A facility comprising integrated systems for the extraction, and optionally upgrading and/or refinement, of unconventional oil sources, using fossil fuels as a primary source of energy. In particular, this facility provides a means to gasify one or more fossil fuels in an efficient manner, converting it into intermediate products such as heat, steam and electricity, which are then used by the system to obtain useful fuel products from unconventional oil sources such as tar sands and oil shale. The design of the components of this facility is optimized such that the overall costs are competitive with an equivalent unconventional oil source processing facility that uses natural gas as a source of processing energy. The facility can be used on its own, may use supplemental natural gas energy sources, or may be used in conjunction with an existing facility that uses natural gas as an energy source in order to improve the overall cost effectiveness of the processing and/or reduce the requirement for other energy sources, such as natural gas.
Figure 2A

- **Feed**
- **Pre-heated Air**
- **Controlled Speed**
- **Feedstock Pile**
- **Gas Out**
Figure 4

FEED

20

PRE-HEATED AIR

SCREW

83

GAS

70

CHAR
Figure 5
Figure 9

Char

Air/Oxygen

Steam

Steam

Char

Air/Oxygen

Gas

Ash
Figure 10
From primary chamber

Char

Plasma heat

To syngas cooler

Motor

Agitator

Secondary Chamber

Heated air inputs

Air/Oxygen

Oxygen/Air

Plasma heat

Rotating Grate

Slag Chamber

Slag

Figure 13
Figure 14
Figure 25B
Figure 30
Radio Frequency Plasma & Microwave Plasma

Figure 40
Figure 45

- Laser Plasma
- Carrier gas
- Laser
- Laser beam
- Focussing Lens
- Nozzle
- Pressurized gas inlet
- Work piece
Figure 46: Corona Plasma (Cold Plasma)

- 1-5 atm gas
- Glass
- Vacuum
- 45°, 90° angles
- 3-5 nozzle diameters
- Corona electrode (+V)
Figure 57
Figure 68
Figure 70C
Figure 72
Figure 74
(i) Passive Grid

(ii) Active Grid

(iii) Linear Varying Flow Obstruction

Shear Generator

Figure 75C
Figure 76
Active Grid

Figure 77
Figure 78

Variable Obstruction for shear generation

Blocked Area

Open Area
Figure 82
Figure 83

- Feed
- Syngas
- Steam, Nitrogen
- Heat exchangers
- GASIFIER
- Pyrolysis
- Catalytic Cracking
- Char
- To Residue chamber
- Oxygen or Air
- Air
- Plasma torch
- Reformulating Chamber
Figure 84

- Feed to Gasifier
- Air to Gasifier
- Volatiles at 600°C to Gasifier
- Air to Catalyst Bed
- Volatiles at 950°C to Catalyst Bed
- Catalyst Bed at 850°C to Energizing Field
- Gas at 1000°C from Energizing Field

Diagram shows a process flow involving a gasifier, catalyst bed, and energizing field.
Figure 85
Figure 86
Figure 87
Figure 92B
Figure 97
Integrated Gasification Combined Cycle With Plasma Coal Converter Envisioned

SAGD--

Figure 119
SYSTEM COMPRISING THE GASIFICATION OF FOSSIL FUELS TO PROCESS UNCONVENTIONAL OIL SOURCES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims benefit of priority under 35 U.S.C. § 119(e) from U.S. Provisional Application Ser. No. 60/917,612, filed May 11, 2007. This application also claims benefit of priority under 35 U.S.C. § 119(e) from U.S. Provisional Application Ser. No. 60/917,610, filed May 11, 2007. This application also claims the benefit of priority to International Patent Application No. PCT/US07/0456, filed Jun. 5, 2007. This application also claims benefit of priority under 35 U.S.C. § 119(e) from U.S. Provisional Application Ser. No. 60/950,322, filed Jul. 17, 2007. This application also claims benefit of priority under 35 U.S.C. § 119(e) from U.S. Provisional Application Ser. No. 60/986,213, filed Nov. 7, 2007. This application also claims benefit of priority under 35 U.S.C. § 119(e) from U.S. Provisional Application Ser. No. 60/986,212, filed Nov. 7, 2007. This application also claims the benefit of priority to International Patent Application No. PCT/CA08/00355, filed Feb. 27, 2008. This application also claims benefit of priority under 35 U.S.C. § 119(e) from U.S. Provisional Application Ser. No. 61/042,571, filed Apr. 4, 2008. The contents of all of the aforementioned applications are hereby expressly incorporated by reference in their entirety and for all purposes.

FIELD OF THE INVENTION

[0002] The present invention pertains to the field of processing oil from unconventional oil sources, and in particular to a facility comprising integrated systems for the extraction, and optionally upgrading and/or refinement, of unconventional oil sources, using the gasification of fossil fuels as a primary source of energy.

BACKGROUND OF THE INVENTION

[0003] The world’s oil resources fall into two main categories, conventional oil resources and unconventional oil resources. Conventional oil is also known as light oil, and much of the world’s conventional oil resources are found in Saudi Arabia. Production and processing costs associated with this type of oil are relatively low compared to those associated with unconventional oil. Unconventional oil refers, in general, to oil resources that are more difficult to extract than conventional oil. The majority of unconventional oil resources are found in Canada and Venezuela. Unconventional oils include, for example, heavy oils, tar sands, and oil shale. Heavy oil is characterized by its content of asphaltenes and is a very dense and viscous oil. Tar sands and oil shale are described below.

[0004] Oil shale is a fine-grained sedimentary rock, containing significant amounts of kerogen (a solid mixture of organic chemical compounds), from which liquid hydrocarbons can be manufactured. The oil shale industry is well-established in Estonia, China, and Brazil, and the United States is taking steps in that direction.

[0005] Oil shale is usually mined and then shipped elsewhere, after which it is directly burnt to generate electricity or undergoes further processing. The most-often used methods of surface mining are open pit mining and strip mining. These procedures remove most of the overlying material to expose the oil shale deposits, and are practical when the deposits are close to the surface. Underground mining of oil shale, which removes less of the overlying material, employs the room-and-pillar method.

[0006] The extraction of its useful components usually takes place above ground (ex situ processing), although several newer technologies perform this underground (on-site or in situ processing). In either case, after access to the shale is gained, its kerogen is converted to synthetic crude oil and shale gas through the chemical process of pyrolysis. Most conversion technologies involve heating shale in the absence of oxygen to a temperature at which kerogen is decomposed (pyrolysed) into gas, condensable oil, and a solid residue; these usually takes place between 450°C (842°F.) and 500°C (932°F.). The process of decomposition begins at relatively low temperatures (300°C/570°F.), but proceeds more rapidly and more completely at higher temperatures.

[0007] During the course of in-situ processing, the oil shale is heated underground. These technologies can potentially extract more oil from a given area of land than ex-situ processes, since they can access the material at greater depths than surface mines. Several companies have patented methods for in-situ retorting. However, most of these methods are still in the experimental phase. The methods are usually classified as true in-situ processes (TIS) and modified in-situ processes (MIS). True in-situ processes do not involve mining the oil shale. Modified in-situ processes drill a large shaft to transport workers and equipment to the shale formation, fracture the deposit and crush it, and ignite the rubble.

[0008] U.S. Pat. Nos. 4,449,586 and 4,067,390 describe processes for the recovery of hydrocarbonaceous oil from oil shale.

[0009] Tar sands (also referred to as oil sands) are a combination of clay, sand, water, and bitumen, a heavy black viscous oil. Tar sands can be mined and processed to extract the oil-rich bitumen, which is then refined into oil. The bitumen in tar sands cannot be pumped from the ground in its natural state; instead tar sand deposits are mined, usually using strip mining or open pit techniques or produced in situ by underground heating or other tertiary recovery processes.

[0010] Tar sands deposits near the surface can be recovered by open pit mining techniques. After mining, the tar sands are transported to an extraction plant, where a hot water process separates the bitumen from sand, water, and minerals. Regardless of the exact nature of the physical composition of sand and bitumen in the tar sands, the bitumen may be readily separated from the sand by hot-water separation techniques wherein the bitumen phase is disengaged from the sand phase. U.S. Pat. Nos. 3,556,981; 3,847,789; and 3,893,907 are illustrative of a number of patents describing hot water extraction processes for the separation of bitumen from tar sands.

[0011] In those instances where bitumen deposits are buried too deep for mining to be economical, wells are drilled to access the bitumen deposits, and in-situ production methods are used to extract the bitumen. These in situ production methods include steam injection, solvent injection, and firefloods, in which oxygen is injected and part of the resource burned to provide heat. Typically, steam injection methods are used.

[0012] There are a number of different steam-injection techniques in use including the Cyclic Steam Stimulation (CSS) or “huff-and-puff” method where the well is put through cycles of steam injection, heat soak, and pumped oil
production. This process is repeated until the cost of injecting steam becomes uneconomical, for instance if the cost is higher than the money made from producing oil. The CSS method has the advantage that recovery factors are around 20 to 25% and the disadvantage that the cost to inject steam is high.

[0013] Another steam-injection method, steam assisted gravity drainage (SAGD), utilizes directional drilling technology. Two horizontal wells are drilled in the oil sands, one at the bottom of the formation and another about 5 metres above it. These wells are typically drilled in groups of central pads and can extend for miles in all directions. In each well pair, steam is injected into the upper well, the heat melts the bitumen, which allows it to flow into the lower well, where it is pumped to the surface. SAGD is cheaper than CSS, allows very high oil production rates, and recovers up to 60% of the oil in place.

[0014] Vapour extraction (VAPEX) is similar to SAGD but instead of steam, hydrocarbon solvents are injected into the upper well to dilute the bitumen and allow it to flow into the lower well. An advantage of VAPEX is better energy efficiency than steam injection and it results in some partial upgrading of bitumen to oil right in the formation. This is a recently developed technique but has attracted much attention from oil companies, who are beginning to experiment with it.

[0015] The above three methods are not mutually exclusive. For example, wells can be put through one CSS injection-pump production cycle to condition the formation prior to going to SAGD production, and companies are experimenting with combining VAPEX with SAGD to improve recovery rates and lower energy costs.

[0016] The extraction methods described above, particularly SAGD, require a considerable amount of natural gas for generating steam, aiding flow through the drilled wells, for producing hydrogen for hydrotreating, and for producing electricity for heating and pumping the bitumen through the system. While natural gas, due to economic, environmental, and technological changes may be desirable as a fuel of choice due to its clean burning nature, the increased demand and costs of natural gas and oil make it desirable to explore the options of using traditionally less attractive sources of fuel such as coal, the cheapest fossil fuel for generating electricity (and the dirtiest and most polluting), pet coke, and bitumen, in ways such that developing regulations surrounding the resulting emissions can be respected in order to lessen environmental damage.

[0017] Once bitumen has been extracted from reservoirs, it must be processed and upgraded to a lighter oil product such as a synthetic crude oil. The upgrading process can be carried out at the site of extraction, or diluents can be added to the bitumen to facilitate transportation to an upgrading facility. The upgrading process (also called cracking or distillation) into lighter oil products has been around for a while; however, doing so in an economic fashion has been difficult in small scale fields.

[0018] By-products of the bitumen upgrading process include materials such as petroleum coke or asphalt. Petroleum coke, or pet coke, can be used as a fuel for coke furnaces which produce the heat required for certain aspects of the upgrading process. Typically more pet coke is produced than is used in the upgrading process, resulting in stockpiling of excess pet coke at or near the upgrading site.

[0019] Gasification is a process that enables the production of a combustible or synthetic gas (e.g., H2, CO, CO2, CH4) from carbon-based feedstock, referred to as carbonaceous feedstock. The gas can be used to generate electricity or as a basic raw material to produce chemicals and liquid fuels. This process enables the production of a gas that can be used for generation of electricity or as a primary building block for manufacturers of chemicals and transportation fuels.

[0020] In particular, the gas can be used for the combustion in a boiler for the production of steam for internal processing and/or other external purposes; for the generation of electricity through a steam turbine; the combustion directly in a gas turbine or a gas engine for the production of electricity; fuel cells; the production of methanol and other liquid fuels; as a further feedstock for the production of chemicals such as plastics and fertilizers; the extraction of both hydrogen and carbon monoxide as discrete industrial fuel gases; and other industrial heat requirements as required.

[0021] Gasification is not an incineration or combustion process. Both incineration and combustion processes operate to thermally destroy the carbonaceous feedstock with excess oxygen to produce CO2, H2O, SO2, NO2 and heat. Incineration also produces bottom ash and fly ash, which must be collected, treated, and disposed as hazardous waste in most cases. In contrast, gasification processes operate in the absence of oxygen or with a limited amount of oxygen and produce a raw gas composition comprising H2, CO, H2S and NH3. After clean-up, the primary gasification products are H2 and CO.

[0022] In contrast to incineration, which works with excess air to fully convert the input material into energy and ash, gasification converts carbonaceous materials into energy-rich fuels by heating the carbonaceous feedstock under controlled conditions. Gasification processes deliberately limit the conversion so that combustion does not take place directly. Gasification processes operate at substoichiometric conditions with the oxygen supply controlled (generally 35 percent of the O2 theoretically required for complete combustion or less), enabling gasification to convert the carbonaceous feedstock into valuable intermediates that can be further processed for materials recycling or energy recovery. Some gasification processes also use indirect heating, avoiding combustion of the carbonaceous feedstock in the gasification reactor and avoiding the dilution of the product gas with nitrogen and excess CO2.

[0023] Generally, such a gasification process consists of feeding carbon-containing materials into a heated chamber (the gasification reactor) along with a controlled and limited amount of oxygen and steam. At the high operating temperature created by conditions in the gasification reactor, chemical bonds are broken by thermal energy and by partial oxidation, and inorganic mineral matter is fused or vitrified to form a molten glass-like substance called slag.

[0024] Several types of carbonaceous feedstocks can be used in gasification, including coal of varying grades. Such coal includes low grade, high sulfur coal, which is not suitable for use in coal-fired power generators due to the production of emissions having high sulfur content. Waste coal particles and silt that remain after coal has been mined, sorted and washed is also be useful for gasification. Coal can be gasified with oxygen and steam to produce so-called "synthesis gas" containing carbon monoxide, hydrogen, carbon dioxide, gaseous sulfur compounds and particulates. The gasification step is usually carried out at a temperature in the range of about
650° C. to 1200° C., either at atmospheric pressure or, more commonly, at a high pressure of from about 20 to about 100 atmospheres.

[0025] Because coal often contains sulfur compounds, attempts have been made to provide processes for the gasification of coal to produce a clean product fuel gas wherein the sulfur is removed from the product fuel gas prior to its use, e.g., in gas turbines to generate electricity. In addition, gases from the gasification zone may be purified to remove coal dust and fly ash and also many other impurities, e.g., vaporized ash, alkali, etc.

[0026] There are a number of patents relating to different technologies for the gasification of coal for the production of synthesis gases for use in various applications, including U.S. Pat. Nos. 4,141,694; 4,181,504; 4,208,191; 4,410,336; 4,472,172; 4,606,799; 5,331,906; 5,486,269, and 6,200,430.

[0027] With respect to the use of Gasification Systems in tar sands, Shell Oil Company has described various methods of using in-situ heating of tar sand formation to produce syngas. For example, U.S. Patent Publication No. 2003/0155111 describes an in situ process for treating a tar sands formation which may include providing heat from one or more heaters to at least a portion of the formation. The heat may be allowed to transfer from the one or more heaters to a part of the formation such that heat from the one or more heat sources pyrolizes at least some hydrocarbons within the part. Synthesis gas (or syngas) may be produced from the formation and can be converted to heavier condensable hydrocarbons, combusted as fuel, used to synthesize organic and inorganic compounds, used to generate electricity, or used to power fuel cells.

[0028] U.S. Pat. No. 4,067,390 describes another apparatus and method for in situ gasification of tar sands. This apparatus and method utilizes a plasma arc torch as heat source for recovering useful fuel products from in situ deposits of coal, tar sands, oil shale, and the like. The useful fuel products include crude oil.

[0029] U.S. Patent Publication No. 2007/0017228 describes a method for enhancing the efficient operation of an electrical power plant utilizing a waste conversion unit to convert organic matter and electrical power into a useful fuel. The waste conversion unit is in electrical communication with an electrical power plant, where it uses electrical power from the electrical power plant and organic matter to form a useful fuel during periods when the electrical power plant has relatively high excess capacity. The useful fuel is then supplied to an electrical generator during periods of relatively low excess capacity, thereby allowing electrical generator to increase the power delivered by said power plant during periods of peak electricity demand. The waste conversion unit is described as one which uses electrical energy to create plasma which can be used to gasify a feedstock such as tar sands, coal and oil shale.

[0030] U.S. Patent Publication No. 2007/005536 describes a system for treating a hydrocarbon containing formation that includes a steam and electricity cogeneration facility. In this system, at least one injection well is located in a first portion of the formation. The injection well provides steam from the steam and electricity cogeneration facility to the first portion of the formation. At least one production well is located in the first portion of the formation. The production well in the first portion produces first hydrocarbons. At least one electrical heater is located in a second portion of the formation. At least one of the electrical heaters is powered by electricity from the steam and electricity cogeneration facility. At least one production well is located in the second portion of the formation. The production well in the second portion produces second hydrocarbons. The steam and electricity cogeneration facility uses the first hydrocarbons and/or the second hydrocarbons to generate electricity.

[0031] This background information is provided for the purpose of making known information believed by the applicant to be of possible relevance to the present invention. No admission is necessary intended, nor should be construed, that any of the preceding information constitutes prior art against the present invention.

SUMMARY OF THE INVENTION

[0032] This invention provides a facility to process unconventional oil sources. In accordance with one aspect of the present invention, there is provided a facility integrating a number of systems for the extraction of useful fuel products from an unconventional oil source, wherein the facility uses fossil fuels as a primary source of energy and comprises:

[0033] a. a Gasification System for converting a feedstock comprising a fossil fuel into slag, an off-gas, heat and steam;

[0034] b. a Gas Reformulation System operatively associated with said Gasification System for converting the off-gas to a reformulated gas and heat, said reformulated gas comprising hydrogen and carbon monoxide;

[0035] c. a Control System operatively associated with said Gasification System and said reformulation system for monitoring and regulating said systems to ensure efficient conversion of said feedstock;

[0036] d. one or more Gas Conversion Systems operatively associated with said gas reformulation system that use the reformulated gas to produce electricity, steam, hydrogen, carbon dioxide, or light oils, or a combination thereof, and

[0037] e. one or more Extraction Systems operatively associated with at least one or said Gas Conversion Systems for extracting crude fuel products from the unconventional oil source using the electricity, steam, hydrogen, carbon dioxide, or light oils, or a combination thereof, produced in the one or more Gas Conversion Systems.

[0038] In accordance with another aspect of the present invention, there is provided a process for producing useful fuel products from an unconventional oil source, said process comprising the steps of:

[0039] a. gasifying a feedstock comprising a fossil fuel to produce slag, an off-gas, heat and steam;

[0040] b. reformulating the off-gas to provide a reformulated gas comprising hydrogen and carbon monoxide;

[0041] c. providing the reformulated gas to one or more Gas Conversion Systems to produce electricity, steam, hydrogen, carbon dioxide, or light oils, or a combination thereof, and

[0042] d. providing the electricity, steam, hydrogen, carbon dioxide, or light oils, or a combination thereof, to an Extraction System for extracting crude fuel products from the unconventional oil source.

BRIEF DESCRIPTION OF THE FIGURES

[0043] These and other features of the invention will become more apparent in the following detailed description in which reference is made to the appended drawings.
FIG. 1 depicts an overview of the flow of the sources of energy between the systems comprised by an unconventional oil processing facility on one embodiment of the invention.

FIG. 2A depicts a schematic diagram depicting in cross section a chamber having a rotating arm solids removal device, in accordance with one embodiment of the invention.

FIG. 2B is a schematic diagram depicting a top view of the rotating arm solids removal device of FIG. 1, in accordance with one embodiment of the invention.

FIG. 3 is a perspective, cut away view of a chamber having an extractor screw solids removal device, in accordance with one embodiment of the invention.

FIG. 4 shows a cross-sectional view of a variation of a chamber using an extractor screw-based solids removal device, where the solid residue outlet is moved away from the main processing chamber to avoid direct drop, in accordance with one embodiment of the present invention.

FIG. 5 is a perspective, cut away view of a chamber having a pusher ram solids removal device, in accordance with one embodiment of the present invention.

FIG. 6 is a perspective, cut away view of a chamber using a pusher ram-based solids removal device, in accordance with one embodiment of the invention.

FIG. 7 is a cross-sectional view of a variation of a chamber using pusher ram-based solids removal device, in accordance with one embodiment of the present invention.

FIG. 8 shows one embodiment of a horizontal primary chamber.

FIG. 9 is a schematic diagram of an entrained flow conversion chamber, in accordance with one embodiment of the invention.

FIG. 10 is a schematic diagram of a fluidized bed conversion chamber, in accordance with one embodiment of the invention.

FIG. 11 is a schematic diagram of a moving bed conversion chamber, in accordance with one embodiment of the invention.

FIGS. 12A and 12B depict embodiments of rotating grates that can be used in a moving bed conversion chamber, in accordance with different embodiments of the present invention.

FIG. 13 is a schematic diagram of a moving bed conversion chamber in relation to a solid residue conditioning chamber and a gas reformulation chamber, in accordance with one embodiment of the invention.

FIG. 14 is a cross-sectional schematic of a cascade of a fixed-bed char conversion chamber relative to a plasma heated residue conditioning chamber.

FIG. 15 is a cross-sectional view through one embodiment of the gasifier, detailing the feedstock input, gas outlet, ash outlet, lateral transfer system, additive ports and access ports.

FIG. 16 shows a general schematic of a vertically oriented primary chamber, in accordance with one embodiment of the present invention.

FIG. 17 shows a general schematic of a vertically oriented primary chamber, in accordance with another embodiment of the present invention.

FIGS. 18A and B show various embodiments for movement of reactant material from one processing chamber to another in a two-processing chamber gasifier. The material displacement control modules employed include (a) gravity; (b) gravity with sideways top valve; (c) gravity with hopper; (d) gravity with screw; (e) vertical screw; (f) horizontal extractor screw; (g) vertical screw with hopper; (h) gravity with screw and hopper; and (i) horizontal extractor screw and hopper.

FIG. 19 is a schematic of a horizontally-oriented stepped floor gasifier of the invention, detailing the feedstock input, gas outlet, ash outlet and lateral transfer system.

FIG. 20 is a flow diagram showing the different regions of the primary chamber in general terms.

FIG. 21 is a representation of the gasification processes occurring in different regions of one embodiment of the primary chamber.

FIG. 22 is a perspective view of one embodiment of the primary chamber, detailing the feedstock input, gas outlet, ash outlet, ram enclosure and access ports.

FIG. 23 is a side view of the primary chamber illustrated in FIG. 22 detailing the air boxes, ash can and dust collector.

FIG. 24 is a central longitudinal cross-sectional view through the primary chamber illustrated in FIGS. 22 and 23, detailing the feedstock input, gas outlet, ash outlet, lateral transfer system, thermocouples and access ports.

FIG. 25A is a diagrammatical representation of a vertically oriented primary chamber comprising a gas passage conduit for input of process additives therein, in accordance with one embodiment of the present invention.

FIG. 25B is a diagrammatical representation of a vertically oriented primary chamber comprising a gas passage conduit for output of gas therefrom, in accordance with one embodiment of the present invention.

FIG. 25C is a diagrammatical representation of a horizontally oriented primary chamber comprising a gas passage conduit for input of process additives therein, in accordance with one embodiment of the present invention.

FIG. 25D is a diagrammatical representation of a horizontally oriented primary chamber comprising a gas passage conduit for output of gas therefrom, in accordance with one embodiment of the present invention.

FIG. 26A is a diagrammatical representation of a vertically oriented gasifier comprising three processing regions and two gas passage conduits for output of gas therefrom in different directions, in accordance with one embodiment of the present invention.

FIG. 26B is a diagrammatical representation of a vertically oriented gasifier comprising three processing regions and two gas passage conduits, one of which for input of process additives therein and the other for output of gas therefrom, in accordance with one embodiment of the present invention.

FIG. 27A is a diagrammatical representation of a gasifier having three processing regions defined therein and comprising a gas passage conduit for output of gas therefrom, in accordance with one embodiment of the present invention.

FIG. 27B is a diagrammatical representation of a gasifier having three processing regions defined therein and comprising a gas passage conduit for output of gas therefrom, in accordance with one embodiment of the present invention.

FIG. 27C is a diagrammatical representation of a gasifier having three processing regions defined therein and comprising a gas passage conduit for output of gas therefrom, in accordance with one embodiment of the present invention.

FIG. 28 shows the extraction of gas separately from the different processing regions as in the same direction.
FIG. 29 shows the injection of additives independently into the different processing regions and the off-gases collected in multiple jackets around the gasifier.

FIG. 30 shows the internal design of the gas passage conduit used for separate extraction of off-gases from different processing regions, as shown in the embodiment of FIG. 28.

FIG. 31 is a schematic representation of the multi-zone carbon converter in general terms, namely showing the general features of the carbon conversion zone, inter-zonal region or inter-zone and the slag zone.

FIGS. 32A-F depict various impedance mechanisms for use in a fixed-bed char conversion chamber, in accordance with embodiments of the invention.

FIGS. 33A, 33B, 34AA, 34AB, 34BA, and 34BB show the various zones of the gas reformulating system. The dotted lines show zones that are optional. The gases may undergo processing in a serial cascade of the zones in or parallel array as depicted in FIGS. 34BA and 34BBB.

FIG. 35 is a schematic of the gas reformulating system according to an embodiment of the invention.

FIG. 36 is a schematic of one embodiment of a Gas Reformulating System of the invention coupled to a gasifier.

FIG. 37 is a schematic of one embodiment of a Gas Reformulating System of the invention coupled to two gasifiers.

FIG. 38 is a schematic of one embodiment of the gas reformulating chamber of the invention coupled to two gasifiers, through a common initial gas inlet.

FIGS. 39, 40, 45 and 46 show the following types of gas energizing sources: hydrogen burner, radio frequency (RF) and microwave plasma, laser plasma, corona plasma.

FIG. 41 shows the following types of plasma sources: non-transferred arc torch, transferred arc torch, inductively coupled plasma torch, microwave plasma torch.

FIG. 44 shows a hydrogen burner.

FIGS. 42 and 43 illustrate the use of an inductively coupled plasma torch, microwave plasma torch and a hydrogen burner in a gas reformulating system, in accordance with various embodiments of the invention.

FIG. 47 shows various embodiments of gas reformulating channels.

FIG. 48 shows various embodiments of gas reformulating channels.

FIG. 49 shows various embodiments of gas reformulating channels.

FIG. 50 shows various embodiments of gas reformulating channels.

FIG. 51 shows a gas reformulating channel using a mixer device.

FIGS. 52A-B show the use of constrictions in the gas reforming chamber for enhancing gas mixing, in accordance with two embodiments of the invention.


FIG. 56 shows various embodiments of the Gas Reformulation System wherein the gas stream is separated into smaller streams, which undergo reformulation in parallel.

FIG. 57 shows various arrangements of the gas energizing sources vis-à-vis the initial gas stream.

FIGS. 58A-C show different shapes of flow restrictors inserted into a gas reformulating chamber, in accordance with various embodiments of the invention.

FIGS. 59A-B and 74 show flow restrictors that extend for substantially whole length of the gas reformulating chamber, in accordance with three embodiments of the invention.

FIGS. 60A-B and 76 show the three dimensional view of gas reformulating chambers equipped with flow restrictors that extend for substantially whole length of the chamber, in accordance with two embodiments of the invention.

FIG. 61A-G show different embodiments of the flow restrictors.

FIG. 62A shows a rotational shaft with multiple disks, in accordance with one embodiment of the invention. FIG. 62B show different disk structures that can be used with the rotational shaft for enhanced interaction of the gas with energizing fields.

FIGS. 63A-C show different rotational methods for the shaft and the disks, in accordance with various embodiments of the invention.

FIGS. 64 and 65 show the use of deflectors and Corad-A-effect deflectors respectively for directing the gas energizing fields, in accordance with two embodiments of the invention.

FIGS. 66A-B show the use of one or more air nozzles for active control of the spatial distribution of the plasma plume, in accordance with two embodiments of the invention.

FIGS. 67A-D show the use of different deflectors for redirection of the plasma plumes within the gas reformulating chamber.

FIGS. 68A-D show the use of asymmetric rotating shaft objects deflectors, in accordance with various embodiments of the invention.

FIG. 69 is a schematic of a portion of the Gas Reformulating System detailing the torch mounting system and according to an embodiment of the invention.

FIG. 70A shows a gas energizing source positioned to direct the gas energizing field counter-current to the flow of the gas stream, in accordance with one embodiment of the invention. FIG. 70B shows the embodiment of FIG. 70A with the gas entering near the top and exiting towards the bottom. FIG. 70C is a schematic illustrating the orientation of the inlets and plasma torches of one embodiment.

FIGS. 71 and 72 show various arrangements of the gas energizing sources vis-à-vis the gas reformulating chamber and the input gas stream.

FIG. 73 illustrates arrangements of baffles in the gas reformulating chamber. FIG. 73A illustrates air-flow within the gas reformulating chamber comprising bridge wall baffles. FIG. 73B illustrates air-flow within the gas reformulating chamber comprising turbulator or choke ring baffles.

