that is oxygen blown and operated as an auto-thermal gasifier at high pressure with hot gas clean up as described in U.S. Patent Number 6,832,565 Chandran, et al. December 21, 2004 (incorporated herein by reference).

[0060] Pressurization of carbon feedstock to high pressure for injection in the pulse gasifier can be achieved at a slurry stage. Recovery of condensable liquid hydrocarbons from a pre-conditioning process step can enable the formation of slurry that in turn can enable a high pressure-operating regime for a pulse gasifier. In this case, the pressure of a pulse gasifier can be maintained well above the pressure required by the balance of plant so as to allow the expansion of synthetic fuel gas produced in a turbine expander. Such turbine expander may be a cooled stage, with ceramic coatings on the turbine expander blades or a ceramic turbine expander. A pulse gasifier can operate in a temperature range from about 1,750 °F to about 3,000 °F, with preferential temperature generally depending at least in part on the nature of the feedstock. In certain embodiment, for example the case of certain low ash fusion temperature feedstock, the temperature may be lower, for instance about 1,650 °F.

[0061] As an example, one exemplary embodiment is directed to the generation of electric power in a Combined Cycle Gas Turbine that requires a syngas fuel pressure of 250 PSIA. In this embodiment, the pulse gasifier could be operated at about 1,250 PSIA. This would allow a fuel gas expansion pressure ratio of 5:1.

[0062] Use of ceramic membranes or nano filters can be considered for reducing the partial pressure of hydrogen and CO to lower values in the gasifier to maintain reasonable gasification reaction rates at the gasifier temperature and pressure, depending on the specific application. Such ceramic membranes or nano filters may also be employed in the steam reformer or Thermochemical reactor that enables the use of a wide spectrum of feedstock as a preconditioning step.

[0063] In an embodiment directed to ethanol production from biomass, the pressure required by the balance of plant such as a biological process for example is on the order of about 65 PSIA. In this case, the pressure of the pulse gasifier that would be employed would be on the order of only about 520 PSIA or more for an expansion pressure ratio of 8:1 or more. In the case of biomass, the temperature of pulse gasifier could be on the order of between 1,700 °F to about 1,800 °F to avoid slag formation.

[0064] In another embodiment directed to the formation of ethanol using a liquid phase methanol (LPM) process, in the balance of plant requiring very high pressure (for example on the order of 1,500 PSI) the opportunity for the use of a syngas expander turbine would probably not be feasible. Nevertheless, the pressurization of the pulse gasifier to a pressure even on the order of 1,000 PSI to 1,500 PSI would still be of value. This can reduce the pressure ratio for pressurizing the hydrogen laden synthetic gas to the LPM process requirements after cold has clean up with some heat recovery. In this case, heat exchange between the syngas at pressure and the fluid-bed stage could be employed, for instance in tapered cross-section heat exchanger tubes, to reduce or eliminate the need for firing some of the product gas in the indirect heaters.

[0065] In another embodiment, disclosed are methods and processes for the production of liquid and gaseous fuels from syngas. The state of the art today of some processes that make liquid and gaseous fuels from syngas requires high syngas pressurization. In particular, most processes that make ethanol from syngas require syngas pressures as high as 1,200 psig or even as high as 1,500 psig. Therefore, even with the pressurization of an autothermal gasification process to the level of 1,500 psig, there is little to no opportunity for expansion and a pressure ratio between the output of the autothermal gasification process and the required input pressure of the syngas to liquid and gaseous fuels conversion process. This limits the value of the system integration between the syngas generation process and the syngas to liquid fuels processes. This is the case even if the fuel being produced from the syngas is synthetic natural gas (Methane) where the pressure required for syngas is too high.

[0066] Clearly there would be system efficiency advantages if the parasitic pressurization energy load and requirements for the pressurization of the syngas gas can be reduced.

[0067] In one embodiment of this disclosure an innovative approach is being provided to improve the system efficiency, in this case, by reducing materially the parasitic energy consumption load and requirements of the process of making such fuels.

[0068] In this embodiment the first step would be to make first appropriate liquid fuels from syngas using processes that require significantly lower syngas pressure. For example, methanol and DME could be made using processes that require syngas pressure of only 600 psig to 750 psig. This is followed by a second step, using the methanol and DME to make ethanol, for example, in a Homologation step. The pressurization of the Methanol and the DME to high pressures such as 1,200 psig to 1,500 psig would require significantly lower parasitic energy consumption load since this is being achieved by pressurization of liquid phase substances.

[0069] In the high pressure Homologation reactor, the exothermic heat emanating from the process can be used to steam reform the DME at the reactor temperature to make the syngas gas needed to react via indirect heating. Carbon monoxide and hydrogen separation membranes may also be used to separate the hydrogen and carbon monoxide from the products of the steam reforming process of DME to enhance the reaction rates. The syngas made from the DME at pressure and the Homologation process in the presence of an appropriate Homologation Catalyst such as Co-Mo disulfide (available commercially today) would convert the methanol and the syngas into ethanol.

[0070] This innovative approach can materially reduce the parasitic power load for the pressurization of the syngas and its economic advantage becomes more significant, as is the case in any higher efficiency process. This is due to the increase in demand for petroleum and natural gas, national security considerations and the price volatility of premium fuels.