FIGS. 75A-B show the inclusion of turbulence zones for enhanced reformulation.

FIG. 75C show examples of turbulence generators.

FIG. 76 shows the gas to be reformulated entering tangentially into the reformation reactor creating a swirl which is treated by the plasma torches and the Gas Manipulator.

FIGS. 77 and 78 show exemplary means for generating turbulence.

FIG. 79 is a diagram illustrating air-flow out of a Type A nozzle.
FIG. 92A is a schematic of one embodiment of the gas reformulating chamber.

FIG. 92B is a cross sectional view of the gas reformulating chamber of FIG. 92A detailing the refractory supports.

FIGS. 93 to 96 show various configurations of gas reformulating chambers, gasifiers and carbon converters.

FIG. 97 shows a gasifier which may be linked to the Gas Reformulating System of the invention.

FIGS. 98 to 100, 106 and 109 show various views of an exemplary Gas Manipulator designed to be retrofitted to a cylindrical gas reformulating chamber.

FIGS. 101, 102, 104, 105, 107, 108 show various views of the exemplary Gas Manipulator of FIG. 66 as installed in the cylindrical gas reformulating chamber.

FIG. 103 shows a top view of the gas reformulating chamber without the exemplary Gas Manipulator of FIG. 98.

FIG. 110 show various representations for the gas energizing sources as used in the FIGS. 33 to 109. All representations are equivalent and can be used to indicate any of the gas energizing sources specifically indicated herein, or as would be known to a worker skilled in the art.

FIG. 111 is a schematic diagram depicting the recovery of heat from the syngas produced in the gas refining chamber using the heat recovery subsystem according to one embodiment of the instant invention.

FIGS. 112 to 115 depict different combinations of the different function block processes of a facility for gasifying two feedstocks, wherein “1” depicts function block 1 (a volatilization chamber), “2” depicts function block 2 (a char conversion chamber), “3” depicts function block 3 (a solid residue conditioning chamber), and “4” depicts a function block 4 (a Gas Reformulating System).

FIG. 116 depicts various SAGD options configured around a GGCS.

FIG. 117 presents an exemplary configuration of a Gasification System and steam generator combination, according to one embodiment of the invention.

FIG. 118 presents an exemplary configuration of a Gasification System and steam generator combination, according to another embodiment of the invention.

FIG. 119 depicts a process flow diagram of a Gasification System according to an embodiment of the invention in which steam is generated from latent heat in syngas and electrical generator outputs.

FIG. 120 depicts an embodiment of the system in which bitumen is partially gasified.

FIG. 121A to D depicts various configurations of gasification reactors or converters suitable for use with the system of the invention.

FIG. 122 depicts a process overview diagram of a GGCS suitable for use with the system of the invention.

FIG. 123 depicts an embodiment of the system in which syngas is produced from the gasification of bitumen.

FIG. 124 depicts an embodiment of the system in which light oil production is maximized upstream with syngas being used to produce H2, CO2, power, and steam.

FIG. 125 depicts an embodiment of the system in which feedstocks can be used to produce steam.

FIG. 126 depicts a block flow diagram of CO2 and diluent applications.

FIG. 127 depicts an embodiment of the system in which various feedstocks are used to produce steam, H2 and electricity for upgrading bitumen.

FIG. 128 depicts a fluid plasma gasifier suitable for use in an embodiment of the system.

FIG. 129A to C each depict a different arrangement of the components of the system in one embodiment.

FIGS. 130A and B depict embodiments of a cooler and remover system for use in the system of the invention.

FIG. 131 is a schematic diagram depicting one embodiment of the multi-chamber carbonaceous feedstock Gasification System, in accordance with one embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

This invention provides a facility comprising integrated Systems for the extraction, and optionally upgrading and/or refinement, of unconventional oil sources, using fossil fuels as a primary source of energy. There are a number of processes involved in efficiently gasifying a fossil fuel, converting the gas into a more useful chemical composition, converting the gas into one or more different energy sources, as well as extracting, upgrading and refining the products obtainable from an unconventional oil source. Each of these processes requires a source of energy that is usually provided in the form of heat, steam, electricity, or a chemical reagent (e.g., H2, O2, CO2, etc.).

Processes that use reformulated gas include electricity generation via an engine such as a G.E. Jenbacher gas engine. Pressurized gas can be used to drive a gas turbine engine.

Processes that use steam include, for example, in situ extraction processes, as a process additive during the reformulation of gas, etc.

Processes that use electricity include, for example, reactive species generating processes (such as plasma generation), gas reformulation processes, syngas purification processes, underground heating processes for in situ extraction of crude fuel products, pumping processes for transferring crude fuel products and refined fuel products through the system, upgrading processes and refining processes.

Processes that use heat include, for example, gasification processes, gas reformulation processes, syngas purification processes, steam generation processes and in situ extraction processes.

Processes that use H2 include, for example, hydrotreating crude fuel products in upgrading processes and fuel cell processes for generating electricity.
[0157] Processes that use CO₂ include, for example, enhanced oil recovery (EOR) processes and methane recovery processes.

[0158] Processes that use light oils include, for example, extraction and pumping processes that use the light oils as diluents to improve the flowability of the crude fuel product.

[0159] The energy used to conduct these processes within this system is largely generated within one or more of the systems of this invention, which comprise:

[0160] Gasification Systems that convert feedstock to slag, gas, heat and steam;

[0161] gas reformation systems that convert offgas to quality syngas and heat;

[0162] Gas Conversion Systems that convert gas to electricity, steam, H₂, CO₂, or light oils;

[0163] Extraction Systems that extract crude fuel products, such as bitumen, kerogen and heavy oil, from the unconventional oil source.

[0164] upgrader and refining systems that purify the crude fuel product to provide a useful fuel product (plus in some instances heat and/or feedstock), and

[0165] a Control System to manage the overall processes in an integrated manner.

[0166] The effectiveness of the overall processes of the facility is determined, in part, by the amount of products produced relative to the amount of reactants consumed. One skilled in the art would appreciate that the amount, quality, availability, etc. of the energy required for each of the above processes is taking place wherein the overall system needs to be coordinated with the systems that supply these energy resources. Thus, the systems and the processes need to be integrated for the overall efficiency and effectiveness of unconventional oil processing.

[0167] In particular, this facility provides a means to gasify one or more fossil fuels in an efficient manner, converting it into intermediate products such as heat, steam and electricity. These intermediate products are then used by the facility to obtain useful fuel products from unconventional oil sources such as tar sands and oil shale and/or to provide energy to the Gasification System or Gas Reformation System. The design of this facility is optimized such that the overall costs are competitive with an equivalent unconventional oil source processing facility that uses natural gas as a source of processing energy.

[0168] This invention can be used on its own or may be used in conjunction with an existing facility that uses natural gas as an energy source in order to improve the overall cost effectiveness of the processing and/or reduce the requirement for other energy sources, such as natural gas. One embodiment of the facility of this invention may also optionally use natural gas to supplement the energy source required to obtain useful fuel products from unconventional oil sources. One skilled in the art would appreciate how to use natural gas to appropriately supplement the processes within the facility of this invention.

[0169] This facility uses one or more fossil fuels as a primary feedstock, such as coal, products from the unconventional oil source, such as oil shale, kerogen, heavy oils or bitumen, or by-products from the processing of the unconventional oil source, such as petroleum coke (pet coke), kerogen coke, and the like. By using feedstock that is locally available, the system can decrease overall operating costs in a number of ways. For example, decreased reliance on shipped-in energy sources, including natural gas, can reduce overall operating costs as well as providing valuable “carbon credits” in certain countries, in addition to decreasing the facility’s environmental impact.

[0170] As described in more detail below, the facility comprises integrated systems designed for the optimized conversion of a carbonaceous feedstock into intermediate products that are then used within the facility to obtain useful fuel products from unconventional oil sources such as tar sands and oil shale or to assist the feedstock conversion process. A particularly important intermediate is reformulated synthesis gas (syngas) having a defined chemical composition that can be effectively used, for example, as a combustion fuel in the oil source processing. Reformulated syngas can also be used to generate electricity, for example, by combustin it as a fuel, by reducing the pressure of the syngas in turbines, using the temperature of the syngas to make steam to drive turbines, or can be used to drive steam generators to generate steam required in the steam-assisted extraction of unconventional oil sources. Alternatively, hydrogen in the reformulated syngas may be used in the oil upgrading process.

[0171] Optimized conversion will be defined by the overall requirements for the facility. For example, optimized conversion will in some embodiments represent the least cost effective or energy efficient process to provide a syngas having a composition that meets a minimal threshold for its intended application. In other embodiments, optimized conversion will represent the process that produces the highest amount of syngas with a desired composition from a given amount of feedstock.

[0172] The facility is able to optimize conversion within each process by staging out the conversion process within a system and allowing the overall effectiveness of each stage to be maximized, as necessary. In one embodiment, maximizing overall effectiveness of each stage of the conversion process enables this facility to be used in a commercially viable manner as a source of energy and/or reagents that can be utilized in obtaining useful fuel products from the unconventional oil source. The energy conversion ratio reflects the true “overall balance sheet” for a facility evaluating the value of the products produced by the facility relative to the costs of building and operating the facility.

[0173] In general the facility is designed to stage out the conversion processes in a manner that enables the potential for optimizing the effectiveness of the dominant processes at each stage as appropriate to enhance the overall effectiveness of the facility. For example, the facility is designed to minimize the amount of energy required to be input to the facility, for instance by using recycled heat to drive the gasification process. In addition, this facility incorporates process manipulators designed to optimize the transference of energy (endothermic and exothermic) throughout the conversion processes to enhance the effectiveness of the dominant process at each stage throughout the conversion of carbonaceous feedstock into slag and reformulated syngas. The design strategies embodied by the process manipulators function to: minimize the amount of input-energy required for driving the conversion processes; facilitate the speed and thoroughness of the conversion processes; and maximize the thoroughness of the processes.

[0174] Accordingly, in one embodiment, the facility provided by this invention is an integrated system comprising staged processing. Process Manipulators and a Control System designed to optimize the Energy Conversion Ratio, i.e., the “Output-Energy” relative to the “Input-Energy.”
In the broadest sense the term, “Input-Energy,” is used to denote the factors that are present to make the reaction possible, or are supplied to the reaction to make it more efficient. Input-Energy is conceptualized in the broadest sense to mean any source of input required for the facility (for example, carbonaceous feedstock, electricity, labor, air, steam, facility operating costs, land costs, building costs etc.) that has a cost associated with it. For example, coal, which is generally purchased has a cost associated with it, whereas by-products of the unconventional oil source processing are readily available on site and thus have a lower associated cost.

In the broadest sense the term, “Output-Energy,” is used to denote all of the products of the facility, which are either useful in their immediate form (such as syngas, or heat that is recycled and used to fuel the gasification reaction or reclaimed for downstream processes) or can be converted into another form of energy (such as heat used to drive a steam engine, gas which can be combusted in an electricity producing engine, or hydrogen which can be used to energize a fuel cell). Any process where heat is generated is a source of product energy. During the gasification reactions, a large quantity of heat is generated, which immediately drives the gasification reaction within the gasifier. Heat which is extracted from the gas leaving the gasifier can also be directed back into the gasifier to fuel the gasification reaction. Alternatively, excess heat produced by the system can be harnessed and used in downstream processes to facilitate the extraction and/or processing of the unconventional oil source. Moreover, “carbon credits” can be viewed as a product of this system.

DEFINITIONS

Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs.

The terms “carbonaceous feedstock” and “feedstock”, as used interchangeably herein, are defined to refer to carbonaceous material that can be used in the Gasification System. Examples of suitable feedstock include, but are not limited to, fossil fuel based feedstocks, such as bitumen, coal, oil shale, kerogen, coke (including petroleum coke or “pet coke” and kerogen coke) and heavy oils, as well as other carbonaceous feedstocks, such as biomass, hazardous and non-hazardous waste materials, including municipal solid waste (MSW); wastes produced by industrial activity; biomedical wastes; carbonaceous material inappropriate for recycling, including non-recyclable plastics; sewage sludge; heavy refinery residuals; refinery wastes; hydrocarbon contaminated solids; agricultural wastes; and any mixture thereof. The feedstock may be provided as a mixture of two or more of the above feedstocks in various relative proportions.

“Coal” refers to coal of any grade or rank. This can include, but is not limited to, low grade, high sulfur coal that is not suitable for use in coal-fired power generators due to the production of emissions having high sulfur content.

The term “unconventional oil source” as used herein refers to any natural source of oil or fuel product that is more difficult (for example, requires more energy input) to extract than conventional or “light” oil. One skilled in the art will appreciate that a variety of unconventional oil sources are known, although not all are being commercially exploited. However, with the increasing demand for fuel products, commercial exploitation of previously unconsidered oil sources may be initiated in the near future. As this invention provides a means for facilitating the commercial viability of extraction of fuel products from unconventional oil sources, it is envisioned that the invention will also be used in the future exploitation of these unconventional oil sources. Currently exploited unconventional oil sources include, but are not limited to, heavy oils, tar sands, and oil shale.

The term “tar sands” or “oil sands” as used herein refers to a naturally occurring mixture of sand or clay, water and extra heavy crude oil or bitumen.

“Biomass” refers to any material of organic origin, including, but not limited to, pulp and paper waste, wood products such as shredded bark, wood chips or sawdust, sewage and sewage sludge, food waste, plant matter, rice straw, agricultural and animal waste, such as manure, cellulose type industrial waste (e.g., construction waste), waste wood, fresh wood, remains from fruit, vegetable and grain processing, and grass.

“Primary feedstock” refers to the main carbonaceous feedstock that undergoes gasification in the present system. Where only one feedstock is being gasified, it is referred to as the primary feedstock. Where more than one feedstock is being gasified, the feedstock that constitutes the major proportion of the combined feedstocks is the primary feedstock. In accordance with one embodiment of the invention, the primary feedstock is a fossil fuel based feedstock.

“Secondary feedstock” refers to an auxiliary carbonaceous feedstock that undergoes gasification with the primary feedstock and that is different from the primary feedstock. The secondary feedstock may be provided as a process additive to adjust the carbon content of the primary feedstock being gasified. One example could be the use of a carbon-rich source such as plastics or tires to augment a carbon-poor primary feedstock. Another example could be the use of biomass to attenuate a carbon-rich coal feedstock.

“Processed feedstock” or “processed feedstock/char” may include one or more of char, low and ultra-low volatile feedstocks with fixed carbon and ash components, the by-products of a carbonaceous feedstock gasification or pyrolysis process, products obtained from the incomplete conversion of carbonaceous feedstock, or the solids collected in gas conditioning and/or cleanup systems with the heat source inputs from plasma processes.

The term, “reactive species,” refers to energetic species formed throughout the reformulation process. Non-limiting examples include free electrons generated by an energy source such as plasma, or radicals or dissociated intermediates (induced intermediates) that are created in the off-gas (e.g., syngas) that transfer energy to other molecules and/or dissociated intermediates/fragments of the preformulated gas (“preformulated molecules”) enabling them to reformulate into a chemical composition of designed specifications. One skilled in the art appreciates that as the energy transference process continues, some of the preformulated molecules will in turn become reactive species, transferring their acquired energy to other molecules in the gas reformulating zone.

The term, “off-gas,” refers to the gas that comes off the feedstock throughout the process of converting it to slag.

The term, “partially processed off-gas,” refers to the off-gas that has been somehow processed due to the conditions, such as intense heat or reactive species, produced in a Gasification System such as a plasma melting system, designed for the destruction of waste and conversion into gas.
and slag. Such processing can include exposure of the raw off-gas to plasma or other energy sources.

The term, “initial gas,” refers to the gas to be reformulated into a chemical composition designed for one or more downstream applications. It includes off-gas and/or partially processed off-gas.

The term, “preformulated gas,” is used to denote gas as it enters a gas reformulating zone. This gas comprises the initial gas in addition to any optional process additives that might have been added to adjust the chemical composition of the gas prior to reformulating it into a designed chemical composition. In some embodiments, it might be just the off-gas. In some embodiments, it might include process additives. For example, if the gas requires increased levels of hydrogen, steam may be added as a process additive upstream of a gas reformulation zone, such that the reformulating gas will contain sufficient amounts of hydrogen species to provide for the proper chemical composition of the final reformulated gas product. If no optional process additives have been added “preformulated gas” has the same composition as “initial gas.”

The term, “reformulated gas,” refers to the gas that exits the gas reformulation system.

The term, “Gas Reformulation Ratio,” is used to describe the amount of gas that is reformulated relative to the amount of gas that is input into the gas reformulation system. It can be described by the formula:

\[
\frac{\text{Amount of Reformulated Gas}}{\text{Amount of Preformulated Gas}} \times 100 = \% \text{ of gas reformulated}
\]

Alternatively, and especially if no process additive gases are used, it can be described by the formula:

\[
\frac{\text{Amount of Reformulated Gas}}{\text{Amount of Initial Gas}} \times 100 = \% \text{ of gas reformulated}
\]

The Gas Reformulation Ratio can be assessed directly or indirectly. Indirect assessment of the gas reformulation ratio can be made by comparing downstream energy production of reformulated gas and preformulated gas. Downstream energy production is reflective of percent gas reformulated. An increase in downstream energy production is indicative of increased percent gas reformulated.

The term, “Gas Manipulators,” denotes the features incorporated into the Gas Reformulation System that function to facilitate the process of gas reformulation.

The terms ‘carbonaceous feedstock’ and ‘feedstock’, as used interchangeably herein, are defined to refer to carbonaceous material that can be used in the gasification process. Examples of suitable feedstock include, but are not limited to, hazardous and non-hazardous waste materials, including municipal wastes; wastes produced by industrial activity; biomedical wastes; carbonaceous material inappropriate for recycling, including non-recyclable plastics; sewage sludge; coal; heavy oils; petroleum coke; bitumen; heavy refinery residuals; refinery wastes; hydrocarbon contaminated solids; biomass; agricultural wastes; municipal solid waste; hazardous waste and industrial waste. Examples of biomass useful for gasification include, but are not limited to, waste wood; fresh wood; remains from fruit, vegetable and grain processing; paper mill residues; straw; grass, and manure.

The term, “gas energizing sources,” refers to any source of energy known to one skilled in the art that could be used to impart energy to the preformulated gas, enabling it to reformulate into gas of a defined composition. Examples include, without limitation, plasma generating sources, radiation sources, hydrogen burners, electron beam guns, etc.

The term, “gas energizing field,” is used to denote the field effect produced by one or more of the gas energizing sources used within the Gas Reformulation System to provide the energy to the gas that is required for the reformulation process to occur. For example, the gas energizing field that is created by an energy source such as a plasma torch will exhibit a three-dimensional space that will vary with torch power, working gas composition, torch position, torch orientation, etc.

As used herein, the term “sensing element” is used in the broadest sense to describe the aspect of any element related to the facility that is configured to sense, detect, read, monitor, etc. one or more characteristics, parameters, and/or information of the system, inputs and/or outputs.

As used herein, the term “response element” is used to describe the aspect of any element related to the facility that is capable of responding to a signal.

As used herein, the term “about” refers to approximately a +/-10% variation from a given value. It is to be understood that such a variation is always included in any given value provided herein, whether or not it is specifically referred to.

The Gasification System and Gas Reformulation Systems

The gasification and gas reformulation systems of this invention provide for staging and optimizing the dominant process within each stage throughout the conversion of a carbonaceous feedstock into slag and reformulated gas of a desired composition.

Feedstocks suitable for gasification in the system include any carbon-containing (carbonaceous) material. Examples include, fossil fuel based materials, such as bitumen, coal, oil shale, kerogen, coke (including petroleum coke or “pet coke” and kerogen coke) and heavy oils, as well as other carbonaceous feedstocks, such as biomass, hazardous and non-hazardous waste materials, including municipal solid waste (MSW); wastes produced by industrial activity; biomedical wastes; carbonaceous material inappropriate for recycling, including non-recyclable plastics; sewage sludge; heavy refinery residuals; refinery wastes; hydrocarbon contaminated solids; agricultural wastes; and any mixture thereof.

As is also known in the art, combinations of feedstock can be used in order to vary the composition and quality of the syngas generated, or depending on the downstream use of the syngas generated. The feedstock may be provided as a mixture of two or more of the above feedstocks in various relative proportions. In one embodiment of the invention, the primary feedstock comprises fossil fuel based materials. In one embodiment, the primary feedstock comprises products from the unconventional oil source being processed, such as oil shale, kerogen, heavy oils or bitumen, or by-products from the processing of the unconventional oil source, such as petroleum coke (pet coke), kerogen coke, and the like. The primary feedstock can be a combination of fossil fuel based materials.
In one embodiment, the primary feedstock is a combination of coal and one or more products from the unconventional oil source or by-products from the processing of the unconventional oil source.

[0205] In one embodiment, the Gasification System uses bitumen as a feedstock. In another embodiment, the Gasification System used bitumen in combination with additional feedstocks. In yet another embodiment, the Gasification System uses a heavy fraction of the product resulting from the distillation of bitumen and tars. In another embodiment, the Gasification System uses coke as a feedstock. In still another embodiment, the Gasification System uses coal as a feedstock. In another embodiment, the Gasification System uses a combination of bitumen, coke, and coal as a feedstock.

[0206] The present system can also be adapted to gasify a mixture of primary and secondary feedstocks in any proportion as may be desired. The secondary feedstock functions as a process additive to adjust the carbon content of the primary feedstock in order to modulate the carbon content to maintain a consistency in the final gas output. For example, where a high carbon feedstock (such as coal or other fossil fuel based material) is the primary gasification feedstock, it is contemplated that a lower carbon secondary feedstock (such as biomass or MSW) can be provided to offset the high carbon content as may be required.

[0207] When two or more feedstocks are used, they may be combined prior to their introduction into the Gasification System and then introduced through a common feedstock inlet, or they may each be introduced separately through dedicated individual inlets.

[0208] Coal of varying grades can be employed as a feedstock in the Gasification System, including low grade, high sulfur coal which is not suitable for use in coal-fired power generators due to the production of emissions having high sulfur content. Waste coal particles and silt that remains after coal has been mined, sorted and washed may also be useful for gasification.

[0209] Examples of biomass useful for gasification include, but are not limited to, waste or fresh wood, remains from fruit, vegetable and grain processing, paper mill residues, straw, grass, and manure.

[0210] In another embodiment of the invention the feedstock depending on its nature and to increase efficiencies and achieve desired syngas and energy outputs can be pretreated, for example, to reduce its volume overall or increase its surface area to volume ratio by shredding, pulverizing, or shearing. Alternatively, the feedstock can be preheated, or dried, etc.

[0211] As will be evident to one of skill in the art, the choice of feedstock to be used in the system can vary depending on the type of energy to be generated with the system. For example, if hydrogen is being produced by the energy-producing component, then a feedstock that has hydrogen content can be used. However, as is also known in the art, in such a circumstance it is possible to use feedstocks containing less hydrogen, but adding steam/water to the gasifier as the hydrogen source. In one embodiment, the desired quality of the end product determines the choice of feedstock to be used, i.e. if a higher quality end product is required, then a higher quality feedstock should be used.

Coal

[0212] In one embodiment, coal can be used as feedstock. In such a process, the coal is first pulverised to a size which provides the necessary rapid reaction. Generally, the coal should be of a particle size of 0.75 inches or smaller. Suitable examples of particle size include particle sizes of 30 mesh, or -100 mesh or the size recognised in the coal industry as “Buckwheat No. 1”. The pulverised coal may optionally be fed through a pre-heater where it is heated to a temperature in excess of about 100°C before being fed to the gasifier. Such pre-heated pulverised coal is fed to the gasifier via heated coal line.

[0213] In one embodiment of the invention, and dependent on the coal composition, such pulverised coal may be fed continuously into the gasifier at a rate of, e.g., 2.2 lb coal/min, which is correlated to the feeding of steam at a rate of, e.g., 0.5 lb/min.

[0214] There are several different types of coal, each displaying different properties resulting from geological history. The degree of coal development is referred to as coal’s “rank.” Peat is the layer of vegetable material directly underlying the growing zone of a coal-forming environment. The vegetable material shows very little alteration and contains the roots of living plants. Lignite is geologically very young (less than 40,000 years). It can be soft, fibrous and contains large amounts of moisture (typically around 70%) and has a low energy content (8-10 MJ/kg). Black coal ranges from 65-105 million years old to up to 260 million years old. These are harder, shinier, less than 3% moisture and can have energy contents up to about 24-28 MJ/kg. Anthracite contains virtually no moisture and very low volatile content, so it burns with little or no smoke. It can have energy contents up to about 32 MJ/kg.

Municipal Solid Waste

[0215] In one embodiment, municipal waste can be used as a secondary feedstock for the gasification process. Municipal waste may be provided in solid or liquid form. For the gasification of solid wastes, the waste is introduced to the gasifier through a solid waste inlet feed port. The gasifier may also be designed to optionally include liquid waste feed inlet ports for the processing of liquid waste.

[0216] There are multiple stages to these conversion processes, which include, but are not limited to:

[0217] Drying of the Material: This stage of the gasification process is drying. The normal temperature range for this process lies between about 25 and 900°C. Drying predominantly occurs at the top and in middle of a pile of material and at a temperature above about 100°C. As water leaves the material in the form of steam, one embodiment removes the water from the system in order to facilitate the energetics of the downstream processes.

[0218] Primary Volatilization of the Material: This stage of this conversion process is volatilization, which occurs mainly between about 400 and 950°C. The dominant process being driven in this stage is the conversion of solid carbonaceous material into gaseous molecules.

[0219] Char-to-Ash Conversion: This stage of the conversion process is that of carbon conversion with a lesser amount (the remainder) of volatilization. The temperature range lies between about 500 and 1600°C. Although, in one embodiment in order to avoid agglomeration of the ash, the maximum temperature in this region generally does not exceed about 950°C.
[0220] Ash Melting and Vitrification: This stage uses intense heat to melt the ash, comprising mostly inorganic material into molten slag (which can then cool into an obsidian-like glassy substance).

[0221] Gas Reformulation Process: This stage uses one or more energy sources to initiate the process of reformulation of a gas by initiating the dissociation of molecules into reactive dissociation fragments (intermediates). The reformulation of gas entails at least four chemical processes throughout the reformulation of a gas including: 1) initiation of the intermediates; 2) propagation of at least a portion of the intermediates; 3) termination of the intermediates; and 4) product gas stabilization.

[0222] The conversion process of the material at each stage requires unique chemical and/or thermal conditions and has been categorized accordingly.

[0223] The facility comprises multiple zones for the conversion of feedstock to slag and reformulated offgases. The facility comprises direct or indirect process additive capabilities in order to adjust the chemistry of the reactant materials throughout the process. The facility also comprises a Control System to monitor and regulate the different stages of the process to ensure the efficient and complete or substantially complete conversion of the carbonaceous feedstock into reformulated syngas.

[0224] The Control System also provides for the production of a reformulated syngas product having a consistent and/or specified composition. The Control System comprises one or more sensing elements for monitoring and obtaining data regarding operating parameters within the facility, and one or more response elements for adjusting operating conditions within the facility. The sensing elements and the response elements are integrated with the facility, and the response elements adjust the operating conditions within the facility according to data obtained from the sensing elements in addition to other information and/or instructions that may be provided to the Control System.

[0225] This facility comprises system designs wherein zones are created to optimize the dominant process at each stage of the conversion process. In one embodiment each zone exists within a separate chamber. In another embodiment, one or more zones are combined within a single chamber. In embodiments in which one or more zones are combined within a single chamber, the single chamber may be segmented into a finite number of regions by one or more physical barriers or impediments or the chamber may be shaped to provide distinct zones or regions. For example, the chamber may be shaped to provide separate regions or may comprise one or more baffles placed to segregate the individual zones.

[0226] In multi-chamber embodiments, the chambers may be oriented horizontally, vertically or some combination thereof. In one embodiment of the invention, the facility comprises five interconnected chambers with the first processing chamber having a feedstock input and at least partially favouring drying, the second processing chamber receiving processed feedstock from the first chamber and at least partially favouring volatilization, the third processing chamber receiving char from the second chamber and at least partially favouring carbon conversion and the fourth processing chamber receiving residual solid material and at least partially favouring ash melting and vitrification. Off-gas produced in these processing chambers is reformulated within a fifth processing chamber, the reformulating chamber.

[0227] In one embodiment, the first three stages are substantially completed housed within a zonally segregated chamber that is operatively associated with separate chambers specifically adapted for Ash Melting and Vitrification and Gas Reformation Process stages. In one embodiment, the first three stages and the Gas Reformation Process stages are substantially completed housed within a zonally segregated chamber that is operatively associated with a separate Ash Melting and Vitrification chamber.

[0228] The facility of this invention provides a Gasification System that can be integrated with one or more energy producing components for producing energy or reagents required for processing material from tar sands or oil sands. In its simplest form, the Gasification System comprises a gasifier, a gas reformulating zone and a melting chamber. The system can optionally also include one or more heat recovery subsystems and/or a gas quality conditioning system (GQCS). Additional optional components such as a cooler and tar separator, a second gas reformulating zone, a gas regulating system, or a gas storage system can be added to the Gasification System depending on the feedstock to be consumed and/or the energy or reagents to be produced. The energy or reagents can be, for example, in the form of steam, electricity, heat, light oils, hydrogen, CO₂ or slag.

Process Manipulators

[0229] As described above the facility system incorporates process manipulators designed to optimize the transference of energy (endothermic and exothermic) throughout the conversion processes to enhance the effectiveness of the dominant process at each stage throughout the conversion of carbonaceous feedstock into slag and reformulated syngas. The design strategies embodied by the process manipulators function to: minimize the amount of input-energy required for driving the conversion processes; facilitate the speed and thoroughness of the conversion processes; and maximize the thoroughness of the processes. The types of process manipulators that may be incorporated into each stage of the system are described in more detail below.

The Gasification System—Material Drying Stage

The Dominant Process

[0230] The dominant process in this Stage is drying the carbonaceous feedstock which occurs predominantly at the top and in middle of the pile of material and at a temperature above about 100°C. The normal temperature range for a zone or region which favours the Material Drying Stage (as measured at the bottom of the material pile) lies between about 100 and 900°C. In one embodiment, the temperature range is 100 to 900°C. In another embodiment, the temperature range is 100 to 300°C. In a further embodiment, the temperature range is about 200°C.

The Energy Sources

[0231] In one embodiment, the zone or chamber which favours the Material Drying Stage utilizes low quality heat as the energy source, such as preheated air. In one embodiment, the source of heat is a source of recycled heat. In one embodiment, the air used in the Material Drying Stage is pre-heated through heat exchange with sensible heat from the syngas prior to introduction to the zone or chamber that favours this
Stage. Accordingly, the zone or chamber that favours the Material Drying Stage can further optionally include one or more inlets for recycled heat. In one embodiment, there is an inlet for recycled heat in the floor of the zone or chamber that favours the Material Drying Stage. Optionally, air can be specifically supplied to this stage by the use of independently controlled airboxes and/or air nozzles.

The Process Manipulators

[0232] Design strategies can be utilized to optimize the drying of the material in a fast and economical manner, for example, by using preheated air that has been pre-heated through heat exchange with sensible heat from the syngas.

[0233] Drying may also be optimized by evaporating the resulting steam from the zone or chamber which favors the Material Drying Stage. Accordingly, this zone or chamber which favors the Material Drying Stage can optionally be equipped with a system to remove moisture and thereby facilitate drying. A worker skilled in the art could readily determine appropriate systems to remove moisture. For example, the system to remove moisture may include one or more steam outlets that allow for the evacuation of steam. A worker skilled in the art could readily determine an appropriate location for the one or more steam outlets. In one embodiment, the zone or chamber which favors the Material Drying Stage comprises one steam outlet in the roof. The one or more steam outlets may vent to the external environment, or the steam may be further processed or recycled back into one or more of the gasification process or other downstream processes. Optionally, the drying of the feedstock (i.e., removal moisture) may be accomplished by the directed application of heat to the feedstock. Optionally, the source of heat may be a source of dry heat.

[0234] Design strategies which control the movement and height of the pile of feedstock may further be utilized to optimize the drying of the feedstock. For example, one or more physical barriers may be strategically placed in the zone or chamber which favors the Material Drying Stage to limit the movement of unprocessed material or to limit the movement of the material pile. In one embodiment, a baffle extends from the roof of the zone or chamber that favors the Material Drying Stage. In addition, the shape of the chamber or zone that favors the Material Drying Stage may facilitate the movement of feedstock and thereby optimize the process. For example, the movement of the material may be facilitated by the slope of the floor of the zone or chamber which favors the Material Drying Stage. Movement may also be actively controlled by an active conveyance means.

[0235] Following the removal of the majority of moisture, the processed feedstock is subsequently directed to a zone or chamber which favors the Volatilization Stage of the material by passive conveyance (e.g., by gravity), or by active conveyance means.

The Gasification System—Volatilization Stage

The Dominant Process

[0236] The dominant process in this Stage is volatilization of volatile components in the carbonaceous feedstock. The normal temperature range for a zone or region which favors the Volatilization Stage (as measured at the bottom of the material pile) is about 350° to 950° C. In one embodiment, the temperature range is about 400° to about 950° C. In another embodiment, the temperature range is about 600° to about 900° C. In a further embodiment, the temperature is about 850° C.

The Energy Sources

[0237] In one embodiment, the zone or chamber which favors the Volatilization Stage utilizes low quality heat as the energy source, such as preheated air. In one embodiment, the source of heat is a source of recycled heat. In one embodiment, the air used in this Stage is pre-heated through heat exchange with sensible heat from the syngas prior to introduction to the zone or chamber that favors the Volatilization Stage. Accordingly, the zone or chamber that favors the Volatilization Stage can further optionally include one or more inlets for recycled heat. In one embodiment, there is an inlet for recycled heat in the floor of the zone or chamber that favors Volatilization Stage. Optionally, air can be specifically supplied to this stage by the use of independently controlled airboxes and/or air nozzles.

The Process Manipulators

[0238] Design strategies can be utilized to optimize the volatilization of the volatile components in the carbonaceous feedstock in a fast and economical manner, for example, by using preheated air that has been pre-heated through heat exchange with sensible heat from the syngas.

[0239] Design strategies which control the movement and height of the pile of processed feedstock may further be utilized to optimize the volatilization of the volatile components. For example, one or more physical barriers may be strategically placed in the zone or chamber which favors the Volatilization Stage to limit the movement of unprocessed material or to limit the movement of the material pile. The zone or chamber may also be shaped to control the movement of the material pile. In one embodiment, a baffle extends from the roof of the zone or chamber that favors the Volatilization Stage. In addition, the shape of the chamber or zone that favors the Volatilization Stage may facilitate the movement of feedstock and thereby optimize the process. For example, the movement of the material may be facilitated by the slope of the floor of the zone or chamber which favors the Volatilization Stage. Movement may also be actively controlled by an active conveyance means.

[0240] The remaining processed feedstock/char (with the majority of moisture and volatiles removed) is subsequently directed to the zone or chamber which favors the volatilization by passive conveyance (e.g., by gravity), or by active conveyance means.

[0241] The composition of air supplied in this region is typically varied depending on the feedstock supplied (e.g., oxygen enriched or depleted air).

[0242] Process manipulators in the Material Drying and Volatilization Stages can also be embodied in the design of the chamber or chambers in which the Stages take place. In one embodiment, the two Stages are combined in a single chamber referred to as a Primary Chamber. The main function of the primary chamber is to dry the feedstock and to volatilize the volatile components in the carbonaceous feedstock.

[0243] Optionally, the primary chamber may be segregated into a finite number of regions by one or more physical barriers. For example, the primary chamber may be shaped to provide separate zones for the Material Drying Stage and the Volatilization Stage or may comprise one or more baffles. In
one embodiment, the baffle is strategically placed to limit the movement of unprocessed material or to limit the movement of the material pile.

[0244] The primary chamber is therefore used to drive off all the moisture and volatiles from the feed stream at relatively low processing temperatures in a fast and economical manner by using low quality heat such as preheated air.

[0245] In one embodiment, the air used in this step is preheated through heat exchange with sensible heat from the syngas prior to introduction to the chamber. The remaining processed feedstock/char (with the majority of moisture and volatiles removed) is subsequently directed to the secondary chamber by passive conveyance (e.g., by gravity). Or by active conveyance means that allow for the controlled movement of the material to the next Stage of the process.

[0246] In one embodiment of the invention, the primary chamber is a chamber having a feedstock inlet through which a primary feedstock to be gasified is introduced. In one embodiment a secondary additive feedstock is combined with the primary feedstock prior to its entry into the primary chamber. In one embodiment, the secondary additive feedstock is input into the primary chamber through a secondary feedstock inlet.

[0247] To limit the introduction of air, the feedstock inlet(s) may comprise a series of airlocks. Accordingly, in one embodiment, one or more feedstock inlets comprise one or more airlocks. Optionally, the airlock system can include a means to remove air. Appropriate means are known in the art and include a vacuum.

[0248] The primary chamber also includes heated air inlets for the introduction of the heated air required to drive the drying and Volatilization Stages, a first chamber gas outlet through which the gases produced in the primary chamber are passed to the secondary chamber, exit, and a residue/processed feedstock/char outlet through which the resulting residue/processed feedstock/char product is passed out of the primary chamber prior to being passed into a secondary chamber. The gases produced in the primary chamber (referred to as the first chamber gas product) include the volatilized constituents of the feedstock, water vapour where the feedstock contained moisture, and gaseous products of a small amount of carbon conversion.

[0249] The present system can also be adapted to gasify a mixture of feedstocks in any proportion as may be desired. In one embodiment, the mixture of feedstocks is a combination of primary and secondary feedstocks. In one embodiment, the secondary feedstock is provided as a process additive to adjust the carbon content of the primary feedstock being gasified. For example, a lower carbon secondary feedstock can be used to decrease the proportion of carbon in a high carbon primary feedstock, such as coal, bitumen, kerogen, coke and the like, if required.

[0250] In one embodiment, where primary and secondary feedstocks are being gasified, the two feedstocks are combined prior to their introduction into the primary chamber through a common feedstock inlet.

[0251] In one embodiment, where primary and secondary feedstocks are being gasified, each of the feedstocks is introduced separately to the primary chamber through dedicated primary and secondary feedstock inlets.

[0252] In one embodiment, where a mixture of two different feedstocks undergoes gasification, the two feedstocks are fed into the primary chamber in alternation.

[0253] In one embodiment, where two feedstocks are being gasified, each feedstock undergoes the initial Volatilization Stage separately, in respective primary chambers, and their respective processed feedstock/char products are combined in a common secondary chamber for conversion to a gaseous product and ash.

[0254] In one embodiment, the system comprises a material feeder subsystem adapted to the physical characteristics of the input feedstock in association with the feedstock inlet of the primary chamber. For example, augers, rams, feedhoppers, rotary valves, or top gravity feeds are feeder systems that can be incorporated into the system to facilitate the introduction of the feedstock.

[0255] In one embodiment of the invention, the material feeder subsystem comprises an auger which feeds directly into the primary chamber feedstock inlet to provide a granular feed.

[0256] In one embodiment of the invention, the material feeder subsystem attached to the primary chamber may consist of a rectangular feedhopper and a hydraulic assisted ram. Limit switches on the feeder control the length of the ram stroke so that the amount of feedstock fed into the chamber with each stroke can be controlled.

[0257] A pre-conditioning process for conditioning the feedstock in the feed system may also be utilized prior to being fed to the first chamber. In one embodiment, the feedstock is prepared in order to control the particle size before feeding into the primary chamber. In one embodiment, the feedstock undergoes a pre-drying step to remove excessive moisture before feeding into the primary chamber.

[0258] In accordance with the present invention, heated air inputs provide the heat required for the drying and volatilization processes. Accordingly, the heated air inlets are located throughout the primary chamber at locations suitable for optimum exposure of the feedstock to the heated air to ensure sufficient heating of the feedstock to dry it and volatilize the volatile constituents. In one embodiment, the heated air inlets are located in the walls of the chamber proximal to the base, to ensure that the hot air is passed into and over the pile of material for optimum exposure. In one embodiment, the heated air inlets are located in the floor of the chamber, so that the hot air is carried up through the pile of material to ensure penetration into and through the pile of material. In one embodiment, the heated air inlets are located in the walls and floor of the chamber.

[0259] In one embodiment, the heated air used to drive the processes is preheated in a heat exchanger using sensible heat recovered from the hot syngas products of the carbonaceous feedstock gasification.

[0260] In order to facilitate initial start up of the Gasification System, the chamber can include access ports sized to accommodate various conventional burners, for example natural gas or propane burners, to pre-heat the chamber.

[0261] The primary chamber can be of any shape and dimension suitable for Stage I and II of the conversion process.

[0262] In one embodiment, the primary chamber is a vertically oriented chamber having a feedstock inlet located near the top and a processed feedstock/char outlet located near the bottom. In such an embodiment, the feedstock enters from the top and accumulates in a pile while being heated with hot air to drive the drying and volatilization processes. As the moisture and volatiles are driven off, the feedstock is gradually converted to char. The resulting processed feedstock/char is passed, actively or passively, out through the processed feed-
stock/char outlet located at the bottom of the primary chamber and into the secondary chamber.

[0263] In one embodiment, the pile of feedstock/char by action of the heated air with no mechanical mixing or active movement of the solids through the chamber, and the processed feedstock/char product is allowed to passively drop from the primary chamber to the secondary chamber through an opening between the two chambers.

[0264] In one embodiment, the bottom of the chamber gradually slopes downward toward the processed feedstock/char outlet, whereby the material is passively drawn by gravity toward the processed feedstock/char outlet.

[0265] In one embodiment, the feedstock undergoes a mechanical mixing by a mechanism such as rotating paddles, rotating wheels or rotating arms, which rotate horizontally to ensure exposure to the heated air. Such mixing means can also serve to actively convey the processed feedstock/char product towards the processed feedstock/char outlet in a controllable manner.

[0266] Controlling the movement of the processed feedstock/char towards the processed feedstock/char outlet and out of the primary chamber enables the optimization of residence time in the chamber to ensure that moisture and volatiles are removed from the feedstock prior to being passed into the secondary chamber. The rate of movement of material out of the primary chamber and into the secondary chamber is regulated by the use of a controllable solids removal means. The solids removal means can be one of a variety of devices known in the art. Examples include, but are not limited to, screws, pusher rams, horizontal rotating paddles, horizontal rotating arms, and horizontal rotating wheels.

[0267] In one embodiment, the solids removal device is a rotating paddle with thin spokes which moves the processed feedstock/char toward the processed feedstock/char outlet and out of the chamber. FIG. 2A depicts one embodiment of the screw removal device comprises a rotating paddle 81 at the bottom of the primary chamber 20 which moves the processed feedstock/char out of the chamber 20 through a small processed feedstock/char outlet 70. To avoid the passage of partially processed feedstock/char through the processed feedstock/char outlet 70 by a direct drop, a barrier 82 is placed over the processed feedstock/char outlet 70. Limit switches may be optionally used to control the speed of the bar rotation and thus the rate of removal of residue. FIG. 2B is a top view of the rotating arm solids removal device depicted in FIG. 3, showing the relationship between the barrier 82 and the processed feedstock/processed feedstock/char outlet 70.

[0268] In one embodiment, the solids removal device is a set of screws which move the out of the chamber. In such an embodiment, the bottom portions of the chamber walls are optionally made to slant towards the screws at the bottom of the chamber, so that the processed feedstock/processed feedstock/char may be directed towards the screws. FIG. 3 depicts one embodiment of the screw removal device comprises a set of extractor screws 83 at the bottom of the primary chamber 20 which moves the processed feedstock/char outlet of the chamber 20. Optional serration on the edge of the extractor screw flight helps in the breaking up of agglomerations that could otherwise result in jamming at the processed feedstock/char outlet 70. A barrier 82 is provided to avoid the passage of partially processed processed feedstock/char through the processed feedstock/char outlet 70 by a direct drop. A barrier is not required if the residue outlet 70 is moved away from the processing chamber, as for the embodiment shown in FIG. 4. Limit switches may be optionally used to control the speed of the screws and thus the rate of removal of residue.

[0269] In one embodiment, the solids removal device is a single thin ram which moves the processed feedstock/char toward the processed feedstock/char outlet and out of the chamber. In such an embodiment, the bottom portion of the side opposite to the ram is made slanting so that the processed feedstock/char may be directed towards the ram leaving space for the exit hole. FIGS. 5 and 6 depict embodiments in which the solids removal device comprises a single thin pusher ram 85 for the primary chamber 20 which moves the processed feedstock/char out of the chamber 20 through a small processed feedstock/char outlet 70. Depending on the position of the processed feedstock/char outlet 70, a barrier 82 may or may not be required as shown in FIG. 7. Limit switches may be optionally used to control the length of the pusher ram stroke and thus the amount of processed feedstock/char moved with each stroke.

[0270] In one embodiment, the primary chamber is a horizontally oriented chamber having a feedstock inlet located at one end of the chamber, and a processed feedstock/char outlet located at an opposite end of the chamber. As the feedstock progresses from one end of the horizontal primary chamber to the other, it loses its moisture and volatile fraction to form the resulting processed feedstock/char product. In such an embodiment, the chamber optionally comprises one or more means for laterally transporting solid material through the chamber from the feedstock inlet end toward the processed feedstock/char outlet end. Controlled lateral movement of material through the primary chamber via the use of one or more lateral transfer units allows for the optimization of the Drying and Volatilization Stages of the gasification process that are carried out in the primary chamber, by controlling the residence time of the material at each Stage.

[0271] In one embodiment, the lateral transfer units are one or more pusher rams in which material is predominantly pushed through the primary chamber. In one embodiment, the lateral transfer units are moveable shelves/platforms onto which material is predominantly moved through the chamber by sitting on top of a shelf/platform; a fraction of material may also be pushed by the leading edge of the movable shelf/platform. Controlled lateral movement by the shelf/platform-type lateral transfer units can be accomplished by varying the movement speed, the distance each lateral transfer unit moves and the sequence in which the plurality of transfer units are moved in relation to each other. The one or more lateral transfer units can act in coordinated manner or individual lateral transfer units can act independently. In order to optimize control of the material movement and pile height, the individual lateral transfer units can be moved individually, at varying speeds, at varying movement distances, at varying frequency of movement.

[0272] FIG. 8A is a schematic depiction of a stepped floor horizontal primary chamber with arrows indicating the lateral movement of solids through the chamber. FIG. 8B is a schematic depiction of a sloped floor horizontal primary chamber with arrows indicating the lateral movement of solids through the chamber.

[0273] In embodiments where the primary chamber is substantially horizontal, the lateral transfer unit can include, but is not limited to, a shelf/platform, pusher ram or carrier rams,
plow, screw element, conveyor or a belt, moving grate or a roller grate. The rams can include a single ram or multiple-finger ram. The roller grate can, for example, be a Dusseldorfer grate.

[0274] In one embodiment where the primary chamber is substantially horizontal, the lateral transfer unit is a screw mechanism located along the bottom of the primary chamber, whereby the material is transferred laterally by rotation of one or more screws toward the processed feedstock/char outlet. Controlled lateral movement by the screw-type lateral transfer units can be accomplished by varying the screw rotation speed.

[0275] In one embodiment where the primary chamber is substantially horizontal, the lateral transfer system is a single ram or multiple-finger ram.

[0276] In one embodiment where the primary chamber is substantially horizontal, the lateral transfer system is a multiple-finger ram. In the multiple-finger ram designs, the multiple-finger ram may be a unitary structure or a structure in which the ram fingers are attached to a ram body, with individual ram fingers optionally being of different widths depending on location. The gap between the fingers in the multiple-finger ram design is selected to avoid particles of reactant material from bridging. In one embodiment, the individual fingers are about 2 to about 3 inches wide, about 0.5 to about 1 inch thick with a gap between about 0.5 to about 2 inches wide.

[0277] In one embodiment where the primary chamber is substantially horizontal, the lateral transfer system is “T-shaped”.

[0278] In one embodiment where the primary chamber is substantially horizontal, the lateral transfer system is a pusher that is shaped as a cylinder with a tapered end.

[0279] In one embodiment where the primary chamber is substantially horizontal, the lateral transfer system is a plurality of rollers with horizontal and parallel axes lie in an inclined plane. An example of a plurality of rollers is the Dusseldorfer/Bubecor grate. See, for example, U.S. Pat. Nos. 5,967,064 and U.S. Pat. No. 5,448,957.

[0280] In embodiments in which movement through the gasifier is facilitated by a system such as, similar to, or inspired by a Dusseldorfer Grate, hot air can optionally be added to the gasifier through a system of independently controlled air boxes that supply hot air to the rollers. In such a system, the rollers are hollow perforated cylinders through which the hot air enters the gasification chamber. The distribution of hot air to the rollers is dependent on the location of the rollers within the gasifier with the quantity of hot air being supplied to the individual rollers being optimized for the predominant process occurring at that location.

[0281] In certain embodiments in which the system operates at very high temperatures, cooling can optionally be provided for the lateral transfer system. In one embodiment using a ram or shelf, cooling within the ram or shelf can be provided. Such cooling could be by fluid (for example, air or water) circulated inside the ram or shelf from outside of the chamber. In one embodiment using a roller grate such as a Dusseldorfer grate, cooling within the roller and/or around each roller can be provided. Such cooling could be by fluid (for example, air or water) circulated inside each roller. In one embodiment, the flow of fluid to each roller may be separately controlled thereby allowing the temperature of each roller to be varied individually. Optionally, the rollers may be designed to facilitate the introduction of air.

[0282] In one embodiment where the primary chamber is substantially horizontal, the lateral transfer system is a plow which has folding arms which can be withdrawn when the plow is retracted.

[0283] In one embodiment where the primary chamber is substantially horizontal, the lateral transfer system is a belt or flighted chain conveyor.

[0284] In one embodiment where the primary chamber is substantially horizontal, the lateral transfer system is a movable shelf/platform in which material is predominantly moved through the gasifier by sitting on top of the shelf/platform. A fraction of material may also be pushed by the leading edge of the movable shelf/platform.

[0285] In one embodiment where the primary chamber is substantially horizontal, the lateral transfer system is a carrier ram in which material is predominantly moved through the gasifier by sitting on top of the carrier ram. A fraction of material may also be pushed by the leading edge of the carrier ram.

[0286] In one embodiment where the primary chamber is substantially horizontal, the lateral transfer system is a pusher ram in which material is predominantly pushed through the gasifier. Optionally, the ram height is substantially the same as the depth of the material to be moved.

[0287] In one embodiment where the primary chamber is substantially horizontal, the lateral transfer system is a combination of rollers and pushers. For example, in embodiments which have a combination stepped and sloped floor movement across the slope portion may be facilitated by a roller grate while movement across the stepped portion may be facilitated by pushers. In another embodiment, a pusher pushes the material onto the uppermost roller of the Roller Grate.

[0288] In one embodiment, the lateral transfer system can be a set of conveyor screws. Optionally, the conveyor screws can be set in the floor of the chamber thereby allowing material to be moved without interfering with air introduction.

[0289] Power to propel the lateral transfer system is provided by a motor and drive system and is controlled by actuators.

[0290] The individual lateral transfer units may optionally be powered by dedicated motor and have individual actuators or one or more lateral transfer units may be powered by a single motor and shared actuators.

[0291] Basically any controllable motor or mechanical turning device that can provide accurate control of the lateral transfer system can be used to propel the lateral transfer system. Appropriate motors and devices are known in the art and include electric motors, motors run on syngas, steam, gases, gasoline, diesel or micro turbines.

[0292] In one embodiment, the motor is an electric variable speed motor which drives a motor output shaft selectively in the forward or reverse directions. Optionally, a slip clutch could be provided between the motor and the motor output shaft. The motor may further comprise a gear box.

[0293] Movement of the lateral transfer system can be effected by a hydraulic system, hydraulic rams, chain and sprocket drive, or a rack and pinion drive. These methods of translating the motor rotary motion into linear motion have the advantage that they can be applied in a synchronized
manner at each side of a unit to assist in keeping the unit aligned and thus minimizing the possibility of the mechanism jamming.

A worker skilled in the art would readily appreciate that the lateral transfer units in addition to conveying the feedstock through the primary chamber, can also be configured to convey the processed feedstock/char product out of the processed feedstock/char outlet.

The Gasification System—Char-To-Ash Conversion Stage

The Dominant Process

The dominant process at this Stage is conversion of the char received from the Volatilization Stage to a gas product and ash and takes place in a Char-to-Ash Conversion Stage zone or chamber. The normal temperature range lies between about 500 and 1000° C. Although in one embodiment, temperatures higher than 1000° C. may be employed depending on the material's ash fusion temperature. In one embodiment in order to avoid agglomeration of the ash, the maximum temperature in this region does not exceed about 950° C. In one embodiment, the temperature is about 850° C. Optionally, cold air can be added in order to reduce the temperature and prevent melting of the residual solid material or ash.

The Energy Source

Receiving the char into the Char-to-Ash Conversion Stage chamber at the highest possible temperature results in the most efficient process, producing the maximum CO and H2, and the minimum CO2 and H2O. The processing temperature is selected to be as high as possible to further maximize the yield of CO and H2, while still maintaining the char at a temperature below its fusion temperature. In one embodiment, the char is received directly from the Volatilization Stage, thereby minimizing heat loss during the transfer.

The char is heated, at least in part, by heated air introduced through heated air inlets. In one embodiment, the air is preheated through heat exchange with sensible heat from the syngas product. The heated air inlets are strategically located in and around the chamber to ensure full coverage of heated air into the processing zone. Optionally, air can be specifically supplied to this stage by the use of independently controlled air boxes and/or air nozzles.

The heat required for the char conversion process is also provided, in part, by partial oxidation of the char. The heated air inputs, in addition to providing sensible heat, also supply the oxygen required to convert carbon to gaseous CO and some CO2. The reaction of carbon with O2, whether resulting in the formation of CO or CO2, is exothermic. This exothermic reaction therefore also serves to provide a proportion of the heat required for the char-to-ash conversion. The carbon-to-ash conversion is therefore, in part, self-driving, but such reactions may also result in a non steady-state reaction resulting in an uncontrolled increase in temperature (e.g. approaching ash fusion temperature), which may result in undesired slagging in the Char-to-Ash Conversion Stage zone or chamber. In one embodiment, the amount of heated air input into the Char-to-Ash Conversion Stage zone or chamber is controlled to avoid such uncontrolled increases in temperature. In one embodiment, the temperature is controlled by the input of cold air.

The Process Manipulators

Design strategies can be utilized to optimize the conversion of char to ash. For example, the zone or the chamber that favours the Char-to-Ash Conversion Stage may be designed to optimize the residence time required for char to ash conversion. In one embodiment, the zone or chamber that favours the Char-to-Ash Conversion Stage may comprise a means for controlling the residence time of the char. In addition, the design strategies relate to the type and location of process additives in order to optimize the char to ash conversion and the composition of any gas produced. The design strategies may also relate to optimizing the exposure of char to heat and process additives in order to enhance the conversion process.

The zone or chamber that favours the Char-to-Ash Conversion Stage can be a region of a chamber or a separate chamber.

In one embodiment, the Char-to-Ash Conversion Stage is in a separate chamber comprising a char inlet proximal to the top of the chamber through which char from the Volatilization Stage is received, one or more heated air inlets, a gas outlet, a solid residue (i.e., ash) outlet, one or more optional process additive (e.g., steam) inlets, and optionally means for controlling the residence time of the char in the Char-to-Ash Conversion Stage chamber. In one embodiment, the one or more air inlets are located proximal to the bottom of the chamber.

The gases produced in the Char-to-Ash Conversion Stage chamber, referred to as the Char-to-Ash Conversion Stage gas product, comprises the products of the carbon conversion reaction, as well as what amount of the volatile constituents remained in the char product after the Volatilization Stage.

In one embodiment, the Char-to-Ash Conversion Stage chamber is a vertically oriented chamber. Examples of vertically oriented chambers known to be suitable for use in the present system include, but are not limited to, moving bed gasifiers, fixed bed gasifiers, entrained flow gasifiers and fluidized bed gasifiers. In those embodiments that employ heated air to convert the char to gaseous products and ash, the gasifiers comprise heated air inputs located to provide optimal exposure of the char to the heated air inputs and to ensure full coverage of heated air into the processing zone.

The Char-to-Ash Conversion Stage chamber optionally comprises a mechanical mixing means for ensuring efficient exposure of the char to heated air and any process additives as may be required to convert the char to ash and the desired gaseous products. The mechanical mixing means can also prevent gas channelling and keep the material from agglomerating.

The type and quantity of the process additives are therefore selected to optimize the conversion of char to a Char-to-Ash Conversion Stage gas product and ash, while minimizing operating costs and maintaining adherence to regulatory authority emission limits. Steam input ensures sufficient free oxygen and hydrogen to maximize the conversion of the char into the Char-to-Ash Conversion Stage gas product having a heating value and ash. Air input assists in processing chemistry balancing to maximize carbon conversion to a fuel gas (minimize free carbon) and to maintain the optimum processing temperatures while minimizing the cost of input heat. The quantity of both additives is established and controlled as identified by the outputs for the feedstock being processed. The amount of air injection is established to ensure a maximum trade-off for relatively high cost of input heat while ensuring the overall process does not approach any of
the undesirable process characteristics associated with incinera-
tion, and while meeting and bettering the emission standards
of the local area.

[0306] In one embodiment, heated air and steam inlets may
comprise high temperature resistance atomizing nozzles, as
are commercially available.

[0307] In one embodiment, the heated air inlets are located
proximal to the floor of the Char-to-Ash Conversion Stage
zone or chamber.

[0308] The zone or chamber can include access ports sized
to accommodate various conventional burners, for example,
natural gas or propane burners, to pre-heat the chamber.

[0309] In one embodiment, steam additives are provided to
the Char-to-Ash Conversion Stage zone or chamber in order
to convert the maximum of carbon to chemical heat while
avoiding raising the processing temperature to levels detri-
mental to the main objective of this chamber (i.e., conversion
of char to gaseous products and ash). Accordingly, the Char-
to-Ash Conversion Stage zone or chamber can also optionally
comprise process additive (steam) inlets to allow input of
additional process additives to facilitate efficient conversion
of the carbon in the char into product gases. In one embed-
ment, the Char-to-Ash Conversion Stage zone or chamber
includes a plurality of steam inlets strategically located to
direct steam into high temperature regions.