[0071] In this disclosure for flexible and hybrid energy conversion systems, there are, therefore, many opportunities for thermal integration of the systems that can make them versatile in maximizing feedstock and products flexibility, system efficiency and return on capital investment as well as investment security that is beyond what could be achieved with current state of the art technologies.

[0072] The commercial and energy security value of this disclosure, given current premium fuel prices, energy security issues and feedstock and products flexibility, in light of the projected insufficient availability and price volatitly of premium fuels are simply huge.

[0073] The fact that there can be two primary feedstock processing unit operations need not increase the capital and operating costs. The moderate temperature fluid-bed unit can have a high throughput capacity (hence low capital cost) as well as lower maintenance and operating costs. This can also be true, via an appropriate engineering design, of the pressurized pulse gasifier. This, together with the flexibility of process optimization and system integration opportunities made possible by the disclosed system can make the disclosed hybrid systems significantly superior to other current state of the art technologies.

[0074] This is, at least in part, due to the increased prices and reduced reliability of supply of the traditional petroleum and Natural gas derived fuels. It also because of the need to manage the global environment in getting rid of wastes and reduce dependence on net CO2 and greenhouse gas emitting energy sources.

[0075] It will be appreciated that the foregoing examples, given for purposes of illustration, are not to be construed as limiting the scope of this invention. Although only a few exemplary embodiments of this invention have been described in detail above, those skilled in the art will readily appreciate that many variation of the theme are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention that is defined in the following claims and all equivalents thereto. Further, it is recognized that many embodiments may be conceived in the design of a given system that do not achieve all of the advantages of some embodiments, yet the absence of a particular advantage shall not be construed to necessarily mean that such an embodiment is outside the scope of the present invention.

WHAT IS CLAIMED IS:

1. A system configuration and process for the efficient, feedstock flexible, environmentally clean and cost effective conversion of the energy content of a wide spectrum of carbonaceous and hydrocarbons laden feedstock to electric power and/or liquid and gaseous (such as synthetic methane gas) fuels and/or chemicals (for example that would be made from methanol).

2. The first part of the process (first stage) is a moderate temperature (900 degrees F to 1,500 F) and moderate pressure (10 psig to 110 psig) indirectly heated Thermochemical fluid bed stage for preprocessing a wide spectrum of carbonaceous and hydrocarbons laden feedstock. Said first stage is used for the production of syngas, char and condensable hydrocarbon vapors. The objective of this first stage to efficiently enable the expansion of the usable spectrum of feedstock, provide for a low capital cost/ high throughput and high heat transfer stage and to precondition the material for further processing.

3. The second part of he process (second stage) is a higher temperature stage (1,500 degrees F to 3,000 degrees F) for further processing of the char and the separated condensable hydrocarbons for the efficient and low capital cost production of more syngas.

4. A first option for the second stage is an entrained flow higher-pressure partial oxidation based gasifier operating at a temperature in the range stated in claim 3 above and a pressure of up to 1,500 psig for the production of more syngas.

5. The use of and thermal integration of the enthalpy of the high pressure and high temperature syngas resulting from the species change. This use is for the first option of the second stage is for power production and/or further processing (by heating) and pressurization, via an eductor, of the syngas from the first stage to maximize overall system efficiency and product(s) yield.

6. A second option of the second stage is an indirectly heated Thermochemical stage at a temperature up to 1,550 degrees F and up to 150 psig for the production of more syngas. The choices between the first option and the second option for the second stage depend of the feedstock characteristics as well as the desired hydrogen to CO ratio for the application in the down stream

processes (power production or liquid fuels production) without the need to use catalytic, water gas shift exothermic processes that generate waste heat.

7. Use of high membranes and/or nanofilters for the separation of selected gaseous species in the first stage and second stage for enhancement of reaction rates and flexibility is the Hydrogen to CO ratio in the syngas to conform with the optimum ratio of the down stream processes.

8. Use of the exothermic heat and energy in the tail gas from syngas to hydrocarbon fuels and chemicals production processes, in the case of liquid fuels, synthetic natural gas and chemicals production for offsetting part or all of the syngas consumption normally used for firing the indirect heaters of the indirectly heated Thermochemical processes of the system. This materially improves overall economics and efficiency over the state of the art performance. This includes air preheat for indirect heaters (typically coupled with flue gas re-circulation), production of power from the exothermic heat and using the electricity in electric heaters to provide some or all of the endothermic heat for the indirectly heated Thermochemical processes.

9. Using a moderate pressure to make appropriate liquid fuels such as methanol and DME and pressurizing the liquid fuels to the high pressures required for making fuels such as ethanol to reduce parasitic power consumption and hence improve overall system efficiency and economics.

10. Employing tapered cross section heat transfer tubes instead of or in conjunction with pulsating heaters for indirect heating of the indirectly heated Thermochemical reactors.

11. Employing down bed material flow conduits for passive dynamic entertainment of low density fines from particulate separation dip legs to lower elevations in the fluid bed reactor to enhance residence time of fines and hence to improve reaction rates in general and carbon conversion rates in particular in the fluid bed reactor(s).

12. Use of subsonic and particularly supersonic motive jets, or both, employing superheated steam and/or hot high pressure product gas, that also serve as “attrition mills” in the fluid bed as well as to provide for desired bed material flow patterns and for the control of the mean particle size distribution in fluid bed reactors.