[0310] In one embodiment using an entrained flow Char-
to-Ash Conversion Stage chamber 22, with reference to FIG.
9, the heated air (and optional steam) inputs travel in a co-
current flow relative to the char inputs. Here, the char is at
least partially suspended by the movement of the additives,
thereby promoting a more distributed contact between the
input and the char. The reaction occurs as the reactant material
moves downward, driven by gravity, in the direction of travel
of additives. The Char-to-Ash Conversion Stage gas product
exits through a gas outlet, and the resulting solid residue (ash)
exits at the bottom through the solid residue outlet.

[0311] In one embodiment of the invention using a fluidiz-
ed bed Char-to-Ash Conversion Stage chamber 24, with
reference to FIG. 10, the char is suspended in the upward
moving additives. In fluidized beds, the additives enter the
Char-to-Ash Conversion Stage chamber at velocities that
greatly overcome any gravitational force, and the char bed
moves in a much more turbulent manner thereby causing a
more homogeneous reaction region and behaving in a fashion
similar to that of a turbulent fluid even though the char may in
fact be solid. The heated air and steam additives enter the
Char-to-Ash Conversion Stage chamber from the bottom and
pass counter-current to the char. The resulting solid residue
(ash) exits through the solid residue outlet and the Char-to-Ash
Conversion Stage gas product leaves the Char-to-Ash Conversion
Stage chamber through the gas outlet at the top.

[0312] In one embodiment of the invention using a moving-
bed Char-to-Ash Conversion Stage chamber 26, with refer-
cence to FIG. 11, the chamber 26 comprises a feedstock input
proximal to the top of the Char-to-Ash Conversion Stage
chamber, a plurality of heated air inlets, a gas outlet, a solid
residue outlet and an actively controlled rotating grate at the
base of the Char-to-Ash Conversion Stage chamber. Process
additive inlets are also optionally provided for addition of
steam into the Char-to-Ash Conversion Stage chamber. Also,
mixing mechanisms 27 may be used to promote enhanced
interaction between the additives and the char within the
processing chamber. The resulting solid residue (ash) exits
through the solid residue outlet and the Char-to-Ash Conver-
sion Stage gas product leaves the Char-to-Ash Conversion
Stage chamber through the gas outlet at the top. FIGS. 12A
and 12B depict embodiments of rotating grates that can be
used in a moving-bed Char-to-Ash Conversion Stage cham-
ber, in accordance with different embodiments of the present
invention.

[0313] FIG. 13 schematically depicts one embodiment of a
moving bed Char-to-Ash Conversion Stage chamber in rela-
tion to an Ash Melting and Vitrification Stage chamber and a
Gas Reformulation Stage chamber. In the illustrated embed-
ment, the Char-to-Ash Conversion Stage comprises a pro-
cessed feedstock/char input, heated air inlets, an agitator with
externally mounted motor assembly, a solid residue outlet in
communication with a plasma heated Ash Melting and Viti-
ication Stage chamber, and a Char-to-Ash Conversion Stage
gas product outlet in communication with Gas Reformulation
Stage chamber. The Gas Reformulation Stage chamber also
receives a gas product from the Volatilization Stage chamber
and converts the combined gas products to a syngas using
plasma heat. The Char-to-Ash Conversion Stage chamber
comprises a rotating grate to regulate the flow of material
from the carbon conversion zone to the Ash Melting and
Vitrification Stage chamber. Residual solid material enters
the Ash Melting and Vitrification Stage chamber and is heated
with a plasma heat source to vitrify and blend the solid resi-
due.

[0314] In one embodiment of the invention, the Char-to-
Ash Conversion Stage chamber is a fixed-bed chamber. In
fixed-bed systems, the char enters the chamber from the top
and rests on a surface through which the heated air inputs and
optional steam (or other additives) are introduced. The gas
inputs pass through the char bed from the bottom in a counter-
current fashion. The resulting solid residue (ash) exits
through the solid residue outlet and the Char-to-Ash Conver-
sion Stage gas product leaves the Char-to-Ash Conversion
Stage chamber through the gas outlet at the top.

[0315] In accordance with the present invention, the Char-
to-Ash Conversion Stage chamber is optionally provided with
means for controlling the residence time of the char in
the Char-to-Ash Conversion Stage chamber. Controlling the
residence time of the char in the Char-to-Ash Conversion
Stage chamber ensures that sufficient time is provided for
optimal mixing of the char, heated air and optional steam,
thereby providing for the maximum conversion of char to
the Char-to-Ash Conversion Stage gas product and ash.

[0316] In one embodiment, the means for controlling the
residence time of the processed char in a fixed-bed Char-
to-Ash Conversion Stage chamber is provided by any mecha-
nism suitable for controllably conveying solids out of the
chamber. In such an embodiment, once the processed char has
been in the chamber for a residence time sufficient for con-
version to the Char-to-Ash Conversion Stage gas product and
ash, the ash product is actively conveyed out of the chamber.
Such mechanisms include, but are not limited to, any of the
controllable solids removal means that may be employed to
actively convey the char product out of the primary chamber.
Accordingly, the means for controlling the residence time of
the char in the Char-to-Ash Conversion Stage chamber can
comprise screws, pusher rams, horizontal rotating paddles,
horizontal rotating arms, or horizontal rotating wheels. In one
embodiment, the means for controlling the residence time of
the char in the Char-to-Ash Conversion Stage chamber is any
of the devices used for solids removal as depicted in any of
FIGS. 1 to 8.
FIG. 14 depicts one embodiment of a fixed-bed Char-to-Ash Conversion Stage chamber comprising a rotating wheel solids removal device and the relationship of the Char-to-Ash Conversion Stage chamber to a solid residue conditioning chamber.

In one embodiment, the ash product is removed in a continuous manner at a rate appropriate to ensure that a sufficient residence time for carbon conversion is achieved.

In one embodiment, the ash product is removed on an intermittent basis, once a sufficient residence time for carbon conversion has been achieved.

In one embodiment, the means for controlling the residence time of the char in the Char-to-Ash Conversion Stage chamber is provided by any mechanism which impedes the progress of the char out of the chamber, thereby retaining solids in the chamber for a residence time sufficient to ensure conversion of the char to the Char-to-Ash Conversion Stage gas product and ash. In one embodiment, as the char gradually converts to ash, the ash product passively progresses out of the Char-to-Ash Conversion Stage chamber.

In one embodiment, the Material Drying Stage is carried out in one chamber and the Volatilization Stage and Char-to-Ash Conversion Stage are carried out in another chamber.

In one embodiment, the zones for the Material Drying Stage, the Volatilization Stage and the Char-to-Ash Conversion Stage are combined into a single chamber. Referring to FIG. 15, in one embodiment, the system (2100) comprises a refractory-lined horizontally-oriented chamber (2102) having a feedstock input (2104) with two air locks, steam outlet, gas outlet (2106) and a solid residue outlet (2108). The gasification chamber (2102) has a stepped floor with a plurality of floor levels (2112, 2114 and 2116). Each floor level is sloped between about 15 and about 35 degrees. Each floor level has a series of additive inputs (2126) located in the side walls proximal to the floor level to allow for the addition of oxygen and/or steam. A baffle extends from the roof of gasifier to form a contained drying zone when feedstock is present. Steam resulting from the heating of feedstock exits the drying zone through steam outlet. Temperature in the drying zone is approximately 200°C.

Movement through the steps is facilitated by the lateral transfer system. In this example, the lateral transfer system comprises a series of pushers. As shown, each floor level is serviced by a pusher. Corresponding sealable openings in the gasification chamber walls allow for entry of each pusher. Cold air is introduced proximal to the ash outlet of the Char-to-Ash Conversion Stage chamber. The ash outlet of the Char-to-Ash Conversion Stage chamber is equipped with a grate that separates it from the ash collection chamber. The ash collection chamber is equipped with a pusher to facilitate the transit of ash to an Ash-to-Slag Conversion Chamber.

In another embodiment where the zones for the Material Drying Stage, the Volatilization Stage and the Char-to-Ash Conversion Stage are combined into a single chamber, the single chamber can be one of a number of gasifiers known in the art for gasifying liquid or solid feedstock. Examples of suitable gasifiers include, but are not limited to entrained flow reactor vessels, fluidized bed reactors, moving bed reactors and rotary kiln reactors, each of which is adapted to accept feedstock in the form of solids, particulates, slurry, liquids, gases, or a combination thereof. The feedstock is introduced through one or more inlets, which are disposed to provide optimum exposure to the heated exchange-air for complete and efficient conversion of the feedstock to the syngas. In one embodiment, the gasifier is a plasma gasifier. In one embodiment, the plasma gasifier uses plasma in a stage of the converter. In one embodiment, a stage of the gasifier that uses plasma has a pressure limitation. In one embodiment the gasifier is a fluid gasifier.

In one embodiment the Gasification System comprises one or more gasifiers. In one embodiment, the Gasification System comprises a fluid gasifier and a solids gasifier.

The Gasification System—Chamber Designs as Process Manipulators

As indicated above various chamber designs known in the art are suitable for use in the Gasification System. For example, the gasifier can have a wide range of length-to-diameter ratios and/or can be oriented either vertically or horizontally. One skilled in the art would appreciate that the overall design of a chamber including the internal dimensions, positioning of energy sources, process additives, material transfer means, etc., are all carefully determined to promote the efficient transference of energy throughout the relevant stages of the conversion processes. A brief description of selected, non-limiting examples of gasifier designs is included below.

Vertically Oriented Gasifier

Vertically-oriented gasifiers comprise two or more vertically successive processing regions, within certain stages such as the Material Drying Stage, Volatilization Stage, or Char-to-Ash Conversion Stage is at least partially favoured. The processing regions are identified by their different temperature ranges that enable the different stages therein. The gasifier comprises one or more processing chambers; the vertically successive processing regions are distributed throughout the one or more processing chambers. Additive input elements are associated with the processing regions to promote the at least partially favoured process therein. Thus, the processing regions can be considered to be promoted by a combination of the one or more processing chambers and/or by a positioning of the one or more additive input elements in each of the processing chambers. The gasifier comprises one or more feedstock inputs located near the first processing region, one or more gas outputs, one or more residue outputs, one or more material displacement control modules and optionally, a global Control System.

In one embodiment of the invention, the system comprises a gasifier with three vertically successive processing regions with the first processing region at least partially favouring the Material Drying stage, the second processing region at least partially favouring the Volatilization Stage and the third processing region at least partially favouring the Char-to-Ash Conversion Stage. A worker skilled in the art will understand that the gasifier can, in general, comprise a large number of processing regions with a different proportion of drying, volatilization or Char-to-Ash Conversion occurring in each processing region. Thus, the number of processing regions can be as many or as few as desired, without loss of generality.

For example, with reference to the embodiment of FIG. 16, a gasifier 10 having a single processing chamber 20 may comprise two or more distinct additive input elements 30, or groups thereof, positioned so to respectively promote or favour processes within respective vertically successive
processing regions 40 within the single processing chamber 20. A feedstock input 50 provides feedstock to the first of the processing regions 40, a gas output 60 for output of gas from the gasifier 10, and a residue output 70 for output of residue from the gasifier 10. The orientations and positions of the input and output elements for feedstock, additives, residue and gas, in FIG. 16 are merely exemplary and any variations in their orientations and positions are considered to be within the scope and nature of the invention disclosed herein.

[0330] A material displacement control module operatively controlling one or more process devices and/or mechanisms (not shown) configured to control a vertical displacement or a rate of vertical displacement of the material through the vertically successive processing regions, is also provided thereby promoting the efficient processing of the material within each of these processing regions wherein a particular process is at least partially favoured. For example, as will be described in greater detail below, various devices and/or mechanisms may be controlled by the material displacement control module to implement a downward displacement of the material, either by direct control of material displacement between each processing region, by controlled extraction of material from a lowermost processing region thereby indirectly controlling a downward displacement of material from an uppermost processing region toward the lowermost processing region under gravity, or using any combination thereof.

[0331] As depicted by the additives input and off-gas output phantom lines of FIG. 16, it will be appreciated that additives may be input in each processing region, for instance via appropriate positioning of additive input elements adapted therefor, or provided to a select number of these processing regions as appropriate for a given design and embodiment of the gasifier 10. It will also be appreciated that the additive input elements may be actively controlled by a common response element configured to provide a pre-selected quantity or input rate of additives (e.g. set absolute or relative input) for a given sensed process characteristic (e.g. process temperature, pressure, throughput, etc.; product gas quality, quantity, composition, pressure, flow, heating value etc.; feedstock input rate, quality, composition, etc; and the like), or again controlled by distinct response elements, possibly operatively linked via a same local, regional and/or global Control System.

[0332] Similarly, gas outputs may be provided for each processing region independently, or provided by one or more cooperative gas outputs allowing for the output of off-gases from the processing chamber 20 from more than one processing region simultaneously.

[0333] In the embodiment of FIG. 17, a gasifier 110 may comprise two or more processing chambers 120 vertically and operatively coupled, each comprising one or more additive input elements 130, or groups thereof, positioned so to respectively promote or favour processes within respective processing regions 140 of each processing chamber 120, thereby providing a vertical succession of two or more processing regions 140 when the processing chambers 120 are combined. A feedstock input 150 provides feedstock to the first of the processing regions 140, a gas output 160 provides for output of gas from the gasifier 110, and a residue output 170 provides for output of residue from the gasifier 110. The orientations and positions of the input and output elements for feedstock, additives, residue and gas, in FIG. 17 are merely exemplary and any variations in their orientations and positions are considered to be within the scope and nature of the invention disclosed herein.

[0334] A material displacement control module operatively controlling one or more process devices and/or mechanisms (not shown) configured to control a vertical displacement of the material through the vertically successive processing regions (i.e. between chambers and/or through the processing regions of a same chamber), is also provided thereby promoting the efficient processing of the material within each of these processing regions wherein a particular process is at least partially favoured. For example, as will be described in greater detail below, various devices and/or mechanisms may be controlled by the material displacement control module to implement a downward displacement of the material, either by direct control of material displacement between each processing region, by controlled extraction of material from a lowermost processing region thereby indirectly controlling a downward displacement of material from an uppermost processing region toward the lowermost processing region under gravity, or using any combination thereof.

[0335] As depicted by the additives input solid and phantom lines of FIG. 17, it will be appreciated that additives will generally be input in each processing chamber, though not exclusively, and may also optionally be input at multiple locations within a given processing chamber to promote definition of two or more processing regions therein. It will also be appreciated that the additive input elements may be actively controlled by a common response element configured to provide a pre-selected quantity or input rate of additives (e.g. set absolute or relative input) for a given sensed process characteristic (e.g. process temperature, pressure, throughput, etc.; product gas quality, quantity, composition, pressure, flow, heating value etc.; feedstock input rate, quality, composition, etc; and the like), or again controlled by distinct response elements, possibly operatively linked via a same local, regional and/or global Control System.

[0336] Similarly, off-gas outputs may be provided for each processing chamber independently, or provided by one or more cooperative off-gas outputs allowing for the output of gas form more than one processing chamber 120 at a time.

[0337] Various combinations of processing chambers and additive input elements therefore can be adapted to provide two or more vertically successive processing regions as contemplated herein, wherein an appropriate material displacement control module can be adapted for a given embodiment to enable the controlled displacement of material through these processing regions to enhance a processing thereof. Such control may be imparted uniquely for each of the one or more processing chambers of the gasifier, optionally imparting direct displacement of material through successive processing regions of the same processing chamber within which more than one processing region is defined and/or imparting a displacement of material from a first processing chamber to a subsequent vertically successive processing chamber of a gasifier comprising more than one processing chamber. Alternatively, control may be imparted to various cooperative control devices and/or mechanisms configured to directly control displacement of material from one processing region to another, possibly within a same processing chamber.

[0338] For the embodiments using two processing chambers, FIGS. 18A and B shows a variety of different devices and/or mechanisms that can be used by the material displacement control module for displacement of reactant material
from one processing chamber to another. A worker skilled in the art will understand that the options in this figure are merely exemplary and other appropriate designs for such devices/mechanisms can be considered to be within the scope and nature of the invention disclosed herein.

Horizontally-Oriented Gasifier

[0339] FIG. 19 depicts a horizontally-oriented gasifier (2000) having one or more feedstock input(s) (2004), one or more gas outlet(s) (2006) and a solid residue (ash) outlet (2008). Material enters the gasifier (2000) via the one or more feedstock input(s) (2004) and is moved through the gasifier (2000) during processing by one or more lateral transfer units (2010) which is controlled by a Control System. The horizontally-oriented gasifier (2000) comprises a lateral transfer system to facilitate the extraction of gaseous molecules from carbonaceous feedstock. The gasifier facilitates the gasification process by sequentially promoting drying, volatilization and char-to-ash conversion. This is accomplished by allowing drying to occur at a certain temperature range prior to moving the material to another region and allowing volatilization to occur at another temperature range, prior to moving the material to another region and allowing char-to-ash conversion to occur at another temperature range. Accordingly, as the material in the gasifier is moved from the feed area towards the solid residue end by one or more lateral transfer units (2010) it goes through different stages of drying, volatilization and char-to-ash conversion (carbon conversion). A flow diagram depicting the different regions of the gasifier in general terms is shown in FIG. 20 and a representation of the gasification processes occurring in Regions 1, 2 and 3 of one embodiment of the gasifier is shown in FIG. 21. Referring to FIG. 20, Region I, which promotes drying of the material, is the area between lines 310 and 320. Feedstock is delivered into the gasifier at Region I. The normal temperature range for this region (as measured at the bottom of the material pile) lies between about 300 and 900°C. The major process here is that of drying which occurs predominately at the top and in middle of the pile of material and at a temperature above about 100°C. In addition, some volatilization at some char-to-ash conversion (carbon conversion) occurs in this region. Referring to FIG. 21, Region TI promotes volatilization of the material and is the region between lines 320 and 330. The material pile has a bottom temperature range between about 400 and 950°C. The main process occurring in Region II is that of volatilization with the remainder of the drying operation as well as a substantial amount of char to ash conversion (carbon conversion). Referring to FIG. 21, Region III, where the char-to-ash conversion takes place, is the region between lines 330 and 340. The Region III temperature range lies between about 500 and 1000°C. In one embodiment, however, in order to avoid agglomeration of the ash, the maximum temperature in this region does not exceed about 950°C. The major process in Region III is that of carbon conversion with a lesser amount (the remainder) of volatilization. By this time the moisture from the reactant material has been removed. By the end of this region, the majority of the solid residue is ash.

[0340] To facilitate movement of reactant material, the individual lateral transfer units (2010) can be controlled independently or a group of two or more lateral transfer units (2010) can be controlled in a coordinated manner. Thus, each area in the horizontally-oriented gasifier experiences temperature ranges and optional process additives (2019) (such as air, oxygen and/or steam) that promote a certain stage of the gasification process. In a pile of reactant material, all stages of gasification are occurring concurrently, however individual stages are favored at a certain temperature range. [0341] By physically moving the material through the gasifier, the gasification process can be facilitated by allowing as much drying as energetically efficient to occur prior to raising the temperature of the material to promote volatilization. The process then seeks to allow as much volatilization as energetically efficient to occur prior to raising the temperature of the material to promote char-to-ash conversion (carbon conversion).

[0342] FIGS. 22, 23, and 24 depict views of one embodiment of a horizontally-oriented gasifier.

Primary Chambers with Gas Passage Conduit

[0343] In an alternate design, the primary chamber comprises one or more processing chambers at least one of which comprises one or more gas passage conduits located therein for facilitating the exit of off-gases from the processing chamber and/or the entry of additives into the processing chamber. Optionally, one or more input elements and/or one or more output elements are disposed around one or more of the one or more processing chambers to facilitate the entry of additives into the processing chamber and the exit of off-gasses from the processing chamber respectively. The primary chamber additionally comprises one or more feedstock inputs for the input of feedstock into the primary chamber, one or more residue outputs for output of residue from the primary chamber, and optionally, one or more material displacement control modules for facilitating the movement of the reactant material through the primary chamber, which may be operatively coupled to a global Control System for controlling various aspects of the gasification process. Furthermore, one or more processing regions may be defined within the primary chamber within each one of which a certain process such as drying, volatilization or carbon conversion may be at least partially favoured. This type of primary chamber can be horizontally or vertically oriented.

[0344] Different embodiments of the present invention are shown in FIGS. 25A to 25D. For example, the gasifier 1 can be oriented vertically, as illustrated schematically in FIGS. 25A and 25B, or horizontally, as shown in FIGS. 25C and 25D, or comprise a combination of vertically and/or horizontally oriented processing chambers.

[0345] FIGS. 25A and 25B show vertically oriented gasifiers 110 and 210, respectively, in accordance with different embodiments of the present invention, each comprising one processing chamber. The one or more feedstock inputs (140 and 240 respectively) are placed near the top of the processing chamber to allow for the entry of feedstock therein. In the embodiment illustrated in FIG. 25A, output elements 135 disposed around the periphery of the processing chamber 110 are used for the extraction of off-gasses therefrom, while the gas passage conduit 120 placed within the processing chamber 110 is used for the injection of additives therein. For the embodiment of FIG. 25B, input elements 230 disposed around the periphery of the processing chamber 210 are used for the injection of additives therein while the gas passage conduit 220 placed within the processing chamber 210 is used for the extraction of off-gasses therefrom.

[0346] FIGS. 25C and 25D show horizontally oriented gasifiers 301 and 401, respectively, in accordance with different embodiments of the present invention, each comprising one processing chamber. In the embodiment illustrated in FIG. 25C, output elements 35 disposed around the periphery of
the processing chamber 310 are used for the extraction of off-gases therefrom, while the gas passage conduit 320 placed within the processing chamber 310 is used for the injection of additives therein. For the embodiment of FIG. 25D, input elements 430 disposed around the periphery of the processing chamber 410 are used for the injection of additives therein while the gas passage conduit 420 placed within the processing chamber 410 is used for the extraction of off-gasses therefrom.

[0347] The processing chambers of the gasifier may comprise different processing regions, within each one of which a certain process such as drying, volatilization or carbon conversion may be at least partially favoured, promoted by the chemical conditions existing therein. FIGS. 26A and 26B show two embodiments, where the single processing chamber of the gasifier comprises three processing regions. In FIG. 26A, input elements 531, 532, 533 disposed around the periphery of the processing chamber 510 allow for injection of additives into the three processing regions 511, 512, 513 while the two gas passage conduits 520 located within, allow for the extraction of off-gases. In the embodiment of FIG. 26B, one gas passage conduit 620 each is used for injection of additives and extraction of off-gases. Input elements 631, 633 disposed around the periphery of the processing chamber 610 are used for injection of additives into the first and third processing regions 611 and 613, while output elements 638 disposed around the periphery of the processing chamber 610 are used for extraction of off-gases from the second processing region 612. It will be appreciated that several conduits may be provided for supplying additives and/or removing off-gases from (optionally for use in heat and/or by-product recycling, as discussed further below) the one or more chambers of a given gasifier, in accordance with different embodiments of the present invention, as can any number or group of these conduits may be provided with a header and be configured to be removed and/or replaced for maintenance and/or cleaning.

[0348] A worker skilled in the art will readily understand that the exact location, size, use (e.g. exit of off-gases, entry of additives, etc.) and the direction of gas flow within the gas passage conduits are not limited to those exemplified in the embodiments of FIGS. 25A to 25D, 26A and 26B, nor are the number of inlets and/or outlets provided thereby limited to those specifically identified in the appended Figures.

[0349] FIGS. 27A to 27C show respective side-views of the inner volumes for three different embodiments of a descending bed processing chamber. In all three embodiments, the descending bed processing chambers have the following similarities: three vertically successive processing regions are distributed within the descending bed processing chamber with corresponding input elements respectively used for injection of additives into them; the one or more feedstock inputs are at the top of the processing chamber; and the processing chamber is directly connected to a Gas Reformulating System (GRS) based on plasma torches. In one embodiment and referring to FIG. 27A, the inner wall is shaped such that each processing region 711, 712, 713 has a vertical section followed by an inwardly sloped wall. In one embodiment and referring to FIG. 27B, the inner wall is a refractory-lined cylinder. In one embodiment and referring to FIG. 27C, the inner wall is refractory-lined and downward sloping.

[0350] A worker skilled in the art will readily understand that even within the same processing chamber, the different gas passage conduits can vary in shape and size and can also be used for different functions, as shown in FIG. 26. Additionally, the multiple gas passage conduits can be nested within one another, as shown in FIG. 28, (e.g. concentric cylindrical tubes can be used for exit of off-gases and/or the entry of additives into the different processing regions) and/or distinctly located, as shown in FIG. 26A.

[0351] In one vertically oriented embodiment of the invention and referring to FIG. 29, the additives are injected using the gas passage conduits within the inner volume of the descending bed processing chamber 1710 and the off-gases are extracted using the outlet elements 1737, 1738, 1739 distributed around the processing chamber. Once again, the flow of the additives is substantially cross-flow with respect to the vertically downward movement of the reactant material through the inner volume of the descending bed processing chamber. FIG. 30 indicates how the gas conduit is configured to accomplish this.

Generally Horizontally-Oriented with Lateral Transfer System

[0352] In yet another design the gasifier is a generally horizontally-oriented gasifier with a lateral transfer system. This design is similar to that shown in FIG. 8. As indicated previously, this type of design provides a generally horizontally-oriented gasifier having one or more feedstock input(s), one or more gas outlet(s) and a solid residue (ash) outlet. Optionally, the gasifier further comprises a moisture removal system and/or one or more steam outlets. Material enters the gasifier via the one or more feedstock input(s) and is moved through the gasifier during processing by one or more lateral transfer units which is controlled by a Control System.

[0353] The design of this gasifier facilitates the extraction of gaseous molecules from carbonaceous feedstock. In particular, there is provided a gasifier in which the gasification process is facilitated by sequentially promoting drying, volatilization and char-to-ash conversion (carbon conversion). This is accomplished by allowing drying to occur at a certain temperature range and optionally, the resulting steam or moisture is evacuated from the gasifier to obtain a substantially dry material. The material is moved to another region and volatization is allowed to occur at another temperature range. The material is then moved to another region where char-to-ash conversion occurs. Accordingly, as the material in the gasifier is moved from the feed area towards the solid residue area, the solid residue is moved independently or a group of two or more lateral transfer units can be controlled in a coordinated manner.

[0354] To facilitate movement of reactant material, the individual lateral transfer units can be controlled independently or a group of two or more lateral transfer units can be controlled in a coordinated manner.

[0355] Thus, each area in the horizontally-oriented gasifier experiences temperature ranges and optional process additives (such as air, oxygen and/or steam) that promote a certain stage of the gasification process. In a pile of reactant material, all stages of gasification are occurring concurrently, however individual stages are favored at a certain temperature range.

[0356] By physically moving the material through the gasifier, the gasification process can be facilitated by allowing as much drying as energetically efficient to occur prior to raising the temperature of the material to promote volatilization. The process then seeks to allow as much volatilization as ener-
gically efficient to occur prior to raising the temperature of the material to promote char-to-ash conversion (carbon conversion).

The Gasification System—Ash Melting and Vitrification Stage

The Dominant Process

0357] The dominant process in this Stage is heating the solid residue to the temperature required to melt, blend, and chemically react the solids to form a dense, siliconmetallic, vitreous material.

The Energy Sources

0358] In the zone or chamber that favors Ash Melting and Vitrification Stage, a energy source is used to achieve the high processing temperature required to vitrify the solid residue (around 1400-1500° C. depending on the ash properties) and blend it adequately to homogenize it before releasing it from the chamber, where it cools to form a dense, non-leachable, siliconmetallic solid.

0359] There are a number of energy sources used to achieve the high processing temperature required to vitrify the solid residue. The energy source must meet the required temperature for heating the solid residue to required levels to melt and homogenize the solid residue while allowing the resulting molten solid residue to flow out of the chamber or zone.

0360] Plasma systems appropriate for melting may be based on a variety of technologies, including but not limited to, microwave plasma, inductively coupled plasma, electric arc plasma and thermal plasma. In one embodiment, heat is provided by a plasma system comprising plasma torch systems. Plasma torch systems known in the art include but are not limited to transferred arc torch (TAT) and non-transferred arc torch (NTAT) systems. Both TAT and NTAT systems need positive and negative points for operation. In NTAT systems, both points are metallic while in TAT systems, the points depend on the “workpiece”. As very high temperatures are typically achieved, effective cooling techniques, such as for example rapid water cooling, is required for operation. Torch systems can be designed to work in alternating current (AC) mode, both single and multi-phase, and direct current (DC) mode.

0361] In one embodiment of the invention utilizing NTAT systems, two magnetic field coils can be used to rotate the arcs. A worker skilled in the art will readily understand that the operation of the torch systems can be varied by adjusting the position of the magnetic coils and the materials used as electrodes for the plasma torch systems. Materials that can be used for the electrodes in these torch systems include but are not limited to steel, tungsten, graphite, thoriated tungsten, copper and alloys of copper with Zr, Cr or Ag.

0362] A worker skilled in the art will understand that the choice of carrier gas for a plasma torch system impacts the reaction chemistry within the melter. For example, the carrier gas can be reducing, oxidizing or inert. Typical carrier gases for torch systems include but are not limited to air, nitrogen, helium, argon, oxygen, carbon monoxide, hydrogen and methane.

0363] A worker skilled in the art will understand that the choice of a particular plasma torch system for melting will depend on a variety of factors including but not limited to: electrical to thermal efficiency; heat transfer to the working material; electrode life; electrode cost; ease of electrode replacement; temperature profile; plasma gas enthalpy; simplicity of design and manufacture of support systems such as power supplies and Control Systems; operator qualification requirement; requirement on type of carrier gas; need for de-ionized water; reliability; capital and operating costs; ability to be moved within the melting vessel; and ability to be inserted close to the working material within the vessel.

0364] In one embodiment of the invention, the source of heat for residue melting is Joule heating elements. Joule heating refers to the generation of heat in a conductor by the passage of an electric current within, due to the interaction between the moving charged particles and the atomic ions within the conductor. The heat produced within is proportional to the electrical resistance of the wire multiplied by the square of the current.

0365] In one embodiment of the invention, the source of heat for residue melting is one or more gas burner systems.

0366] A gas burner generates a flame using a gaseous fuel such as acetylene, natural gas or propane. Optionally, an air inlet may be used as appropriate with some gas burners, to mix the fuel gas with air to obtain complete combustion. For example, acetylene is commonly used in combination with oxygen. A worker skilled in the art will know that the selection of appropriate gas for the gas burner will depend on various factors including for example, the desired flame temperature.

0367] A worker skilled in the art would appreciate that in addition to the type of heat source used, the position and orientation of the heat source are additional factors to be considered in the design of the Ash Melting and Vitrification Stage zone or chamber.

The Process Manipulators

0368] Design strategies can be utilized to optimize the ash melting and vitrification process and/or the efficiency of the whole conversion process. For example, the heat generated to convert the ash-to-slag may optionally be recycled back into the system and thereby increase the efficiency of the whole conversion process. The Ash Melting and Vitrification Stage zone or chamber may also be designed to ensure that the residence time is sufficient to ensure that the solid residue is brought up to an adequate temperature to melt and homogenize the solid residue.

0369] The system may comprise an ash collection chamber or zone that collects the ash from Char-to-Ash Conversion Stage prior to it being passively or actively conveyed to a chamber or zone which favors Ash Melting and Vitrification Stage. Appropriate ash collection chambers are known in the art and accordingly, a worker skilled in the art having regard to the requirements of the system would readily know the size, shape and manufacture of an appropriate ash collection chamber. The ash collection chamber may optionally be physically separated from the Char-to-Ash Conversion Stage zone or chamber. In one embodiment, the ash collection chamber is physically separated from the Char-to-Ash Conversion Stage zone or chamber by a grate. In another embodiment, the ash collection chamber is physically separated from the Char-to-Ash Conversion Stage zone or chamber by a perforated plate. In a further embodiment, the ash collection chamber is physically separated from the chamber by a movable or retractable plate. In other embodiments, the ash is collected in a region of the Char-to-Ash Conversion Stage or Ash Melting and Vitrification Stage zone or chamber.
Design strategies may also include strategies to optimize the transfer of ash to the Ash Melting and Vitrification Stage zone or chamber from the Char-to-Ash Conversion Stage zone or chamber and/or the ash collection chamber. For example the ash collection region or chamber may be shaped to facilitate the transfer of ash to the Ash Melting and Vitrification Stage zone or chamber. The ash collection region or chamber may optionally include active conveyance means to actively transport the ash to the Ash Melting and Vitrification Stage zone or chamber. In one embodiment, the ash is pushed into a region or chamber for the conversion of ash-to-slag. In one embodiment, a ram mechanism pushes the ash out of the gasifier into the ash collection chamber. In one embodiment, a pusher pushes the ash into the chamber for conversion of ash to slag. In one embodiment, a system of conveying rams is used to transport the ash to the zone or chamber that favors Ash Melting and Vitrification Stage. Optionally, the length of the ram stroke can be controlled so that the amount of material fed into a solid residue processing chamber with each stroke can be controlled. In another embodiment, a controllable rotating arm mechanism is used to convey ash to the zone or chamber that favors Ash Melting and Vitrification Stage.

Design strategies may also be considered to reduce the agglomeration of ash and/or break up any agglomerated ash. For example, cold air may be added to the end of the Char-to-Ash Conversion Stage zone or chamber or the ash collection region or chamber to reduce the temperature of the accumulated ash and thereby reduce agglomeration of the ash. Agglomerated ash has been shown to cause jamming in drop port type exits. The invention therefore can optionally comprise a means for breaking up ash agglomerates.

In one embodiment, in order to ensure that any agglomerations do not create jamming at the exit from the chamber, a screw conveyor concept is used to extract the ash. The ram motion will push the ash into the extractor and the extractor will pull the ash out of the gasifier and feed it into an ash conveyor system. Rotation of the extractor screw breaks up agglomerations before the ash is fed into the conveyor system. This breaking up action can be enhanced by having serrations on the blade of the screw conveyor flights.

Accordingly, the system of the present invention comprises a Ash Melting and Vitrification Stage zone or chamber adapted to receive solid residue and having one or more heat sources, optional air input means, and a slag outlet.

The molten slag may periodically or continuously be exhausted from the Ash Melting and Vitrification Stage zone or chamber and is thereafter cooled to form a solid slag material. Such slag material may be intended for landfill disposal. Alternatively, the molten slag can be poured into containers to form ingots, bricks tiles or similar construction material. The solid product may further be broken into aggregates for conventional uses.

In one embodiment, the solid residue processed in the solid residue conditioning chamber includes solids transferred from a downstream process, for example, solids retrieved from a baghouse filter in a downstream gas conditioning process.

In one embodiment, Char-to-Ash Conversion Stage and Ash Melting and Vitrification Stage are combined in a single chamber referred to as a carbon converter. In such embodiments, the carbon converter comprises the Char-to-Ash Conversion Stage or carbon conversion zone in communication with the Ash Melting and Vitrification Stage or ash melting and vitrification zone for melting residual substantially carbon free solid material into molten slag and/or for maintaining slag in a molten state. The Char-to-Ash Conversion Stage zone and the Ash Melting and Vitrification Stage zone are separated by an inter-zonal region or inter-zone that restricts or limits the movement of material between the two zones. Referring to FIG. 31, the carbon converter comprises char inputs (20) into the Char-to-Ash Conversion Stage or carbon conversion zone (11) of the refractory-lined chamber (15), where heated air inputs (35) convert the unreacted carbon in the processed feedstock into a syngas. Residual substantially carbon-free solid material (i.e., ash) is subsequently converted into a molten slag material in either the inter-zonal region or inter-zone and/or the Ash Melting and Vitrification Stage ash melting and vitrification zone by the direct or indirect (i.e., via heat transfer elements) application of plasma heat. The molten slag material is output from the slag zone of the multi-zone carbon converter and passed into an optional slag cooling subsystem for cooling.

The inter-zonal region can comprise an impedance mechanism upon or in which the char is retained for a sufficient time to ensure char conversion prior to the ash product being passed out of the Char-to-Ash Conversion Stage chamber. The impedance mechanism limits or regulates the movement of material out of the Char-to-Ash Conversion Stage chamber by either partially or intermittently occluding solid residue outlet or by forming a reservoir in which the char temporarily accumulates.

Referring to FIG. 32A to F, the impedance mechanism is mounted at the bottom of the Char-to-Ash Conversion Stage chamber and can be of any physical barrier of suitable shape or design, including but not limited to dome shaped, pyramidal shaped, grates, moving grates, brick grate, plurality of ceramic balls, plurality of tubes etc. The shape and size of the impedance mechanism may in part be dictated by shape and orientation of the chamber.

Referring to FIG. 32A to F, which detail various alternative, non-limiting impedance mechanisms. In one embodiment as illustrated in FIG. 32A, the impedance mechanism is a solid refractory dome (145) mounted by wedge-shaped mounting bricks (150) at the bottom of the Char-to-Ash Conversion Stage chamber. The solid refractory dome is sized such that there is a gap (155) between the outside edge of the dome and the inner wall of the chamber. Optionally, the refractory dome further comprises a plurality of holes (160).

Referring to FIG. 32B, the impedance mechanism comprises a solid refractory brick grate. The refractory brick grate (245) is provided with gaps (255) between the individual bricks to allow for communication between the carbon conversion chamber and the solid residue conditioning chamber.

Referring to FIG. 32C, the impedance mechanism comprises a grate structure manufactured from refractory-lined tubes (345) mounted within a mounting ring (350), which is mounted at the bottom of the Char-to-Ash Conversion Stage chamber.

In one embodiment as illustrated in FIG. 32D, the impedance mechanism is a solid refractory pyramid (145) mounted by mounting bricks at the bottom of the Char-to-Ash Conversion Stage chamber.

Referring to FIG. 32E, the impedance mechanism comprises a plurality of ceramic balls.

Referring to FIG. 32F, the impedance mechanism comprises a domed cogwheel.
The impedance mechanism and any associated mounting elements must be able to effectively operate in the harsh conditions of the Char-to-Ash Conversion Stage chamber and in particular must be able to operate at high temperatures. Accordingly, the impedance mechanism is constructed of materials designed to withstand high temperatures. Optionally, the impedance mechanism may be refractory-coated or manufactured from solid refractory.

In one embodiment, the Material Drying Stage, Volatilization Stage, Char-to-Ash Conversion Stage and Ash Melting and Vitrification Stage are combined in a single chamber.

The Gas Reformulation System

The facility of this invention comprises a system for the effective reformulation of gas derived from the gasification of carbonaceous feedstock. The initial gas to be input into this system will generally comprise a complex mixture of hydrocarbon molecules of varying length. The chemical composition and the contaminant quality of the gas will depend on the composition of the feedstock, the process used to generate the gas and the conditions in the Gasification System. Some gasifiers are designed for a one step process, wherein various forms of heat are used to generate the gas in a single chamber. Other gasifiers generate the gas in a multi-step process, in either different regions of one chamber or different chambers or some combination thereof. Either system might include some pre-processing of the raw off-gas, generally due to the source of heat in the gasification chamber.

One primary objective of these design strategies is to optimize the effective exposure of the amounts of raw syngas and/or preformulated gas to the reactive species in the gas energizing zone. The greater the degree of effective exposure, the greater the efficiencies of energy transferance, and hence, the greater the percent conversion of the preformulated gas into gas of a designed chemical composition in the most overall cost effective manner.

Examples of design strategies include the design of the entire system. For example, important design strategies comprise the flow pattern (turbulence) of the preformulated gas relative to the gas energizing field and particularly the amount of gas that passes through this field in a particular amount of time. One example of these strategies is the system design whereby the preformulated gas passes through plasma generating electric arc(s). Another example is the system design wherein a plasma torch is positioned in a manner that the plasma plume flows counter-current to and directly down into the preformulated gas. In another embodiment, the preformulated gas passes through sequential or parallel gas energizing fields.

The reformulating system of the invention is designed to optimize the amount of preformulated gas that is reformulated into a product gas. In one embodiment, the effectiveness of this process is expressed by the term, Gas Reformulation Ratio, which comprises the amount of reformulated product gas divided by the amount of preformulated or initial reactant gas X 100%.

In one embodiment, the Gas Reformulation Ratio is 95% or greater. In one embodiment, the Gas Reformulation Ratio is 90% or greater. In one embodiment, the Gas Reformulation Ratio is 85% or greater. In one embodiment, the Gas Reformulation Ratio is 80% or greater. In one embodiment, the Gas Reformulation Ratio is 75% or greater. In one embodiment, the Gas Reformulation Ratio is 70% or greater. In one embodiment, the Gas Reformulation Ratio is 65% or greater. In one embodiment, the Gas Reformulation Ratio is 60% or greater. In one embodiment, this concept is expressed as a ratio of the value of the reformulated gas as compared to the initial gas. In one embodiment, the value is the energetic value in terms of electricity generation.

In order to effectively reformulate initial gas into gas of a designed composition, this invention comprises one or more “gas reformulating zones,” and one or more “gas stabilizing zones.” A gas stabilizing zone optionally comprises heat transfer means to capture heat from the gas as it cools. The system optionally comprises one or more “gas additive zones,” generally located upstream of a gas reformulating zone, with or without mixing. It also optionally comprises one or more “gas cleaning zones,” generally located downstream of a gas stabilizing zone.

For the purposes of clarity, these zones are described separately. It is understood, however, that these zones are generally contiguous and interrelated within the system, that the system is not limited to comprising discrete, physically separated zones, although this remains an alternative option. Depending upon the design of a particular embodiment, they will be more or less separated. In addition, for ease of reference only, the zones have been named according to the process step that takes place predominantly in that zone. One skilled in the art will appreciate, however, that due to the nature of the reformulation process other process steps may also take place to a lesser extent in that zone.

A system that effectively reformulates gas must be able to raise the energy of the initial gas molecules so that they begin to reformulate. In particular, reaction intermediates are initiated. The energetic processes of a reaction are represented by a curve such as shown below.
GRE: Gas Reformulating Energy

GRE

With catalysts

GRE

With catalysts

Without catalysts

Potential Energy

Reaction Coordinate
As one skilled in the art would appreciate, the arrow points to a representation of energy that is required to induce the gaseous molecules of an initial chemical composition to begin to recombine into molecules of a designed chemical composition. The dotted line represents the energy required when a catalyst is used to lower the amount of energy required to bring about the reformation of the molecules. One skilled in the art appreciates that, at a general level, sufficient energy will be required to be imparted to the initial gas molecules to drive them to break their bonds and reformulate into reformed molecules and atoms. Under the appropriate conditions, if the reformed molecules and/or atoms are allowed to mix thoroughly, the atoms will recombine according to the relative concentrations of the species present. Moreover, if a significant amount of the preformed gas passes through the energizing field, a significant amount of the gas will be reformulated.

To accomplish the objective of effectively reformulating gas, one skilled in the art can appreciate that the following four chemical processes occur throughout the reformulation of a gas: 1) initiation of the intermediates; 2) propagation of at least a portion of the intermediates; 3) termination of the intermediates; and 4) product gas stabilization.

A gas reformulation process can be envisioned to entail four general processes. In the first process, reactants such as initial gaseous molecules and energy sources (including but not limited to free electrons, and other energized or activated species such as ions and free radicals) are brought together through mixing and reach a state of species-to-species contact. As a result of such contact and a sufficient energy level of the mixture, the interaction of the reactants leads to the formation of chemical intermediates. While some of the intermediates may react together and terminate, at least a portion of the intermediates undergo another step, in which the intermediates react between themselves with or without the participation of the reactants to produce other intermediates, resulting in a chain of chemical reactions. In another process, the intermediates are terminated by chemical and/or physical means and yield specific products. In the fourth and final step, the products formed are stabilized when specific chemical and/or physical conditions are maintained.

The initiation of intermediates may therefore be considered as the dominant process that occurs early within the gas reformulating zone where an intermediate-inducing means (an energy source) is provided and brought into contact with a gas entering the gas reformulating zone. Mixing, energy transfer, and/or radiation which enables the transformation of the reactants into initial intermediates. The reactants can be said to be excited.

The intermediate propagation step may be considered to be another major process that occurs in the gas reformulating zone where the initial intermediates react between themselves to produce other intermediates. It is possible for these intermediates to form a chain of reactions with one group of intermediates being derived from the previous one. In general, the intermediate termination processes can be considered to occur at the end of the gas reformulating zone and, in some embodiments, may even be considered to define the outer edges of the zone wherein the chemical and/or physical conditions are changed such that the chain reactions are consequently stopped from proceeding further. It would be understood, however, that termination processes may take place in other regions of the gas reformulating zone depending on the specifics of the process, the reactants/intermediates and the stability of the final product. At the end of the chain reactions reached either by controlled termination or by undisturbed progression, specific products are formed.

The gas stabilizing zone may be considered to be located where product stabilization is the dominant process and may be defined as a zone where specific conditions are maintained in order to stabilize the products formed at the termination of the recombining of the intermediates. These products are normally desired for specific applications. If different products are required, effort may be made to adjust the intermediate termination point since different points of the chain reaction course correspond to different intermediates which in turn yield different products upon termination and stabilization.

There are many intermediate inducing means. These include thermal heating, plasma plume, hydrogen burners, electron beam, lasers, radiation, etc. In situations where the reactant molecules have sufficient energy to rearrange in the presence of a catalyst and are brought in contact with such a catalyst, the catalyst can be seen to play the role of an intermediate inducing means. The common feature of energy sources that provide intermediate inducing means is to cause chemical changes to reactants and proceed along a pathway to final products. The intermediates formed can therefore differ between different intermediate inducing means and have different levels of activation.

There are a number of ways of elevating the energy of the initial gas to a level such that the molecules will reformulate into the molecules of a designed chemical composition. Heat can be added to the initial gas. Activated species, such as the electrons and positive ions found in plasma or produced from a hydrogen source can be used to transfer the energy required to cause the molecules in the initial gas and process additives, “the preformed gas,” to reformulate into reformed molecules and atoms.

As noted above, there are various catalysts known to one skilled in the art that can be used to lower the amount of energy that must be required to cause the molecules to reformulate. Catalysts such as dolomite, olivine, zinc oxide and charcoal are examples of some commonly used catalysts.

This invention provides a smart, integrated Gas Reformulating System for efficient, deliberately planned reformulation of an initial gas with associated characteristic characteristics (e.g. chemical composition) into an output gas with characteristic characteristics designed for a specific downstream purpose. Optimization includes the most overall cost effective manner of accomplishing the reformulation, including upfront costs such as electricity and downstream costs such as processing contaminated catalysts.

The Gas Reformulating System Process:

1. senses directly or indirectly the adequacy of the characteristic parameters of the initial gas including but not limited to the chemical composition, humidity, flow rates, etc. Optionally, the system may sense characteristic and/or parameters of upstream and/or downstream systems or input or outputs thereof;

2. modifies various input parameters to the reformulation process (e.g. optionally increases or decreases appropriate amounts of process additives, modifies the amount of electricity, etc.) based on the sensed characteristic parameters of the initial gas and the desired parameters of the output gas;
[0407] (3) generates one or more gas reformulating zones comprising sufficient energetic species that can react with the off-gas molecules (the initial gas or preformulated gas) to transfer energy to the gaseous molecules such that the majority of the gaseous molecules reformulate into reformulated molecules and atoms;

[0408] (4) in the reformulating zone, promotes efficient mixing of the initiated gaseous molecular constituents (the initiated intermediates) such that they recombine into a chemical composition determined by the relative concentrations of the species present in the reformulated gas;

[0409] (5) provides a stabilizing zone, whereby the newly formed molecules are de-energized, for example, cooled or removed from the influence of catalysts or gas energizing sources, and thus stabilized to maintain the desired characteristics; and

[0410] (6) provides a Control System for overall control of the gas reformulation process.

[0411] The system and method of gas reformulation may be used to reformulate a substantial amount of off-gas such as produced from gasification of carbonaceous feedstock into a reformulated gas comprising optimal levels of molecules such as carbon monoxide and hydrogen and minimal levels of unwanted molecules.

[0412] In the ensuing description, the following parts of the Gas Reformulating System are considered in greater detail. The basic process will be taught beginning with a description of the “gas reformulating zones,” “gas stabilizing zones.” The strategy and tactics for optimizing the extent and efficiencies of gas reformulation will be described with a discussion of Gas Manipulators including catalysts and other Gas Manipulators. Optional features for inclusion in the system include “gas additive zones,” and “gas cleaning zones.” Finally the description will discuss the design of gas reformulating chamber and a Control System to manage all of the above processes.

The Gas Reformulating Zone

[0413] The reformulating zone is the zone within the system wherein the preformulated molecules that are sufficiently energized to reformulate into molecular species of a designed chemical composition occurs. In general, this zone is designed such that it incorporates means for causing turbulence and mixing during the reformulating process.

Gas Energizing Sources

[0414] Gas energizing sources provide the initial energy required to overcome the molecular bonding energies of the initial gas and the process additives within the Gas Reformulating System (the preformulated gas), thus serving to reformulate these molecules into reformulated molecules and eventually the molecules of designed chemical composition, such as CO and H₂. These energizing sources serve to provide energy for initiation of the reactive intermediates, and when required, to provide energy to support propagation of the intermediates.

[0415] Various elements are envisioned within this invention for the provision of the gas energizing zones. The energy levels required to meet the requirements of the Gas Reformulation Energy depend on a variety of factors including but not limited to the characteristics (e.g. composition) of the initial gas, the process additives, and the presence of catalysts. Means to increase the temperature, residence time and/or turbulence and mixing are also envisioned for inclusion in designing and creating this zone.

[0416] Energy required for gas energizing in order to induce intermediates to become reactive can be provided by various sources referred to as energizing sources, thermal heating, plasma, hydrogen burners, electron beams, lasers, radiation, etc. Their common feature is to cause chemical changes to reactants and proceed along a pathway to final products.

Sources of Plasma

[0417] Plasma provides a source of energy mostly in the form of electrons and positively charged ions that can interact with the preformulated gas to supply Gas Reformulation Energy to the molecules.

[0418] In one embodiment of the invention, one or more plasma-based sources (e.g. plasma torches), operated in conjunction with or without other gas energizing sources, are used to raise the energy of the initial gas to a level sufficiently high for gas reformulation, and thus provide a gas energizing zone. The appropriate energy level depends on a variety of factors including but not limited to the characteristics of the initial gas and the process additives, and is readily determined by a worker skilled in the art.

[0419] Although heat contributes to the process, a significant portion of the majority of the energy is supplied by the reactive species in the plasma. In one embodiment of the invention, the temperature is between about 800° C. to about 1200° C. The amount of energy required of the source may be lowered by the use of catalysts.

[0420] The one or more plasma sources may be chosen from a variety of types including but not limited to non-transferred and transferred arc, alternating current (AC) and direct current (DC), plasma torches, high-frequency induction plasma devices and inductively coupled plasma torches (ICP). In all arc generating systems, the arc is ignited between a cathode and an anode. Selection of an appropriate plasma source is within the skills of a worker in the art.

[0421] The transferred arc and non-transferred arc (both AC and DC) torches can employ appropriately selected electrode materials. Materials suitable for electrodes that are known in the art include copper, tungsten alloys, hafnium etc. The electrode lifetime depends on various factors such as the arc-working areas on the electrodes, which in turn depends on the design of the plasma torch and the spatial arrangement of the electrodes. Small arc-working areas generally wear out the electrodes in a shorter time period, unless the electrodes are designed to be cooled by thermionic emission. The electrodes may be spatially adjustable to reduce any variations in the gaps there between, wherein the variations are caused as the electrodes wear down during their lifetimes.

[0422] A variety of gases can be used as a carrier gas for plasma torches including but not limited to air, argon, helium, neon, hydrogen, methane, ammonia, carbon monoxide, oxygen, nitrogen, carbon dioxide, C₂H₄ and C₃H₆. The carrier gas may be neutral, reductive or oxidative and is chosen based on the requirements of the gas reformulation process and the ionization potential of the gas. Selection of an appropriate carrier gas and understanding the means of introducing the carrier gas into the plasma torch can impact its efficiency is within the ordinary skills of a worker skilled in the art. In particular, that a poorly designed introduction of the carrier gas can result in a non-uniform plasma plume, with hot and cold zones.
In one embodiment, the gas reformulating system comprises one or more non-transferred, reverse polarity DC plasma torches. In one embodiment, the gas reformulating system comprises one or more water cooled, copper electrode, NTAT DC plasma torches. In one embodiment of the invention, the gas reformulating system comprises one or more AC plasma torches.

AC plasma torches may be either single-phase or multiple phase (e.g. 3-phase), with associated variations in arc stability. A 3-phase AC plasma torch may be powered directly from a conventional utility network or from a generator system. Higher phase AC systems (e.g. 6-phase) may also be used, as well as hybrid AC/DC torches or other hybrid devices using but not limited to hydrogen burners, lasing, electron beam guns, or other sources of ionized gases.

Multiple phase AC plasma torches generally have lower losses in the power supply. In addition, the rapid movement of the arc along the electrodes due to rail-gun effect can result in improved redistribution of the thermal load between the electrodes. This redistribution of the thermal load along with any cooling mechanisms for the electrodes, allows the use of high temperatures for electrodes having a relatively low melting point but high thermal conductivity, such as copper alloys.

The plasma source may comprise a variety of commercially available plasma torches that provide suitably high flame temperatures for sustained periods at the point of application. In general, such plasma torches are available in sizes from about 100 kW to over 6 MW in output power. In one embodiment, the plasma torch is two 300 kW plasma torches each operating at the (partial) capacity required.

Hydrogen Burners

In one embodiment of the invention, the gas energizing field is at least partially provided by a hydrogen burner wherein oxygen and hydrogen are reacted to form ultra-high temperature steam (>1200° C). At these high temperatures, the steam may exist in an ionized form which enhances the gas reformulation process. Hydrogen burners may be operated in conjunction with or without other gas energizing sources such as plasma torches. Activated hydrogen species include the benefit of rapid dispersion of the reactive species and extensive steam cracking, both of which lead to a high conversion of the initial gas at a lower temperature than achieved with plasma.

In one embodiment of the invention, hydrogen burners provide a significant portion of the energizing energy, thereby acting as the primary energizing field element.

The hydrogen for the hydrogen burner may be obtained by electrolysis. The oxygen source may be pure oxygen or air. Other sources for hydrogen and oxygen may also be used as would be readily known to a worker skilled in the art. The design of the burner may utilize standard modeling tools e.g. tools based on computational fluid dynamics (CFD). The burner may also be adapted and sized to fit the requirements of the gas reformulating system taking into account various factors including but not limited to the quantity of gases for reformulation, chamber geometry etc.

In one embodiment of the invention, the hydrogen burner comprises a cylindrical nozzle body, with upper and lower covers coupled to its upper and lower ends respectively and defining a predetermined annular space S in the body. A gas supply pipe is connected to a sidewall of the body such that the pipe is inclined downwards therefrom. The upper cover may be integrated with the body into a single structure, and is provided with a heat transfer plate having a thickness sufficient for easy dissipation of heat. A plurality of nozzle orifices, which discharge hydrogen to the atmosphere, is formed through the heat transfer part with an exposing depression formed on the upper surface thereof to communicate with each of the nozzle orifices. An airflow chamber is also defined in the body so that air passes through the chamber. A guide protrusion is formed on the inner surface of the space to guide the current of hydrogen gas to a desired direction in the space. Furthermore, the upper end of the annular space S, which communicates with the lower ends of the nozzle orifices, is configured as a dome shape, thus defining a vaulted guide to guide hydrogen gas to the orifices.

Hydrogen burners operate at a lower temperature and usually mix hydrogen with air. They may also use a oxygen-hydrogen mixture which runs at a significantly higher temperature. This higher temperature can give off more radicals and ions; it is also more reactive with hydrocarbon vapor and methane.

In one embodiment of the invention, a hydrogen burner serves as a source for high temperature chemical radicals which can accelerate the reformulation of gaseous hydrocarbons into syngas. The hydrocarbon burner is operated with an oxidizing agent, with air and oxygen being two common choices. A worker skilled in the art will understand the relative proportion of hydrogen and the oxidizing agent required. In addition to generating high-temperature radicals, the hydrogen burner also generates a controllable amount of steam. Typically, hydrogen burners can be powered with efficiencies similar to a plasma torch.

Electron Beam Guns

Electron beam guns produce electron beams with substantially precise kinetic energies either by emission mechanisms such as thermionic, photo cathode and cold emission; by focusing pure electrostatic or with magnetic fields and by a number of electrodes. Electron beam guns can be used to ionize particles by adding or removing electrons from the atom. A worker skilled in the art will readily know that such electron ionization processes have been used in mass spectrometry to ionize gaseous particles.

The designs of electron beam guns are readily known in the art. For example, a DC, electrostatic thermionic electron gun is formed of several parts including a hot cathode which is heated to create a stream of electrons via thermionic emission; electrodes which generate an electric field to focus the beam, such as a Wehnelt cylinder; and one or more anode electrodes which accelerate and further focus the electrons. For larger voltage differences between the cathode and anode, the electrons undergo higher acceleration. A repulsive ring placed between the anode and the cathode forces the electrons onto a small spot on the anode. The small spot may be designed to be a hole, in which case the electron beam is collimated before reaching a second anode called a collector.

Radiation

Ionizing radiation refers to highly-ennergetic particles or waves that can ionize an atom or molecule. The ionizing ability is a function of the energy of the individual packets (photons for electromagnetic radiation) of the radia
tion. Examples of ionizing radiation are energetic beta particles, neutrons, and alpha particles.
The ability of electromagnetic radiation to ionize an atom or molecules varies across the electromagnetic spectrum. X-rays and gamma rays will ionize almost any molecule or atom; far ultraviolet light will ionize many atoms and molecules; near ultraviolet and visible light will ionize very few molecules. Appropriate sources of ionizing radiation are known in the art.

Recycled Energy

The external energy needed to sustain the gas reformulation process may also be reduced by harnessing any heat generated by the process. The amount of heat generated by the gas reformulation process depends on the characteristics of the initial gas and the reformulated gas. In one embodiment, the heat released during the reformulating of carbon or multi-carbon molecules to mainly CO and H₂ is maximized by optimizing the amount and type (e.g., air, O₂) of process additives injected into the gas reformulating system.

The sensible heat present in the gas leaving the reformulating zone may be captured using heat exchangers in the gas stabilization zone, and recycled to enhance the external efficiency of the reformulation process.

Other energizing sources based on thermal energy or lasers may also be used, as would be evident to a worker skilled in the art.

Process Manipulators—Gas Manipulators

Gas Manipulators represent embodiments of design strategies seeking to optimize the process of gas reformulation. Gas Manipulators are Process Manipulators that are particularly relevant to the Gas Reformulation Process. Gas manipulators comprise designs of the chamber that optimize the flow pattern of the preformed gas relative to the gas energizing field and particularly the amount of gas that passes through this field in a particular amount of time. Another example of a Gas Manipulator is the system design wherein the energy-providing source (such as a plasma torch) is oriented in a manner relative to the incoming reformulating gas that maximizes mixing between the incoming gas and the energetic species in the energy source. Another example is the location and positioning of process additive nozzles that are designed to increase turbulence and mixing. Another might comprise the arrangement of sequential gas reformulating zones versus parallel gas reformulating zones.

The Gas Manipulators comprise structural devices that have been designed and incorporated into the system to increase the efficiency of the gas reformulation process. Examples include, without limitation, structural devices such as baffles and deflectors that direct the preformed gas more effectively towards and through the gas energizing field. Other examples include structural devices that increase the turbulence throughout the process that increase the mixing of the energizing sources and the reformulating gas. The Gas manipulators also include aspects of the system that direct the physical orientation of the energizing source to change the dimensions of the energizing field, e.g., plasma plume directing devices, and/or changes to the energy supplied to a plasma-generating source, the flow rate of the working gas, etc. are non-limiting examples of aspects of the system of the invention that can be modified to effect changes in the dimensions of the preformed gas energizing field.

Catalytic Gas Manipulators increase the efficiencies of the energy transference and include catalysts. One example of a Gas Manipulator is the system design whereby the preformed gas passes through plasma generating electric arc(s). Inclusion of the Gas Manipulators is intended to optimize the balance of the amount of energy expended in the process of providing energy to the preformed gas with the output that is sufficient to enable the system to reformulate syngas into gas of a designed chemical composition. There are different categories of Gas Manipulators.

One category of Gas Manipulators is referred to as "Source Energy Exposure Manipulators." The principal design strategy of this aspect of the invention is to optimize the exposure of the amount of preformed gas necessary to support the reformulation reactions to the initial source of energy.

Another category of Gas Manipulators is referred to as "Mixing Manipulators." The principal design strategy of this aspect of the invention is to optimize the mixing of the reactive species to enhance the energy transference throughout the reformulation process.

Another category of Gas Manipulators is referred to as "Catalytic Manipulators." The principal design strategy of this aspect of the invention is to optimize the catalytic activities within the system to enhance the overall effectiveness of the reformulation process.

Overall effectiveness refers to the thoroughness of the reformulation process (as expressed by the Gas Reformulation Ratio) in addition to the overall costs of achieving reformulation. For example, the overall effectiveness takes into account the cost of using a catalyst that might become "poisoned" during the process and the cost of replacing it. It will also take into account the cost of the energy sources.

The Gas Reformulating System of this invention is designed to enhance the efficiency of the reformulation process. The various means of accomplishing this are referred to as "Gas Manipulators" and they enhance the efficiency, effectiveness and thoroughness of the reformulation process. The reformulation process occurs as the preformed gas is passing through the chamber of the system, so residence time is a critical aspect determining the efficiency of the process and the thoroughness of the transformation. Factors that accelerate the rate and extent of energy transference throughout the preformed gaseous molecules and the mixing of the reformulated species, optimize the thoroughness of the transformation prior to the gas exiting the system.

The proximity of the gaseous molecules to the source of energy-providing activated species, such as those provided within the plasma, and/or heat, is dependent upon the amount of time the gaseous molecules are exposed to the source. Means provided within the system that enhance the process of energy transfer throughout the preformed gas molecules which thereby begin to reformulate, maximizes the number of molecules that will be reformulated. In addition, means that increase the amount of mixing of the activated species/reactive intermediates such that they reform into new chemical species, the composition of which is largely dependent upon the relative concentration of the species present in the reformulated gas, also maximize the amounts of designed molecules that will be generated.

Gas Manipulators are designed, positioned and operated to enhance the efficiency of the reformulation process. In some embodiments, the Gas Manipulators are designed to increase the high turbulence within the system. Increasing turbulence influences the gas by provide thorough mixing of the gas molecules to be energized and those that are
in the process of reformulating into new molecules, the chemical composition of which will be determined largely by the relative concentrations of the individual chemical species in a gas reformulating zone.

0450. Gas Manipulators can be designed to alter the flow dynamics within the Gas Reformulating System by targeted redirection of the at least one of the gas energizing zone, the initial gases, process additives and constituents thereof, resulting in changes in their relative spatial distribution and dynamic evolution thereof. The Gas Manipulators may also be designed to ensure that a high turbulence environment is created in targeted locations to aid the energizing and reformulation processes.

0451. By improving the exposure of the gas energizing field (e.g., plasma plumes) with the initial gas and the process additives, improved reaction processes for the energizing and reformulation is achieved at the lowest possible temperature.

0452. A worker skilled in the art will readily understand that the gas Manipulators have to be designed and positioned based on the location of the gas energizing sources and inlets for process additives and on the overall design of the chamber.

Gas Exposure Manipulators

0453. In some embodiments, the Gas Manipulators are designed and configured to substantially enhance the exposure of the preformed gas to the reforming zone. As mentioned earlier, these Gas Manipulators may be separate structural devices attached to the gas reformulating chamber(s) or be integral to the gas reformulating chambers.

0454. Chamber designs for exposure manipulation: in one embodiment, the Gas Manipulators comprise of chamber designs that optimize the flow pattern of the preformed gas relative to the gas energizing field and particularly the amount of gas that passes through this field in a particular amount of time. This can be achieved by appropriate design of the internal walls of the chamber resulting in differences in the gas reformulation channel, i.e., the gas flow path within a chamber. The gas reformulation channel can be a variety of types including but not limited to the following: straight, curved, diverger-converger and the labyrinth.

0455. Various embodiments of gas reformulation channels are shown in FIGS. 57 to 60. A worker skilled in the art will readily understand that several design variations are possible for each of the embodiments of FIGS. 57 to 60. Based on the design of additional features of the chambers, such as, for example, the ports for air injection. Design considerations for gas reformulation channels include but are not limited to the exposure to the energy source, cross section area, temperature profile, velocity profile, gas residence time, mixing, and pressure drop.

0456. Referring to FIG. 47A and in accordance with one embodiment of the invention, the chamber is straight and comprises a narrow throat wherein the plasma torch is located. The gases passing through the narrow throat is forced to mix with the reactive ionized plasma carrier gas (the gas energizing zone), thus promoting reformulation. The throat is about the size of the visual portion of the plasma plume, associated with temperatures above 2000° C. The carrier gas exists in an ionized phase at such temperatures and is therefore much more active. Design criteria such as the size of the channel (e.g., its cross section area), velocity and temperature profiles etc., are determined by the chemical processes required for enhanced gas reformulation. Any particulate matter present in the reformulated gas may entrain and accumulate in the secondary portion of the chamber due to the higher velocities at the throat.

0457. The chambers may additionally be designed for ease of separation of the particulate matter. Referring to FIG. 47B and in accordance with one embodiment of the invention, the secondary portion of the chamber is located downwards so that the particulate matter may separate at the bottom and be carried away. Alternatively, the secondary portion of the chamber may be designed to have a tangential introduction of the gas from the primary portion of the chamber so that the resulting swirl flow may promote separation of the particulate matter from the gas stream.

0458. The merits of the designs of FIGS. 47A and 47B may also be achieved with a simplified mechanical design by appropriate placement of a structural device internally. Referring to FIG. 47C and in accordance with one embodiment of the invention, the shape of chamber is unchanged throughout its length and the channel is located substantially in the middle of the chamber to force the off-gas through. As the chamber diameter is fixed, the installation of refractory, and the fabrication and installation of the chamber is simplified. The internal structural device may be well insulated and cooled for optimal performance using methods known in the art such as extra cooling piping, fan and controls.

0459. The plasma plume generated by a single plasma torch is of a certain finite length at several milliseconds time period, after which the ionized gas returns to a non-plasma gas state as its temperature drops below about 2000° C. A worker skilled in the art will understand that the time after which the ionized gas returns to a non-plasma gas state depends on various parameters of the plasma torches including but not limited to the enthalpy of the torch, the gas flows, the temperature of the surrounding gas and the amperage. In gas reformulation chambers with curved type channels, two or more plasma torches may be appropriately located to provide a continuous stream of reactive ionized gas for interaction with the incoming off-gas, resulting in enhanced efficacy of the tar cracking processes.

0460. A variety of designs are possible for curved channels not limited to the embodiments of FIGS. 48A to 48C. In accordance with one embodiment of the invention, the secondary portion of the chamber allows for tangential introduction of gas from the primary portion of the chamber so that the resulting swirl flow promotes the separation of the particulate matter from the gas stream. A worker skilled in the art will readily understand that a multitude of curved channel designs are possible, for example, based on differences in the angles of the curves.

0461. Referring to FIG. 49 and in accordance with one embodiment of the invention, the channel is a divergent-convergent type where the shape of the channel allows for variations in the local conditions such as velocities, pressure, etc. if necessary.

0462. Referring to FIG. 50 and in accordance with one embodiment of the invention, the channel is a labyrinth type. A worker skilled in the art will readily understand that this channel design can accommodate for longer residence time, if necessary.

0463. In one embodiment of the invention, the chamber is a straight, substantially horizontal cylindrical structure operatively linked to a source of gas (e.g. gasifier) through a vertically oriented connector. The walls of the chamber and/or connector may be designed to act as a Gas Manipulator i.e.,
to precisely redirect the preformulated gas stream and enhance its interaction with the gas energizing field and optionally the process additives.

[0464] In one embodiment of the invention, the chamber is constricted at appropriate locations to enhance the interaction of the preformulated gases with the gas energizing field (e.g., plasma plumes) and/or the process additives. Referring to FIG. 52A and in accordance with one embodiment of the invention, the constriction 3999 within the chamber 3202 is placed slightly above the two plasma torches 3208. Referring to FIG. 52B and in accordance with one embodiment of the invention, the constriction 3999 is more gradual and is positioned such that the plasma torches 3208 fall within the constricted area of the chamber 3202. A worker skilled in the art will readily understand the impact of the different positions of the constriction vis-à-vis the plasma torches.

[0465] In one embodiment of the invention, an injector plasma torch with its own injector stream as carrier gas is used to generate an ionized field in a chamber comprising electrodes driven by multiple-phase AC currents, and filled with the preformulated gas to be reformed. As the preformulated gas passes directly through the chamber, the energizing and reformation processes are enhanced. Various embodiments of the Gas Manipulators as described below may still be utilized to ensure that the plumes of the injector plasma torch are directed precisely into the gaps of the primary electrodes.

[0466] Referring to FIGS. 21A and 21B, various embodiments of the gas reformulating system may be conceived based on the configurations of the energizing sources, additive streams and gas inputs and gas outputs.

[0467] The gas reformulation system may also be designed for separation of the gas stream into smaller streams which undergo parallel reformulation. Referring to FIGS. 56A and 56B, each of the smaller gas streams pass through dedicated reformulation zones created by independent energizing sources. FIG. 56B shows the use of transferred arc torches. FIG. 56C shows that the dedicated reformulation zone for each separate gas stream may be created by multiple gas energizing sources. FIG. 56D shows the embodiment of FIGS. 56A and 56B where mixing elements are introduced in the path of each of the smaller gas streams.

[0468] FIGS. 57A-C show three gas reformulating systems where the gas energizing sources are positioned at angles in the reformulation chamber. The sources may either direct its energizing field towards the flow of gas or against it; or combination thereof.

[0469] The chamber may further include one or more ports for secondary torch heat sources to assist in the pre-heating or torch heating of the chamber. Preformulated Gas Directing Devices

[0470] Gas manipulators may enhance the exposure of the preformulated gas with the gas energization field by manipulating directly or indirectly, using active or passive means or both, the spatial distribution of the preformulated gas within the chamber(s) and its dynamic evolution thereof. Such Gas Manipulators may be separate structural devices. Examples include, without limitation, structural devices such as baffles and deflectors that direct the preformulated gas more effectively towards and through the gas energizing field. Other examples include the design of the chamber to create certain desired fluid dynamic flow paths.

[0471] In one embodiment of the invention, Gas Manipulators are also located at or near the initial gas inlet to ensure that the initial gas is of more uniform composition and/or temperature, and properly mixed with the process additives.

[0472] Referring to FIGS. 58A-C, and in accordance with one embodiment of the invention, the Gas Manipulators comprise of flow restrictors 3999 that alter the flow of the gases entering the chamber 3202. A worker skilled in the art will readily understand that the differences to the gas flow patterns are dependent on various factors including but not limited to the size and shape of the flow restrictors 3999 and their position.

[0473] The flow restrictors may be attached to the chamber using various fastening means. In one embodiment of the invention, the flow restrictor is suspended from the top (downstream end) of the chamber. In one embodiment of the invention, the flow restrictor is attached using brackets to the walls of the chamber.

[0474] Referring to FIGS. 59A and 59B, and in accordance with one embodiment of the invention, the flow restrictors 3999 extend for substantially the whole length of the chamber 3202 resulting in the formation of an annular space where gas reformation occurs. As shown in FIG. 74, the flow restrictor 3999 may be rotated using a motor 7001, an example of the use of active means for the direct manipulation of the off-gas streams. The rotation of the flow restrictors may be dynamically controlled, optionally in conjunction with a Control System that is designed to regulate and optimize the overall gas reforming process.

[0475] FIGS. 60A and 60B show the three dimensional views of a chamber comprising flow restrictors and directly coupled to a laterally oriented gasifier. The flow restrictors have to be designed to withstand the high temperatures typically present in a chamber.

[0476] FIGS. 61A-G show different flow restrictors, in accordance with various embodiments of the invention. In these figures, the plasma torches are shown to be at the same elevation. Alternately, the flow restrictors may be placed above or below the plasma torches. Additive ports are also shown below the torches for the injection of process additives, such as air and steam.

[0477] In one embodiment of the invention, as shown in FIG. 61A, the flow restrictor has two helical flights that are designed to induce more cyclical flow mixing of the incoming off-gas and the plasma plume. FIG. 61B shows a flow restrictor with two helical flights but with a different shape, in accordance with one embodiment of the invention. In one embodiment of the invention, as shown in FIG. 61D, one helical flight of the flow restrictor is larger than the other and further induces the cyclical flow and mixing of the off-gas with the plasma plumes. In one embodiment of the invention, as shown in FIG. 61G, the flight spiral only covers half of the restrictor before starting as two new flights. In one embodiment of the invention, as shown in FIGS. 61C-E, the flow restrictor is attached to a cooling pipe where a cooling medium (e.g., air, water, thermal oil) controls the temperature of the flow restrictor. In one embodiment of the invention as shown in FIG. 61E, additives (e.g., air, steam etc) flow from the top of the support rod to the bottom of the flow restrictor before it enters the off-gas stream. This design allows for cooling of the flow restrictor while pre-heating of the additives prior to their injection.

[0478] Referring to FIG. 62A and in accordance with one embodiment of the invention, the chamber comprises Gas
Manipulators in the form of one or more rotational shafts attached to a motor, each shaft comprising one or more disks, which may be carefully weighted for stable rotation. For embodiments with multiple disks on a shaft, the disks may be arranged in an off-set pattern. A worker skilled in the art will readily understand that the disks may incorporate cooling. Flow restrictors such as described above may be attached to the end of the rotational shaft.

[0479] FIG. 62B show different types of disks that may be attached to the rotational shaft. Referring to FIG. 62B, the disk has a section that allows gas to flow from one side of the disk to the other. Referring to FIG. 62B, the disk has a spiral section that is designed to pull the gases up and into the middle of the chamber. Alternately, the spiral section may be designed to push gases up and out to the edge of the chamber. Referring to FIGS. 62B, the rotational disk is a spoke with multiple blades. A worker skilled in the art will readily understand that the orientation and weight distribution of the blades should be balanced for stable rotation.

[0480] FIGS. 63A, 63B, show different embodiments of the rotational shaft such as shown in FIG. 74, wherein the top disk is allowed to rotate on ball bearings and is held in place by supports. Optionally, cooling fluids or additives can be piped through the center of the shaft. In one embodiment of the invention, as shown in FIG. 63A, there is a motor on top of one or more supports with a drive shaft attached to a wheel (sprocket) that turns. The mechanical energy turns the disk, and thus the shaft protruding into the chamber.

[0481] Referring to FIG. 63B, electromagnets are used either between the supports or as part of the supports to cause rotation. Referring to FIG. 63C and in accordance with one embodiment of the invention, electromagnets are used to stabilize the shaft in the chamber. The electromagnets can be used either as a primary or a secondary means for creating a rotational moment in the shaft and the disks. In one embodiment of the invention, the disk rotates independently of the shaft; for example, the shaft may be stationary or rotating at another speed or even another direction. In one embodiment of the invention, the disk has permanent magnets and cooling is done on the disk plane as it would be mostly hollow with a thermal fluid cooled ball bearing connection to the shaft.

Energizing Source Directing Devices

[0482] Energizing Source Directing Devices are Gas Manipulators that direct the physical orientation of the energizing source to change the dimensions of the gas energizing field, e.g., plasma plume directing devices, and/or changes to the energy supplied to a plasma-generating source, the flow rate of the working gas, etc. are non-limiting examples of aspects of the system of the invention that can be modified to effect changes in the dimensions of the gas energizing field.

[0483] Gas manipulators may also enhance the exposure of the preformulated gas with the gas energization field by manipulating directly or indirectly, using active or passive means or both, the spatial distribution of the gas energizing field (e.g. plasma plumes) within the chamber(s) and its dynamic evolution thereof. In one embodiment of the invention, this may be achieved by positioning and orientation of the energizing source (e.g. plasma torch).

[0484] In one embodiment of the invention, as shown in FIG. 65A, the Gas Manipulator is a deflector 3998 that redirects the plasma plumes 3997 from a plasma torch 3208. The proper redirection of the plasma plumes is dependent on various design factors of the deflector 3998 including but not limited to its distance from the plasma torch 3208, its angle of orientation vis-à-vis the direction of the plasma plume, its size in comparison to the width of the plasma plume, and its material of construction. Heat resistant materials ensure that the deflector can tolerate the high temperatures present proximal to the plasma torch 3208. A worker skilled in the art will readily know the different materials that can be used to withstand the high plasma temperatures.

[0485] Referring to FIG. 65B and in accordance with one embodiment of the invention, the Gas Manipulator is a Coanda-effect based deflector 3996 used to manipulate the plasma plume 3997.

[0486] Referring to FIGS. 66A and 66B, and in accordance with one embodiment of the invention, one or more fluidic jets 3208 (e.g. air nozzles) are used to redirect the plasma plumes 3997 generated by the plasma torch(es) 3208. The fluidic jets are an example of active means used for the direct manipulation of the plasma plumes. In one embodiment of the invention, the fluidic jets are dynamically controlled, optionally in conjunction with a Control System that is designed to regulate and optimize the overall gas reformulation process.

[0487] FIGS. 67A, 67D show other embodiments of deflectors that can be used for redirecting the plasma plumes within the chamber. In one embodiment of the invention, as shown in FIG. 67A, the deflector is attached to the plasma torch casing. By adjusting the shape of the deflector, the spread of the plasma plume dispersion may be controlled. For example, the deflector of FIG. 67B gives wider plume dispersion than the deflector of FIG. 67A.

[0488] FIGS. 67C, 67D show embodiments of the invention, where the deflector is not attached to the plasma torch casing. In one embodiment of the invention, as shown in FIG. 67D, the deflector is attached to the rotating shaft. A worker skilled in the art will understand that the finish (e.g. smooth, rough, or angled) of the deflector surface will affect the plume dispersion.

[0489] FIGS. 68A-D show different embodiments of the invention where the rotating shaft object has an uneven surface. The number of edges, torches and torch angles can be used to optimize the plasma plume and/or to evenly spread the plasma plume, thus maximizing the plume’s contact with the off-gases. In one embodiment of the invention, the plasma torches point directly to the center of the chamber.

[0490] In one embodiment of the invention as shown in FIG. 68A, the plasma torches are angled so that at least part of the plasma plumes hits the center object. Alternatively, the plasma plumes may be directed away from the central object. In one embodiment of the invention as shown in FIG. 36B, the shaft object is rotated in the opposite angle of the torch resulting in forcing the plasma plumes toward the outside of the chamber.

[0491] In one embodiment of the invention as shown in FIGS. 68C-D, the plasma plume is bounced off deflectors towards the central shaft. The deflectors may be mounted on the plasma torch casing, as shown in FIG. 68C, or on the walls of the chamber, as shown in FIG. 68D. The shafts in FIGS. 68C-D may be rotated in either direction.

[0492] Optionally, ports for mounting plasma torches may be fitted with a sliding mounting mechanism to facilitate the insertion and removal of the plasma torch(es) from the chamber and may include an automatic gate valve for sealing the port following retraction of the plasma torch(es). In one embodiment of the invention, the ports for the tangentially mounted plasma torches are located above the air inlets to
provide maximum exposure to plasma torch heat. Such mounting mechanisms may be modified to allow for adjust-
ability of the position of the gas energizing sources.

[0493] Referring to FIG. 70A and in accordance with one
embodiment of the invention, a plasma torch 3208 is posi-
tioned such that the gases injected into the chamber 3202
flows counter-current to the plasma plumes generated
thereby. A worker skilled in the art should readily understand
the variations in the spatial distribution of the plasma plumes
when the orientations and positions of the plasma torches are
varied.

[0494] In one embodiment of the invention, the gas ener-
gizing sources (e.g. plasma torches) are placed so that the
resulting zone (e.g. plasma plumes) is directed perpendicular
to the direction of the flow of the initial gases. In one embodi-
ment of the invention, the chamber is substantially cylindrical
and the plasma plumes are directed radially to the
substantially axial flow of the initial gas stream. Alter-
nately, the initial gas stream may be directed radially while
the plasma plumes are directed axially along the substantially
cylindrical gas refinement chamber. In one embodiment of
the invention, the chamber is substantially cylindrical and
the plasma plumes are directed tangentially, perpendicular to the
substantially axial flow of the initial gas stream.

[0495] FIG. 71 shows cross-sectional views of cylindrical
gas reformulating chambers with various arrangements of the
gas energizing sources resulting in associated changes in the
shapes and dimensions of the resulting gas energizing fields.
In one embodiment of the invention, the gas energizing
sources used may be either AC or DC plasma torches. FIG.
71A shows two gas energizing sources directed tangentially
into the chamber. Referring to FIG. 71B, the chamber com-
prises three electrodes with an arc passing between them.
The gas passes through this arc and plasma is formed and the
gas is reformulated. FIG. 71C shows a similar embodiment as
FIG. 71B, except that there is a central grounded electrode
where the arc from the electrodes on the wall are to. A worker
skilled in the art will understand that the ground electrode is
electrically shielded except at contact point. FIG. 71D shows
one exemplary embodiment where the chamber comprises
a plurality of gas energizing sources (either point directly in the
middle as shown, or in a swirl pattern) sufficient to ensure that
substantially all of the gas passing through the chamber is
energized. FIGS. 71E and 71F are similar to the embodiments
of FIGS. 71B and 71C, respectively, but with six torches (3 or
6 phase). Higher number of torches can also be similarly
considered for the embodiments of FIGS. 71B, 71C, 71E and
71F.

[0496] FIG. 40 shows two exemplary embodiments of the
invention, wherein the initial gas and/or preformulated gas
stream is introduced into a reformulation chamber directly in
through the gas energizing field created by a gas energizing
source.

[0497] Gas manipulators at least partially manipulate the
spatial distributions of the preformulated gas and the gas
energizing field relative to one another, and their dynamic
evolutions.

Gas Mixing Manipulators

[0498] In some embodiments, the Gas Manipulators are
designed and configured to substantially enhance the mixing
of the reformulating gas and the energetic species in the gas
energizing field. Additionally, the Gas Manipulators may also
enhance the turbulence throughout the process resulting in
improved mixing.

[0499] In one embodiment of the invention, the location and
positioning of process additive nozzles that are designed to
increase turbulence and mixing.

[0500] In one embodiment, the Gas Manipulators are one or
more baffles located in the chamber to induce turbulence and
thus mixing of the reformulating gas. Different baffle
arrangements are known in the art and include but are not
limited to cross bar baffles, bridge wall baffles, choke ring
baffle arrangements and the like. Baffles may also be located
at or near the initial gas inlet to ensure that the initial gas is of
more uniform composition and/or temperature, and properly
mixed with the process additives.

[0501] Referring to FIGS. 75A-B, turbulence may be cre-
ated either prior to or after the gas energizing sources. FIG.
75C shows three exemplary embodiments of means for cre-
ating turbulence: (i) passive grid; (ii) an active grid utilizing a
rotating shaft; and (iii) a shear generator. FIGS. 75 and 78
show additional exemplary embodiments of means for gener-
ating turbulence.

[0502] In one embodiment, the Gas Manipulators comprise
the design of the positioning of the energizing sources, which
can contribute to the mixing of the reformulating gas and the
energetic species in the gas energizing field. The energizing
sources may thus be positioned to optimize the gas reformu-
lation process; the positioning depends on various factors
including but not limited to the design of the gas reformulat-
ing chambers (chamber). In one embodiment of the invention,
two plasma torches are positioned tangentially to create the
same swirl directions as air and/or oxygen inputs do. In one
embodiment of the invention, two plasma torches are posi-
tioned at diametric locations along the circumference of the
chamber.

[0503] The arrangement of the process additive (the chemi-
ical composition contribution of which is discussed below)
inputs is based on a variety of factors including but not limited
to the design of the chamber, the desired flow, jet velocity,
penetration and mixing. Various arrangements of the process
additive ports and ports for the gas energizing sources are
contemplated by the invention.

[0504] For example, the oxygen inputs or ports, steam
inputs or ports and ports for the gas energizing sources may be
arranged in layers around the circumference of the chamber,
allowing for the tangential and layered injection of gas ener-
gizing zones, oxygen and steam. In one embodiment, there is
provided nine oxygen source(s) ports arranged in three layers
around the circumference of the chamber. In one embodiment
there is provided two steam input ports arranged in two layers
around the circumference of the chamber and diametrically
positioned. In embodiments where the air and/or oxygen
input ports are arranged in layers, they may be arranged to
maximize the mixing effects.

[0505] In one embodiment of the invention, the air and/or
oxygen input ports are positioned tangentially, thus allowing
the lower level input ports to premix the gas, torch heat it up,
and start a swirl motion in the gas. The upper level air input
ports can accelerate the swirl motion thereby allowing a re-
circulating vortex pattern to be developed and persisted.

[0506] Referring to FIG. 76 and in accordance with one
embodiment of the invention, the gas to be reformulated
together into the reformulation chamber resulting in
formation of swirls. The embodiment also shows an exem-
plary Gas Manipulator shaped and positioned to enhance the exposure of the gas stream with the gas energizing source.

[0507] In one embodiment, the lowest level of air input ports is composed of four jets which will premix the gases generated from a lower gasifier and torch heat it up. The other upper two levels of air nozzles provide main momentum and oxygen to mix gases and torch heat up to the temperature required. The arrangements of steam inputs or ports is flexible in number, levels, orientations and angle as long as they are located in a position to provide optimized capabilities to temperature control.

[0508] The oxygen and/or steam input ports may also be positioned such that they inject oxygen and steam into the chamber at an angle to the interior wall of the chamber which promotes turbulence or a swirling of the gases. The angle is chosen to achieve enough jet penetration based on chamber diameter and designed air input port flow and velocity. The angle may vary between about 50° and 70°.

[0509] The air input ports maybe arranged so that they are in the same plane, or arranged in sequential planes. In one embodiment the air input ports are arranged in lower and upper levels. In one embodiment, there are four air input ports at the lower level and another six air input ports at upper level in which these input ports are slightly higher than the other three to create cross-jet mixing effects.

[0510] Optionally, air can be blown into the chamber angularly so that the air creates a rotation or cyclonic movement of the gases passing through the chamber. The gas energizing sources (e.g. plasma torches) may be angled to provide further rotation of the stream.

[0511] In one embodiment of the invention, the air and/or oxygen and/or steam inputs comprise high temperature resistance atomizing nozzles or jets. Appropriate air nozzles are known in the art and can include commercially available types such as the type A nozzles and type B nozzles illustrated in FIGS. 79-80. The nozzles may be of a single type or different types. The type of nozzles may be chosen based on functional requirements, for example a type A nozzle is for changing the direction of air flows for creating the desired swirls and a type B nozzle is for creating high velocity of air flow to achieve certain penetrations, and maximum mixing.

[0512] The nozzles can be designed to direct the air at a desired angle. In one embodiment, the air jets are positioned tangentially. In one embodiment, angular blowing is achieved by having a deflector at the tip of the nozzle, thus allowing the inlet pipes and flanges to be square with the chamber.

[0513] In one embodiment of the invention, one or more air jets (e.g. air swirl jets) are positioned at or near the initial gas inlet to inject a small amount of air into the initial gas and create a swirling motion in the initial gas stream by taking advantage of the injected air’s velocity. The number of air swirl jets can be designed to provide substantially maximum swirl based on the designed air flow and exit velocity, so that the jet can penetrate to the center of the chamber.

Gas Catalytic Manipulators

[0514] Catalytic manipulators include catalysts and increase the efficiencies of the energy transference. A catalyst increases the rate of a chemical reaction, by lessening the time needed to reach equilibrium. A catalyst works by providing an alternate and easier pathway from reactants to products by a variety of mechanisms, but in each case by lowering the activation energy of the reaction. Homogeneous catalysts are present in the same phase as the reactants and function by combining with the reacting molecules or ions to form unstable intermediates. These intermediates combine with other reactants to give the desired product and to regenerate the catalyst. Heterogeneous catalysts are present in a phase different from that of the reactants and products. They are usually solids in the presence of gaseous or liquid reactants. Reactions occur at the surface of heterogeneous catalysts. For this reason catalysts are usually finely divided solids or have particle shapes that provide a high surface-to-volume ratio. The cracking of petroleum and the reforming of hydrocarbons are common industry applications of the use of heterogeneous catalysts. One difficulty in the use of heterogeneous catalysts is that most of them are readily “poisoned” wherein impurities in the reactants coat the catalyst with un-reactive or modify its surface, so that the catalytic activity is lost. Frequently, but not always, the poisoned catalyst can be purified and used again.

[0515] The use of appropriate catalysts in the gas reformulating system may reduce the energy levels required for the gas reformulating process, by providing alternate reaction pathways. The precise pathway offered by a catalyst will depend on the catalyst used. The feasibility of the use of catalysts in gas reformulation systems, in general, depends on their lifetimes. Lifetimes of catalysts may be shortened by “poisoning”, i.e., the degradation in their catalytic capabilities due to impurities in the gas.

[0516] The gas reformulating system may be designed to allow for easy replacement of the catalysts. In one embodiment of the invention, catalysts are incorporated into the gas reformulating chambers in the form of a bed mounted on a sliding mechanism. The sliding mechanism allows for easy removal and replacement of the catalyst bed. The bed may be inserted at various locations in the gas reformulating system.

[0517] In one embodiment of the invention, off-gas from a gasification chamber which is at a high temperature contacts a catalyst which effectively lowers the energy threshold required for gas reformulation, such that the off-gas stream undergoes reformulation prior to exposure to a gas energizing field. In one embodiment of the invention, therefore, the gas reformulating system comprises a catalyst at a location upstream of the gas energizing source(s). In one embodiment, as disclosed in FIG. 89 catalytic beds are inserted before and/or after the gas energizing sources (e.g. plasma torches).

[0518] The catalytic capability will also depend on the temperature of operation. The appropriate operating temperature ranges for various catalysts are known in the art. The gas reformulating system may incorporate adequate cooling mechanisms to ensure that the catalysts are maintained within their optimal operating temperature ranges. Additives such as steam, water, air, oxygen or recirculated reformulated gas may be added to help increase or decrease the temperature near the catalyst beds. A worker skilled in the art will understand that the specific additive chosen to control the temperature will depend on the position of the catalyst bed and the gas temperatures thereat.

[0519] The irregularity of the catalyst surface and good contact between the large organic molecules and the surface will increase the opportunity for reformulation into smaller molecules, such as H₂ and CO.

[0520] Catalysts that may be used include but are not limited to olivine, calcined olivine, dolomite, nickel oxide, zinc oxide and char. The presence of oxides of iron and magnesium in olivine gives it the ability to reformulate longer
hydrocarbon molecules. A worker skilled in the art will understand to choose catalysts that do not degrade quickly in the gas environment of the system.

[0521] Both nonmetallic and metallic catalysts may be used for enhancing the reformulation process. Dolomites in calcined form are the most widely used nonmetallic catalysts for reformulation of gases from biomass gasification processes. They are relatively inexpensive and are considered disposable. Catalytic efficiency is high when dolomites are operated with steam. Also, the optimal temperature range is between about 800°C and about 900°C. The catalytic activity and the physical properties of dolomite degrade at higher temperatures.

[0522] Dolomite is a calcium magnesium ore with the general chemical formula CaMg(CO₃)₂ that contains ~20% MgO, ~30% CaO, and ~45% CO₂ on a weight basis, with other minor mineral impurities. Calcination of dolomite involves decomposition of the carbonate mineral, eliminating CO₂ to form MgO-CaO. Complete dolomite calcination occurs at fairly high temperatures and is usually performed at 800°C-900°C. The calcination temperature of dolomite, therefore, restricts the effective use of this catalyst to these relatively high temperatures.

[0523] Olivine, another naturally occurring mineral has also demonstrated catalytic activity similar to that of calcined dolomite. Olivine is typically more robust than calcined dolomite.

[0524] Other catalytic materials that may be used include but are not limited to carbonate rocks, dolomitic limestone and silicon carbide (SiC).

[0525] Char can act as a catalyst at lower temperatures. In one embodiment of the invention, the gas reformulation system is operatively linked to a gasifier, and at least part of the char created within the gasifier is moved to the gas reformulating system for use as a catalyst. For embodiments utilizing char as catalyst, the catalyst bed is typically placed before the energizing zone such as provided by plasma torches.

[0526] FIG. 81 shows a fixed bed of char used as a catalyst in the reformulation chamber. The char used for reforming may be obtained from a gasifier as shown in FIG. 82. This may be particularly applicable when the gas reformulating chamber is operatively linked to a gasifier and used to reformulate the gases generated therefrom. The char may be moved to a residue conditioning chamber or a carbon converter once it loses its catalytic properties.

[0527] FIG. 83 shows exemplary configuration of a gasifier operatively linked to a plasma torch-based gas reformulating chamber wherein the char created in the gasifier aids in catalytic cracking of the off-gases created by gasification. The catalytic cracking achieved in the latter stage of the gasifier is followed by further gas reformulation due to the exposure of the gas with the gas energizing field created by the plasma torch. Various types of gasifiers as would be readily known to worker skilled in the art such as fluidized bed gasifiers and entrained flow gasifiers may also be utilized.

[0528] In one embodiment of the invention, the initial gas is heated to a temperature of 900-950°C and passed over a nickel-based catalyst whereby tar components and light hydrocarbons including methane are converted into CO and H₂. Nickel-based catalysts may be particularly useful when the initial gas contains minimal amounts of sulphur species (such as hydrogen sulphide), such as for example, gas produced by gasification of biomass. Life-times of nickel-based catalysts may be enhanced by the use of promoters such as rare metals.

[0529] In one embodiment of the invention as shown in FIG. 84, a catalytic bed is installed right after the gasifier and transforms the majority of the volatiles. The inlet temperature of the catalytic bed may be raised from 600 to 950°C by combusting a small fraction of the volatiles. The outlet temperature of the catalytic bed is expected to drop to 850°C and the outlet gas is fed into the gas energizing field for further reformulation. The gas energizing zone may be operated at 1000°C. For this purpose and the resulting syngas is sent to the recuperator to start the subsequent gas cleanup process.

[0530] In one embodiment of the invention as shown in FIG. 85, the volatiles from the gasifier passes through the gas energizing zone wherein the temperature is between about 900°C and about 1000°C. The catalytic bed is used for further reformulation. The temperature of the syngas is then heated to 900°C by combusting a small fraction of it and fed into the catalytic bed. The resulting syngas at 850°C is sent optionally for further gas cleanup.

[0531] In one embodiment of the invention as shown in FIG. 86, heat recovery is achieved before the catalytic bed. The majority of the volatiles from the gasifier are reformulated in the gas energizing zone at temperatures of about 1000°C. The hot output gas passes through a heat exchanger (or a recuperator) to preheat process air whereupon its temperature drops to around 700°C. The cooled syngas is then heated to 900°C by combusting a small fraction of it and fed into the catalytic bed. The resulting syngas at 850°C is sent optionally for further gas cleanup.

[0532] For embodiments where the catalytic bed is placed prior to energizing field, the gas temperature is typically appropriate for high catalytic activity. However, for embodiments where the catalytic bed is after the energizing field, such as produced by plasma torches, the gas temperature might be too high for most typical catalysts such as olivine, dolomite, and many others. The gas temperatures may be reduced to appropriate levels (to avoid the degradation of the catalyst beds) by the circulation of cooling fluids, as shown in FIG. 87. Appropriate cooling fluids may include but are not limited to recirculated reformulated gas (as shown in the embodiment of FIG. 88), water and steam.

[0533] For embodiments where the catalytic bed is after the recuperator (heat exchanger) the recirculated steam of reformulated gas may be inserted either prior or after the recuperator.

[0534] In one embodiment of the invention, the reforming zone comprises a catalyst bed and the catalytic manipulators are also designed to enhance the exposure of the preformulated and/or reformulating gas to the catalyst bed.

A Gas Stabilizing Zone

[0535] This system provides one or more stabilizing zones whereby the newly formed molecules are de-energized (e.g., cooled or removed from the influence of catalysts or energizing sources) to ensure they maintain the desired characteristics e.g., the designed chemical composition.

[0536] The temperature of the gas entering the stabilizing zone will range from about 400°C to over 1000°C. The temperature may optionally be reduced by a heat exchange system in the stabilizing zone of the gas reformulating system, which recovers heat from, and thus cools, the reformu-
lated gas. Such a reduction in the gas temperature may be necessitated by downstream applications and components. [0537] Referring to FIG. 54B, the gas reformulating chamber 3002 is a stabilization zone may be specifically shaped to facilitate the de-energization and stabilization of the newly formed molecules. The gas reformulating chamber 3002 is a generally cylindrically shaped chamber having a bulbous expansion downstream of the plasma or optionally proximal to the one or more reformulated gas outlets 3006. The bulbous expansion by allowing for the de-energization of the gas and thereby stabilized the newly formed molecules.

Optional Heat Recycling Means

[0538] Heat may be recovered in the stabilization zone or downstream from the stabilizing zone. The recovered heat may be used for various purposes, including but not limited to the following: heating the process additives (e.g. air, steam) for the gas reformulating process; generating electricity in combined cycle systems. The recovered electricity can be used to drive the gas reformulation process, thereby alleviating the expense of local electricity consumption. The amount of heat captured depends on a variety of factors including but not limited to the characteristics (e.g. chemical composition, flow rates) of the initial gas and reformulated gas.

[0539] In one embodiment of the invention, the heat recovered from the stabilizing zone of the gas reformulating system is supplied to a Gasification System operated in conjunction with the gas reformulating system. The heat exchanger may be operated in conjunction with a Control System optionally configured to minimize energy consumption and maximize energy production/recovery, for enhanced efficiency.

[0540] In one embodiment of the invention, a gas-to-fluid heat exchanger is used in the stabilizing zone to transfer the heat from the reformulated gas to a fluid resulting in a heated fluid and a cooled gas. The heat exchanger comprises means (e.g. conduit systems) for transfer of the reformulated gas and fluid to and from the heat exchanger. Suitable fluids include but are not limited to air, water, oil, or another gas such as nitrogen or carbon dioxide.

[0541] The conduit systems may optionally employ one or more regulators (e.g. blowers) appropriately located to manage the flow rates of the reformulated gas and the fluid. These conduit systems may be designed to minimize heat losses to enhance the amount of sensible heat that is recoverable from the reformulated gas. Heat loss may be minimized, for example, through the use of insulating barriers around the conduits, comprising insulating materials as are known in the art and/or by reducing the surface area of the conduits.

[0542] In one embodiment of the invention, the gas-to-fluid heat exchanger is a gas-to-air heat exchanger, wherein the heat is transferred from the reformulated gas to air to produce a heated air stream. In one embodiment of the invention, the gas-to-fluid heat exchanger is a heat recovery steam generator, wherein the heat is transferred to water to produce heated water or steam.

[0543] Different classes of heat exchangers may be used including shell and tube heat exchangers, both of straight, single-pass design and of U-tube, multiple pass design, as well as plate-type heat exchangers. The selection of appropriate heat exchangers is within the knowledge of a worker of ordinary skill in the art.

[0544] As particulate matter may be present in the gas, the gas-to-air heat exchanger is typically designed for a high level of particulate loading. The particle size may vary typically from about 0.5 to about 100 microns. In one embodiment depicted in FIG. 90, the heat exchanger is a single pass vertical flow heat exchanger 51043, wherein the reformulated gas 5020 flows in the tube side and the air 5010 flows on the shell side. The reformulated gas 5020 flows vertically in a “once through” design, which minimizes areas where build up or erosion from particulate matter could occur. The reformulated gas velocities should be maintained to be high enough for self-cleaning, while still minimizing erosion, and may vary from about 3000 to about 5000 mm/sec.

[0545] Due to the significant difference in the air input temperature and hot product gas, each tube in the gas-to-air heat exchanger preferably has individual expansion bellows to avoid tube rupture. Tube rupture may occur where a single tube becomes plugged and therefore no longer expands/contracts with the rest of the tube bundle. In those embodiments where the air pressure is greater than the reformulated gas pressure, tube rupture presents a high hazard due to problems resulting from air entering gas mixture.

[0546] After heat is recovered in the gas-to-fluid heat exchanger, the cooled reformulated gas may still contain too much heat for the systems further downstream. Selection of an appropriate system for further cooling of the product gas prior to conditioning is within the knowledge of a worker skilled in the art.

[0547] In one embodiment, as depicted in FIG. 91, the hot reformulated gas 5020 passes through the gas-to-air heat exchanger 5103 to produce a partially cooled reformulated gas 5023 and heated exchange-air 5015. The air input to the heat exchanger may be supplied by a process air blower. The partially cooled reformulated gas 5023 undergoes a dry quench step 6103, where the addition of a controlled amount of atomized water 6030 results in further cooled product gas 5025.

[0548] The cooling of the reformulated gas may also be achieved using a wet, dry or hybrid cooling system. The wet and dry cooling systems may be direct or indirect. Appropriate cooling systems are known in the art and as such a worker skilled in the art in view of the requirements of the system would be able to select an appropriate system.

[0549] In one embodiment, the cooling system is a wet cooling system. The wet cooling system can be direct or indirect. In cooling systems that utilize indirect wet cooling, a circulating cooling water system is provided which absorbs the heat from the reformulated gas. The heat is expelled to the atmosphere by evaporation through one or more cooling towers. Alternatively, to facilitate water conservation, the water vapor is condensed and returned to the system in closed loop.

[0550] In one embodiment, the cooling system is a dry cooling system. The dry cooling system can be direct or indirect. In one embodiment, the dry cooling system is a draft dry cooling system. Although, dry cooling will add modestly to the cost of the facility, it may be preferred in areas with a limited water supply.

[0551] In one embodiment, the syngas cooler is a radiant gas cooler. Various radiant gas coolers are known in the art and include those disclosed in US Patent Application No. 20070119577, and U.S. Pat. No. 5,233,943.

[0552] The reformulated gas may also be cooled down by direct water evaporation in an evaporated such as quenchers.

[0553] The exit temperature of the reformulated gas may also be reduced by re-circulating, through appropriately
located inlets, cooled reformulated gas to the stabilizing zone of the gas reformulating system for mixing with newly produced reformulated gas.

Optional Gas Additive Zones

[0554] The chamber may optionally comprise one or more process additive ports for injection of process additives, such as oxygen sources, carbon dioxide, other hydrocarbons or additional gases, into the chamber. Oxygen sources known in the art include but are not limited to oxygen, oxygen-enriched air, air, oxidizing medium, steam and other oxygen sources as would be readily understood by a worker skilled in the art. In one embodiment, the chamber comprises one or more port(s) for air and/or oxygen inputs and optionally one or more ports for steam inputs.

[0555] The optional addition of process additives such as air, steam and other gases, may also be achieved without inlets dedicated to their injection. In one embodiment of the invention, the process additives may be added into the source of gas or conduits wherefrom the Gas Reformulating System obtains its initial gas stream. Process additives may also be added to the chamber through the gas energizing sources, such as plasma torches.

[0556] Optionally, ports or inlets may be provided so that reformulated gas not meeting quality standards may be re-circulated into the chamber for further processing. Such ports or inlets may be located at various angles and/or locations to promote turbulent mixing of the materials within the chamber.

[0557] One or more ports can be included to allow measurements of process temperatures, pressures, gas composition and other conditions of interest.

[0558] Optionally, plugs, covers, valves and/or gates are provided to seal one or more of the ports or inlets in the chamber 3002. Appropriate plugs, covers, valves and/or gates are known in the art and can include those that are manually operated or automatic. The ports may further include appropriate seals such as sealing glands.

Optional Gas Cleaning Zones

[0559] The system optionally comprises one or more gas cleaning zones, located downstream of the gas stabilizing zone. Embodiments of the invention comprising one or more gas cleaning zones incorporate means of injecting substances into the chamber that clean the gas, prior to its exit from the system. For example, oxygen and/or steam can be atomized by high temperature resistance atomizing nozzles and injected into the chamber to clean the stabilized, reformulated gas.

Optional Further Processing

[0560] The stabilized reformulated gas stream may undergo further processing before being utilized in a downstream application, stored or flared off. For example, the reformulated gas may be passed through a gas conditioning system where particulate matter, acid gases (HCl, H2S) and/or heavy metals may be removed, and the temperature and/or humidity of the gas may be adjusted. For example, dust particles, if present, may be removed from the gas using a venturi scrubber, including an electro-filter or fabric baghouse filter. The reformulated gas may also be passed through a homogenization chamber, the residence time and shape of which is designed to encourage mixing of the reformulated gas to attenuate fluctuations in the characteristics thereof.

Gas Reformulating Chambers

[0561] Referring to FIG. 35 and in accordance with one embodiment of the invention, the chamber 3002 of the Gas Reformulating System 3000 comprises one or more initial gas inlets 3004, one or more reformulated gas outlet(s) 3006, one or more gas energizing sources (e.g. plasma sources) 3008, and optionally one or more process additive (e.g. oxygen) inputs 3010. Gas Manipulators (not shown in the figure), and a Control System.

[0562] In one embodiment as shown in FIG. 36, the Gas Reformulating System 3000 is designed so that the chamber 3002 is coupled directly to a source of gas (e.g. gasifier, gas storage tank) and in gaseous communication therewith. To facilitate maintenance or repair, the Gas Reformulating System 3000 may optionally be reversibly coupled to the gasifier such that the Gas Reformulating System 3000, if necessary, may be removed.

[0563] In one embodiment as demonstrated by FIG. 37, the Gas Reformulating System 3000 is a stand-alone unit which receives initial gas from two sources of gas via separate piping or conduits. In one embodiment as shown in FIG. 38, the individual gas streams are combined before they are injected into the Gas Reformulating System 3000. In stand-alone units, the Gas Reformulating System may further comprise appropriate support structures.

[0564] An induction blower may be provided downstream of the chamber and in gaseous communication therewith to maintain the pressure of the chamber at a desired pressure, for example a pressure of about 0 to ~5 mbar.

[0565] The efficacy of the gas reformulating processes occurring within a chamber depends on various factors including but not limited to the chamber internal volume and geometry, gas flow rate, the distance the gas travels and/or the path of the gas through the chamber (i.e., a straight linear passage or a swirling, cyclonic, helical or other non-linear path). The chamber must therefore be shaped and sized to obtain the desired flow dynamics of the gas therein. For example, air jets can be used to promote a swirling flow of the gas through the chamber, such that the passage of the gas is non-linear. Flow modeling of the overall Gas Reformulating System can be used to ensure that a particular chamber design promotes the conditions (e.g. proper interaction of the process inputs) required for the desired gas reformulation.

[0566] The one or more chambers of the Gas Reformulating System may be designed in a variety of shapes and be disposed in a variety of positions, as would be readily known to a worker skilled in the art. The chamber can be oriented substantially vertically, substantially horizontally or angularly.

[0567] In one embodiment of the invention, the chamber is a straight tubular or venturi shaped structure comprising a first (upstream) end and a second (downstream) end and is oriented in a substantially vertical position or a substantially horizontal position. In one embodiment of the invention, the chamber is a straight cylinder with a length-to-diameter ratio ranging between about 2 to about 6, with associated effects on achievable gas velocities. In one embodiment, the length-to-diameter ratio of the chamber is 3:1.

[0568] In one embodiment as depicted in FIG. 92A, the chamber 3202 is configured for direct coupling to a gasifier, and is a straight, substantially vertical, refractory-lined,
capped, cylindrical structure with an open bottom (upstream) end 3204 and one reformulated gas outlet 3206 proximal to or at the top (downstream) end of the chamber. The top (downstream) end of the chamber may be capped with a refractory-lined lid 3203, which may be removable sealed to the chamber in order to facilitate maintenance or repair.

[0569]  The wall of the chamber may be lined with refractory material or otherwise fabricated to withstand high temperatures. The chamber may be encapsulated with a water jacket for cooling and/or generation of steam or recovery of usable torch heat. The chamber may have multiple walls, along with a cooling mechanism for heat recovery, and the gas reformulating system may also include heat exchangers for high pressure/high temperature steam production, or other heat recovery capability.

[0570]  Conventional refractory materials that are suitable for use in a high temperature, un-pressurized chamber are well-known to those skilled in the art and include, but are not limited to, high temperature fired ceramics, i.e., aluminum oxide, aluminum nitride, aluminum silicate boron nitride, zirconium phosphate, glass ceramics and high alumina brick containing principally, silica, alumina, chromia and titania, ceramic blanket and insulating firebrick. Materials such as Didier Didolfo 89CR and Radex Compacell V253 may be used where a more robust refractory material is required.

[0571]  In one embodiment, the refractory design has multiple layers with a high density layer on the inside to resist the high temperature, erosion and corrosion present within the chamber and to provide a heat sink to reduce fluctuations in the gas properties. Outside the high density material is a lower density material with lower erosion resistance properties but higher insulation factor. Optionally, outside this layer is a very low density foam board material with very high insulation factor that can be used because it will not be exposed to a corrosive environment which can exist within the chamber. The multilayer design can further optionally comprise an outside layer, between the foam board and the vessel shell that is a ceramic blanket material to provide a compliant layer to allow for differential expansion between the solid refractory and the vessel shell. Appropriate materials for use in a multilayer refractory are well known in the art.

[0572]  In one embodiment, the multilayer refractory can further comprise segments of compressible refractory separating sections of a non-compressible refractory to allow for expansion of the refractory. The compressible layer can optionally be protected from erosion by overlapping extendible high density refractory. In one embodiment, the multilayer refractory can comprise an internally oriented chromia layer; a middle alumina layer and an outer insulating board layer.

[0573]  In some embodiments of the invention, the chamber includes a layer of up to about seventeen inches, or more, of specialty selected refractory lining throughout the entire chamber to ensure maximum retention of processing heat while being impervious to chemical reaction from the reactive intermediates formed during processing.

[0574]  The refractory lining in the bottom section of the chamber can be more prone to wear and deterioration since it must withstand higher temperatures from the operating sources of plasma torch heat. In one embodiment, therefore, the refractory in the lower section is designed to comprise a more durable “hot face” refractory than the refractory on the chamber walls and top. For example, the refractory on the walls and top can be made of DIDIER RR30 brick, and the different “hot face” refractory for the lower section can be made with RADEX COMPAC-FLO V253.

[0575]  In embodiments in which the chamber is refractory-lined, the wall of the chamber can optionally incorporate supports for the refractory lining or refractory anchors.

[0576]  The chamber may have a collector for solid particulate matter. For embodiments where the chamber is operated in conjunction with a gasifier, any matter that is collected may be fed into a gasifier for further processing or into a solid residue conditioning chamber, for further processing. Collectors for solid particulate matter known in the art include but are not limited to centrifugal separators, inertial impingement baffles and filters. For embodiments where the Gas Reformulating System is directly coupled to the gasifier, additional solid particulate collectors may not be necessary as particulates formed may, in part, fall directly back into the gasifier.

[0577]  Ports, Inlets and Outlets for the Chamber

[0578]  The chamber comprises one or more initial gas inlets that feed the initial gas into the chamber for reformulation, and one or more reformulated gas outlets to pass the reformulated gas further downstream. The inlet may comprise an opening or, alternatively, may comprise a device to control the flow of initial gas into the chamber and/or a device to inject the initial gas into the chamber. The device may include Gas Manipulators for appropriate injection of the initial gas for enhanced reformulation, and/or include sensing elements for measuring the various characteristics of the initial gas.

[0579]  The initial gas inlets may be incorporated to promote concurrent, countercurrent, radial, tangential, or other feed flow directions. In one embodiment, the single initial gas inlet has an increasingly conical shape.

[0580]  The initial gas inlets may be located at or near the first or upstream end of the chamber. In one embodiment, the inlet comprises the open first end of the chamber, whereby it is in direct gaseous communication with the gas source e.g. gasifier. In one embodiment, the inlet comprises an opening located in the closed first (upstream) end of the chamber. In one embodiment, the inlet comprises one or more openings in the wall of the chamber proximal to the first (upstream) end.

[0581]  In embodiments in which the gasifier and Gas Reformulating System are directly coupled, the attachment site on the gasifier for coupling to the Gas Reformulating System may be strategically located to optimize gas flow and/or maximize mixing of the initial gas prior to entering the chamber. In one embodiment, the chamber is located at the center of the gasifier.

[0582]  In embodiments in which the chamber is connected to one or more gasifiers, one or more initial gas inlets of the chamber may be in direct communication with the one or more gasifiers through a common opening or as shown in FIG. 37, may be connected to the gasifier via piping 3009 or via appropriate conduits.

[0583]  The reformulated gas produced in the reformulating reaction exits the chamber through one or more reformulated gas outlets located at or near the second or downstream end. The outlet may comprise an opening or, alternatively, may comprise a device to control the flow of the reformulated gas out of the chamber. The device may include sensing elements for measuring the various characteristics of the reformulated gas.

[0584]  In one embodiment, the outlet comprises the open second (downstream) end of the chamber. In one embodiment, the outlet comprises one or more openings located in
the closed second (downstream) end of the chamber. In one embodiment, the outlet comprises one or more openings in the wall of the chamber near the second (downstream) end.

The chamber optionally comprises various ports including one or more process additive ports, one or more ports for gas energizing sources, optionally one or more access ports, view ports and/or instrumentation ports. Gas energizing sources include but are not limited to plasma-based sources (e.g. plasma torches), hydrogen burners and optional secondary sources. Ports, inlets and outlets may be incorporated at various angles and/or locations to enhance interaction of the reactant flows within the chamber.

Optional Systems for Inclusion in the Gasification and Gas Reformulation Systems

The Heat Recovery Systems

In one embodiment, heat recovery systems facilitate the efficient recovery of sensible heat from the hot syngas product to heat air for use in the gasification process. In one embodiment, heat recovery systems facilitate the generation of steam that can be used to drive downstream processing of unconventional oil sources.

FIG. 11 is a schematic diagram depicting the recovery of heat from the syngas produced in the gas reforming chamber using the heat recovery subsystem of the instant invention. In this embodiment, the heat recovery system is a syngas-to-air heat exchanger, wherein the heat from the syngas produced in the plasma gas reforming chamber is used to heat ambient air, thereby providing heated air and cooled syngas. This heated air can be passed into the volatilization and/or secondary chambers and thus used to drive the gasification process. The cooled syngas is ready for subsequent gas conditioning steps and sensible heat is recovered and transferred as heated air to various stages in the gasification process.

Different classes of heat exchangers may be used in the present system, including shell and tube heat exchangers, both of straight, single-pass design and of U-tube, multiple pass design, as well as plate-type heat exchangers. The selection of appropriate heat exchangers is within the knowledge of the skilled worker.

The heat recovery subsystem employs a conduit system through which the syngas is transported to the heat exchanging means for recovery of the syngas sensible heat. The conduit system will optionally employ one or more regulators and/or blowers, located throughout the system to provide a means for managing the flow rate of the syngas product.

In one embodiment, the heat recovery system employs a conduit system for transferring the heated air to the primary chamber and/or the secondary chamber, where it is introduced to the respective chambers via air inlets. In one embodiment, the system comprises means for controlling the relative amounts of heated air that is distributed to the primary chamber and the secondary chamber, to ensure that sufficient heated air is provided to carry out the volatilization and processed feedstock/char conversion stages, respectively. Accordingly, the air conduit system optionally employs one or more regulators, flow meters and/or blowers, located as required throughout the system to provide a means for controlling the flow rate and/or distribution of the heated air. The heated air conduits also optionally comprise means for diverting the heated air, for example, to venting outlets or to optional additional heat exchange systems.

The heat recovery system optionally recovers further sensible heat from the hot syngas using a heat exchanging means to transfer the heat from the syngas to water, thereby producing steam and yet further cooled syngas. The further sensible heat is recovered from the syngas through a second heat exchange means, for example, a heat recovery steam generator or waste heat boiler, which uses the recovered heat to generate steam. The steam can be used as a process steam additive during the gasification process to ensure sufficient free oxygen and hydrogen to maximize the conversion of the feedstock into the syngas product. The steam produced may also be used to drive rotating process equipment, for example, the air blowers, as well as syngas blowers.

In one embodiment, the heat recovery system comprises a heat recovery steam generator (HRSG) located downstream from the syngas-to-air heat exchanger. In such an embodiment, the HRSG is a shell and tube heat exchanger designed such that the syngas flows vertically through the tubes and water is boiled on the shell side.

Gas Quality Conditioning System (GQCS)

In one embodiment, the facility comprises a first and a second GQCS. In this embodiment, particulate matter removed from the syngas in the first GQCS is processed in a melting chamber and converted to slag and a secondary syngas. The secondary gas is then directed back to the first GQCS to undergo further processing and removal of contaminants.

It is contemplated that in some circumstances it may be necessary to process the syngas through a gas conditioning system (GCS) to remove selected impurities prior to input of the syngas into an energy producing component as the syngas produced by the Gasification System can contain particulate matter, heavy metals, and acid gases (HCl, H2S), all of which are hazardous to the workplace and the environment in high enough concentrations and are typically subject to emission control requirements. The composition of the synthesis gas and the type of contaminants present is determined in part by the composition of the feedstock undergoing gasification. For example, if high sulfur coal is the primary feedstock, the syngas product will contain high amounts of sulfur that must be removed prior to use of the syngas product in downstream applications. Thus, after the syngas is cooled in the HRSG, it enters a GQCS to remove undesired materials.

The GQCS can include acid gas removal components, heavy metal removal components, and/or particle removal units. The GQCS may optionally include humidity control units or temperature control units to modulate the humidity or temperature of the gas as it passes through the GQCS. One or more of these units may be incorporated into the GQCS in order to carry out processing steps to produce a “processed” syngas of desired characteristics. The presence and sequence of processing steps required is determined by the composition of the synthesis gas and the contaminants present therein. Suitable units as listed above for conditioning gas are known in the art and it is within the capabilities of one of skill in the art to determine which of these units are required in order to produce a syngas of the desired characteristics. For example, the design of the GQCS that is incorporated as part of the overall system can be varied depending on the end products required. Alternatively, the sizing of the GQCS is varied based on the feedstock used in the converter, the converter design, syngas requirements, for example.
In one embodiment, the syngas is processed through a GCQCS prior to transfer to an energy or reagent producing component. In one embodiment, the GCQCS is designed to remove particulate matter or ash, heavy metals and sulphur from the syngas. In one embodiment, the design of the GCQCS varies depending on whether the syngas produced is to be used in the generation of H₂, steam, chemicals, or electricity. Once the synthesis gas is cleaned and conditioned, the output gas is then optionally stored or directed to the required downstream application.

Other Optional Systems

The Gasification System can include additional components as necessary in order to further process the syngas. These additional components may be included at different stages of the Gasification System. For example, the additional components may be included at stages prior to entry of the gas into the GCQCS, or they may be included at stages after the syngas is processed through the GCQCS.

For example, in one embodiment where the Gasification System uses bitumen as a feedstock, a cooler and tar separator can be included in the facility. There are many possible syngas cooling technologies and tar removal technologies, however these designs usually include cooling of the gas on the surface of ducting to induce tar to condense out of the gas stream. Wall designs, fins, & flanges are usually designed to trap the tars against the wall where they can pour down into a catch; water-cooled jacketed cyclones are a good example of this process. It is important to design the system so that particulate matter if separated from the syngas at the same time as the tars is separated from the tars. This can usually be done with a strainer if the particles are large enough and the tars will flow though the strainer, otherwise a more aggressive separation technology may need to be used (distillation, evaporation etc.). The cooler and tar separator can be included after gas exits the gasifier and can function to remove tars from the syngas which can then be converted to light oil used as diluents in the oil industry.

In another embodiment where the Gasification System uses bitumen as a feedstock, a second gas reformulation zone can be included in the facility in order to increase the suitability of the syngas for use in an energy producing component such as a chemical plant for producing blue gases and light oils. In one embodiment, the facility includes a distillation column that can be used to separate heavy and light fractions from bitumen and tars. The light fractions can be used as diluents for bitumen transportation or other purposes. The heavy fractions can be then sent to the gasifier for use as a feedstock and any solids produced can be melted in the melting chamber.

In another embodiment, the syngas that is produced in the facility or processed through the GCQCS can optionally be stored in a gas storage tank or syngas regulation system prior to its use as a fuel in an energy producing component. The gas storage tank or syngas regulation system may be a standard fuel or surge tank, or may include regulation by way of a gas homogenization system, which includes a homogenization chamber. In the case of the latter, the chemical composition and other characteristics of the gas, such as flow rate, pressure, and temperature of the gas, may be adjusted to create a regulated gas that satisfies the requirements of a downstream application (i.e. an IGCC system, or a gas turbine). Different types of homogenization chambers for use with the gas homogenization system include, but are not limited to gasometers, gas holders, variable volume and fixed volume tanks. The gas homogenization chamber receives the syngas produced from the Gasification System and allows mixing of the syngas to attenuate any fluctuations in the chemical composition of the syngas in the homogenization chamber. Fluctuations in other gas characteristics, such as pressure, temperature and flow rate, will also be reduced during mixing of the syngas. The gas homogenization chamber is designed to receive syngas from a gasification process and retain the gas for a residence time sufficient for mixing of the gas to achieve a volume of gas with a consistent and/or specified chemical composition.

In one embodiment, the facility includes a gas storage system for storing cleaned and conditioned syngas prior to its utilization in electricity generating systems.

In one embodiment, the facility includes a GCQCS having a water-gas shift component for carrying out a water-gas shift reaction. The water-gas shift component carries out an inorganic reaction in which water and carbon monoxide react to form carbon dioxide and hydrogen. This reaction is known as water splitting. The carbon dioxide and hydrogen generated can be used in processing materials from tar sands.

The Control System

The systems and processes of the facility are managed by a Control System that provides means for monitoring and regulating the different stages of the processes to ensure the efficient conversion of the carbonaceous feedstock into a syngas product. The Control System also optionally provides for the production of a syngas product having a consistent and/or specified composition.

The Control System comprises one or more sensing elements for real-time monitoring of operating parameters of the system; and one or more response elements for adjusting operating conditions within the system to optimize the conversion reaction, wherein the sensing elements and the response elements are integrated within the system, and wherein the response elements adjust the operating conditions within the system according to the data obtained from the sensing elements.

In one embodiment of the present invention, a Control System may be provided to manage one or more processes implemented in, and/or by, the various systems and/or subsystems disclosed herein, and/or provide control of one or more process devices contemplated herein for affecting such processes. In general, the Control System may operate to control various local and/or regional processes related to a given system, subsystem or component thereof, and/or related to one or more global processes implemented within a system, such as a Gasification System, within or in cooperation with which the various embodiments of the present invention may be operated, and thereby adjusts various control parameters thereof adapted to affect these processes for a defined result. Various sensing elements and response elements may therefore be distributed throughout the controlled system(s), or in relation to one or more components thereof, and used to acquire various process, reactant and/or product characteristics, compare these characteristics to suitable ranges of such characteristics conducive to achieving the desired result, and respond by implementing changes in one or more of the ongoing processes via one or more controllable process devices.
[0608] The Control System generally comprises, for example, one or more sensing elements for sensing one or more characteristics related to the system(s), process(es) implemented therein, input(s) provided therefor, and/or output(s) generated thereby. One or more computing platforms are communicatively linked to these sensing elements for accessing a characteristic value representative of the sensed characteristic(s), and configured to compare the characteristic value(s) with a predetermined range of such values defined to characterise these characteristics as suitable for selected operational and/or downstream results, and compute one or more process control parameters conducive to maintaining the characteristic value with this predetermined range. A plurality of response elements may thus be operatively linked to one or more process devices operable to affect the system, process, input and/or output and thereby adjust the sensed characteristic, and communicatively linked to the computing platform(s) for accessing the computed process control parameter(s) and operating the process device(s) in accordance therewith.

[0609] In one embodiment, the Control System provides a feedback, feedforward and/or predictive control of various systems, processes, inputs and/or outputs related to the conversion of carbonaceous feedstock into a gas, so to promote efficiency of one or more processes implemented in relation thereto. For instance, various process characteristics may be evaluated and controllably adjusted to influence these processes, which may include, but are not limited to, the heating value and/or composition of the feedstock, the characteristics of the product gas (e.g. heating value, temperature, pressure, flow, composition, carbon content, etc.), the degree of variation allowed for such characteristics, and the cost of the inputs versus the value of the outputs. Continuous and/or real-time adjustments to various control parameters, which may include, but are not limited to, heat source power, additive feed rate(s) (e.g. oxygen, oxidants, steam, etc.), feedstock feed rate(s) (e.g. one or more distinct and/or mixed feeds), gas and/or system pressure/flow regulators (e.g. blowers, relief and/or control valves, flares, etc.), and the like, can be executed in a manner whereby one or more process-related characteristics are assessed and optimized according to design and/or downstream specifications.

[0610] Alternatively, or in addition thereto, the Control System may be configured to monitor operation of the various components of a given system for ensuring proper operation, and optionally, for ensuring that the process(es) implemented thereby are within regulatory standards, where such standards apply.

[0611] In accordance with one embodiment, the Control System may further be used in monitoring and controlling the total energetic impact of a given system. For instance, a a given system may be operated such that an energetic impact thereof is reduced, or again minimized, for example, by optimising one or more of the processes implemented thereby, or again by increasing the recuperation of energy (e.g. waste heat) generated by these processes. Alternatively, or in addition thereto, the Control System may be configured to adjust a composition and/or other characteristics (e.g. temperature, pressure, flow, etc.) of a product gas generated via the controlled process(es) such that such characteristics are not only suitable for downstream use, but also substantially optimised for efficient and/or optimal use. For example, in an embodiment where the product gas is used for driving a gas engine of a given type for the production of electricity, the characteristics of the product gas may be adjusted such that these characteristics are best matched to optimal input characteristics for such engines.

[0612] In one embodiment, the Control System may be configured to adjust a given process such that limitations or performance guidelines with regards to reactant and/or product residence times in various components, or with respect to various processes of the overall process are met and/or optimised for. For example, an upstream process rate may be controlled so to substantially match one or more subsequent downstream processes.

[0613] In addition, the Control System may, in various embodiments, be adapted for the sequential and/or simultaneous control of various aspects of a given process in a continuous and/or real time manner.

[0614] In general, the Control System may comprise any type of Control System architecture suitable for the application at hand. For example, the Control System may comprise a substantially centralized Control System, a distributed Control System, or a combination thereof. A centralized Control System will generally comprise a central controller configured to communicate with various local and/or remote sensing devices and response elements configured to respectively sense various characteristics relevant to the controlled process, and respond thereto via one or more controllable process devices adapted to directly or indirectly affect the controlled process. Using a centralized architecture, most computations are implemented centrally via a centralized processor or processors, such that most of the necessary hardware and/or software for implementing control of the process is located in a single location.

[0615] A distributed Control System will generally comprise two or more distributed controllers which may each communicate with respective sensing and response elements for monitoring local and/or regional characteristics, and respond thereto via local and/or regional process devices configured to affect a local process or sub-process. Communication may also take place between distributed controllers via various network configurations, wherein a characteristics sensed via a first controller may be communicated to a second controller for response thereof, wherein such distal response may have an impact on the characteristic sensed at the first location. For example, a characteristic of a downstream product gas may be sensed by a downstream monitoring device, and adjusted by adjusting a control parameter associated with the converter that is controlled by an upstream controller. In a distributed architecture, control hardware and/or software is also distributed between controllers, wherein a single but modularly configured control scheme may be implemented on each controller, or various cooperative modular control schemes may be implemented on respective controllers.

[0616] Alternatively, the Control System may be subdivided into separate yet communicatively linked local, regional and/or global control subsystems. Such an architecture could allow a given process, or series of interrelated processes to take place and be controlled locally with minimal interaction with other local control subsystems. A global master Control System could then communicate with each respective local control subsystems to direct necessary adjustments to local processes for a global result.

[0617] The Control System of the present invention may use any of the above architectures, or any other architecture commonly known in the art, which are considered to be within the general scope and nature of the present disclosure.
For instance, processes controlled and implemented within the context of the present invention may be controlled in a dedicated local environment, with optional external communication to any central and/or remote Control System used for related upstream or downstream processes, when applicable. Alternatively, the Control System may comprise a sub-component of a regional and/or global Control System designed to cooperatively control a regional and/or global process. For instance, a modular Control System may be designed such that control modules interactively control various sub-components of a system, while providing for inter-modal communications as needed for regional and/or global control.

[0618] The Control System generally comprises one or more central, networked and/or distributed processors, one or more inputs for receiving current sensed characteristics from the various sensing elements, and one or more outputs for communicating new or updated control parameters to the various response elements. The one or more computing platforms of the Control System may also comprise one or more local and/or remote computer readable media (e.g. ROM, RAM, removable media, local and/or network access media, etc.) for storing therein various predetermined and/or readjusted control parameters, set of preferred system and process characteristic operating ranges, system monitoring and control software, operational data, and the like. Optionally, the computing platforms may also have access, either directly or via various data storage devices, to process simulation data and/or system parameter optimization and modeling means. Also, the computing platforms may be equipped with one or more optional graphical user interfaces and input peripherals for providing managerial access to the Control System (system upgrades, maintenance, modification, adaptation to new system modules and/or equipment, etc.), as well as various optional output peripherals for communicating data and information with external sources (e.g. modem, network connection, printer, etc.).

[0619] The processing system and any one of the sub-processing systems can comprise exclusively hardware or any combination of hardware and software. Any of the sub-processing systems can comprise any combination of none or more proportional (P), integral (I) or differential (D) controllers, for example, a P-controller, an I-controller, an PI-controller, a PD controller, a PID controller etc. It will be apparent to a person skilled in the art that the ideal choice of combinations of P, I, and D controllers depends on the dynamics and delay time of the part of the reaction process of the Gasification System and the range of operating conditions that the combination is intended to control, and the dynamics and delay time of the combination controller. It will be apparent to a person skilled in the art that these combinations can be implemented in an analogous hardware form which can continuously monitor, via sensing elements, the value of a characteristic and compare it with a specified value to influence a respective control element to make an adequate adjustment, via response elements, to reduce the difference between the observed and the specified value. It will further be apparent to a person skilled in the art that the combinations can be implemented in a mixed digital hardware software environment. Relevant effects of the additionally discretionary sampling, data acquisition, and digital processing are well known to a person skilled in the art. A P, I, or D combination control can be implemented in feed forward and feedback control schemes.

[0620] In corrective, or feedback, control the value of a control parameter or control variable, monitored via an appropriate sensing element, is compared to a specified value or range. A control signal is determined based on the deviation between the two values and provided to a control element in order to reduce the deviation. It will be appreciated that a conventional feedback or responsive Control System may further be adapted to comprise an adaptive and/or predictive component, wherein response to a given condition may be tailored in accordance with modeled and/or previously monitored reactions to provide a reactive response to a sensed characteristic while limiting potential overshoots in compensatory action. For instance, acquired and/or historical data provided for a given system configuration may be used cooperatively to adjust a response to a system and/or process characteristic being sensed to be within a given range from an optimal value for which previous responses have been monitored and adjusted to provide a desired result. Such adaptive and/or predictive control schemes are well known in the art, and as such, are not considered to depart from the general scope and nature of the present disclosure.

Control Elements

[0621] Sensing elements contemplated within the present context can include, but are not limited to, means for monitoring operational parameters such as gas flow, temperature and pressure at various locations within the system, as well as means for analyzing the chemical composition of the syngas product.

[0622] The data obtained from the sensing elements is used to determine if any adjustments to the conditions and operating parameters within the Gasification System are required to optimize the efficiency of the gasification process and the composition of the product syngas. Ongoing adjustments to the reactants (for example, rate and amount of primary and secondary feedstock addition, input of heated air and/or steam), as well as to certain operating conditions, such as temperature and pressure within various components within the system, enable this process to be conducted under conditions that enable the efficient and consistent production of the syngas.

[0623] The Control System can be designed and configured with the objective of optimizing the efficiency of the gasification process and to mitigate environmental impacts caused by the gasification process. The Control System can also be designed to operate the Gasification System under continuous operating conditions.

[0624] The following operational parameters may be intermittently or continuously monitored by the sensing elements, and the data obtained are used to determine whether the system is operating within the optimal set point, and whether, for example, there needs to be more power delivered by the torches, more air or steam injected into the system, or if the feedstock input rate needs to be adjusted.

Temperature

[0625] In one embodiment of the invention, the Control System comprises means to monitor the temperature at sites located throughout the system as required for example, inside the volatilization, processed feedstock/char conversion, or gas reformulating chambers. The means for monitoring the temperature may be thermocouples or optical thermometers installed at locations in the system as required.

[0626] Means for monitoring the temperature of the hot syngas product may also be located at the syngas outlet of the
plasma gas reformulating chamber. In one embodiment, where a subsystem for recovering the sensible heat in the hot syngas produced by the plasma gas reformulating process is employed (such as a heat exchanger or similar technology), means for monitoring the temperature at points in the heat recovery subsystem may be incorporated. For example, the temperature may be monitored at the coolant fluid inlet and outlet, as well as at the syngas inlet and outlet.

**System Pressure**

**[0627]** In one embodiment of the invention, the Control System comprises means to monitor the pressure at locations throughout the Gasification System. These pressure monitoring means may include pressure sensors such as pressure transducers, pressure transmitters or pressure taps located anywhere in the system, for example, on a vertical wall of the secondary chamber or at location within the heat exchanger subsystem.

**[0628]** In one embodiment, the pressure in the different components in the system is monitored. In this manner, a pressure drop or differential from one component to another can be monitored to rapidly pinpoint developing problems during processing.

**Gas Flow Rate**

**[0629]** In one embodiment of the invention, the Control System comprises means to monitor the rate of gas flow at sites located throughout the system. Fluctuations in the gas flow may be the result of non-homogeneous conditions (e.g. torch malfunction or interruptions in the material feed), therefore if fluctuations in gas flow persist, the system may be shut down until the problem is solved.

**Gas Composition**

**[0630]** In one embodiment of the invention, the Control System comprises means to monitor the composition of the syngas product. The gases produced during the gasification process can be sampled and analyzed using methods well known to the skilled technician.

**[0631]** In one embodiment, the syngas composition is monitored by means of a gas monitor, which is used to determine the chemical composition of the syngas, for example, the hydrogen, carbon monoxide and carbon dioxide content of the synthesis gas. In one embodiment, the chemical composition of the syngas product is monitored through gas chromatography (GC) analysis. Sample points for these analyses can be located throughout the system. In one embodiment, the gas composition is monitored using a Fourier Transform Infrared (FTIR) Analyzer, which measures the infrared spectrum of the gas.

**[0632]** Although high temperature gas analysis means exist, one skilled in the art can appreciate that it may be required to cool the gas prior to analyzing its composition, depending upon the type of system used for gas analysis.

**Response Elements**

**[0633]** Response elements contemplated within the present context can include, but are not limited to, various control elements operatively coupled to process-related devices configured to affect a given process by adjustment of a given control parameter related thereto. For instance, process devices operable within the present context via one or more response elements, may include, but are not limited to, means for adjusting various operational parameters such as the rate of addition of the primary and secondary feedstock, air and/or steam inputs, as well as operating conditions, such as power to the torch and torch position.

**Plasma Heat Source**

**[0634]** In one embodiment, the present Gasification System uses the controllability of plasma heat to drive the gas reformulating process. Where a solid residue conditioning subsystem is employed, the controllability of plasma heat is also used to ensure the complete melting and vitrification of ash to slag. A more detailed description of the control of the plasma source or other energizing gas source in the gas reformulating system is provided in a separate section below.

**[0635]** In those embodiments where a solid residue conditioning subsystem is employed, the Control System optionally comprises means to adjust the power and/or the position of the plasma heat source. For example, when the temperature of the melt is too low, the Control System is to maintain an increase in the power rating of the plasma heat source; conversely, when the temperature of the chamber is too high, the Control System may command a drop in the power rating of the plasma heat source.

**[0636]** In one embodiment, the power of the torch is maintained at a level that is proportional to the rate of the solid residue addition, i.e., an increase in the solid residue feed rate results in an increase in the torch power. The torch power can also be adjusted to react to changes in the characteristics and composition of the residue, for example, with respect to its melting properties such as temperature, specific heat capacity, or heat of fusion.

**[0637]** In one embodiment, the position of the plasma heat source is adjustable to ensure complete coverage of the melt pool, and the elimination of areas of incompletely reacted materials.

**The Rate of Carbonaceous Feedstock Addition**

**[0638]** In one embodiment of the invention, the Control System comprises means to adjust the supply rate of carbonaceous feedstock to the primary chamber to ensure that the feedstock is input at a rate that does not exceed the drying and volatilization capacity of the primary chamber at a given heated air input rate. This ensures that the volatile fraction is fully removed before the processed feedstock/char is passed to the secondary chamber. The feedstock may be added in a continuous manner, for example, by using a rotating screw or auger mechanism, or it can be added in a discontinuous fashion, for example, periodically and in discrete portions.

**[0639]** In one embodiment, a secondary feedstock is provided as a process additive to adjust the carbon content of the feedstock being gasified. In such an embodiment, the Control System provides a means for adjusting the secondary and primary feedstock input rates to ensure the optimum carbon content of feedstock to provide control over the final syngas composition.

**The Rate of Solids Movement**

**[0640]** The Control System also comprises means to control the movement of solids through the different stages of the gasification process. In one embodiment, the Control System comprises means to adjust the rate of processed feedstock/char transfer out of the primary chamber and into the secondary chamber. In such an embodiment, the rate of transfer of
the processed feedstock/char product is controlled to ensure complete volatilization of the volatile fraction of the feedstock, while also preventing accumulation of processed feedstock/char in the primary chamber after the volatilization is complete.

[0641] In one embodiment, the Control System comprises means to adjust the rate of ash transfer out of the secondary chamber, thereby providing controlling the residence time of the processed feedstock/char in the secondary chamber.

[0642] The transfer rates are adjusted as required to ensure acceptable control over the volatilization or processed feedstock/char conversion steps, thereby preventing the conveyance of incompletely volatilized or unconverted materials out of their respective chambers.

[0643] The solids may be passed from the respective chambers in a continuous or discontinuous manner, using any of the solids removal means previously discussed. In one embodiment where the feedstock/processed feedstock/char input means comprises a series of pusher rams, the Control System may employ limit switches or other means of travel control such as computer controlled variable speed motor drives to control the length, speed and/or frequency of the ram stroke so that the amount of material fed into the respective chamber with each stroke can be controlled. In another embodiment where the input means comprises one or more screw conveyors, the rate of addition of the material to the respective chamber may be controlled by adjusting the conveyor speed via drive motor variable frequency drives.

[0644] In one embodiment, where a horizontal primary chamber is employed, the Control System optionally comprises means to control the movement of one or more lateral transfer units in the primary chamber, thereby controlling the movement of material through the chamber to optimize the drying and volatilization stages by controlling the residence time of the material at each stage.

Addition of Heated Air Inputs

[0645] In one embodiment of the invention, the Control System comprises means to adjust the rate and/or amounts of heated air inputs into the volatilization and secondary chambers.

Addition of Process Additive Inputs

[0646] In one embodiment of the invention, the Control System comprises means to adjust the steam and/or air process additive inputs into the plasma gas reformulating chamber, in order to ensure that the volatiles and gaseous products of the processed feedstock/char conversion are completely converted to a useful gas product by the plasma gas reformulating step. In one embodiment of the invention, the Control System comprises means to adjust the steam and/or air process additive inputs into the secondary chamber, to ensure that the levels of oxygen and hydrogen required for the carbon conversion reaction are present are required to optimize the chemical composition of the syngas product. In one embodiment, the determination of the amounts and types of process additives required is based on data obtained from monitoring and analyzing the composition of the syngas.

Modularity of the Facility

[0647] Modular facilities are facilities where each function block is made of pre-built components, which allows for the components to be built in a factory setting and then sent out to the facility site for plant assembly. These components (or modules) include all the equipment and controls to be functional and are tested before leaving the factory. Modules are often built with a steel frame and generally incorporate a variety of possible sections, such as: Gasifier Block, Gas Conditioning System Block, Power Block, etc. Once on-site, these modules only need to be connected to other modules and the Control System to be ready for plant commissioning. This design allows for shorter construction time and economic savings due to reduced on-site construction costs.

[0648] There are different types of modular plants set-ups. Larger modular plants incorporate a “backbone” piping design where most of the piping is bundled together to allow for smaller footprint. Modules can also be placed in series or parallel in an operation standpoint. Here similar task equipment can share the load or successively provide processing to the product stream.

[0649] One application of modular design in this technology is that it allows more options in the gasification of multiple feedstocks. This technology can allow for multiple gasification lines to be used in a single high-capacity facility. This would allow the option of having each Gasification System co-processed feedstocks together or separately; the configuration can be optimized depending on the feedstocks.

[0650] If an expansion is required due to increasing loads, a modular design allows the technology to replace or add modules to the plant to increase its capacity, rather than building a second plant. Modules and modular plants can be relocated to other sites where they can be quickly integrated into a new location.

Function Block Combinations

[0651] It is possible to combine the functions of different gasification trains (series of equipment) so that common functions can be carried out in function blocks that take in gases or material from more than one stream. The following diagrams demonstrate this concept as applied to carbonaceous feedstock gasification.

[0652] In the following embodiments, there are two trains shown, although this set-up of combined functions between trains can occur for any number of trains and for any feedstock per train (even if one train has a combined feedstock). Once a stream has been combined, one may still choose parallel handling equipment downstream; the parallel streams do not need to be of the same size even if handling the same gases.

[0653] For FIGS. 68 to 71, GGCS refers to the gas conditioning system mentioned above and the numbers represent the following systems: 1) primary chamber, 2) secondary chamber, 3) melting chamber, and 4) gas reformulating chamber.

[0654] FIGS. 68 to 71 depict different embodiments of the present Gasification System that fall within the scope of the present invention. In particular, FIGS. 68 to 71 describe embodiments of the Gasification System in which the separate primary feedstock and secondary feedstock inputs are carried through to the final syngas product.

[0655] The embodiment shown in FIG. 112 depicts one embodiment in which the primary feedstock and secondary feedstock are each volatilized in separate primary chambers, and the resulting processed feedstock/char from each primary chamber is combined in a common secondary chamber. The first chamber gas products from each of the primary chambers
and the second chamber gas product from the secondary chamber are combined in a common gas reformulating chamber.

[0656] The embodiment shown in FIG. 113 depicts one embodiment in which the primary feedstock and secondary feedstock are each volatilized in separate primary chambers, and the resulting processed feedstock/char from each primary chamber is passed into a separate solid residue conditioning chamber. The first chamber gas product from each of the primary chambers and the second chamber gas product from the processed feedstock/char chambers are combined in a common gas reformulating chamber.

[0657] The embodiment shown in FIG. 114 depicts one embodiment in which the primary feedstock and secondary feedstock are each volatilized in separate primary chambers, and the resulting processed feedstock/char from each primary chamber is passed into respective secondary chamber. The first chamber gas product and second chamber gas product from each of the primary and secondary feedstock gasification streams are reformulated in separate gas reformulating chambers.

[0658] The embodiment shown in FIG. 115 depicts one embodiment in which the primary feedstock gasification stream and the secondary feedstock gasification stream are carried separately through the volatilization, processed feedstock/char gasification, solid residue conditioning, and gas reformulating steps, wherein the syngas products are combined only prior to the gas quality conditioning step.

Extraction Systems and Optional Upgrading and Refining Systems

[0659] In accordance with this invention, intermediate products generated in the gasification and gas reformulation systems are utilized directly or indirectly in the ongoing extraction and processing of the unconventional oil source, or are recycled back to improve the efficiencies of the gasification and/or gas reformulating processes. Extraction and processing of unconventional oil sources to yield useful fuel products requires a high input of energy and other reagents. Tar sands, for example, require substantial amounts of energy for mining and separating in strip mine operations or for heating underground reservoirs in situ production. Likewise, extra-heavy oil requires significant effort to bring it to the surface. Upgrading extra-heavy oil or bitumen to syncrude also requires significant amounts of energy. In general natural gas is used to generate electricity to power equipment, as well as to produce hydrogen or to power cokers required for the upgrading process.

[0660] The Gasification System of the invention can be configured to produce a variety of intermediates that can be tailored to the requirements of the particular oil source being processed. Various examples are provided in FIG. 1. For example, intermediates produced in the Gasification System of the invention can be used as sources of energy (heat, electricity, etc.) that can be utilized in one or more of the extraction and/or upgrading processes, either as a supplement to traditional energy sources, such as natural gas, or in some cases, as a sole source of energy. Intermediates produced by the Gasification System that are useful in this context include reformulated syngas having a defined chemical composition that can be effectively used, for example, as a combustion fuel to provide heat or to generate electricity. Heat obtained in this manner can be utilized for example, in the in situ heating of oil shale or tar sand deposits, or to provide heat for downstream upgrading or refining processes. Similarly, electricity generated from the intermediates can be used to power heat sources for in situ extraction processes, to power various components of the upgrading and/or refining system.

[0661] Reformulated syngas can also be used to drive steam generators to generate steam, which is required in in situ extraction processes for tar sands and oil shale. Likewise, steam generated at various points in the Gasification System can be recovered and used directly in such in situ processes.

[0662] Reformulated syngas can also be used as a source of hydrogen, which is required for the oil upgrading process.

[0663] Heat produced at various points in the Gasification System is also considered a useful intermediate. For example, heat is generated in the reformulating stage of the Gasification System and can be recovered from the reformulated gas. Heat recovered from the Gasification System and used, for example, to generate steam using a heat recovery steam generator (HRSG). Heat can also be recycled back to drive the gasification process and/or syngas purification processes. Syngas can also be combusted to provide heat, for example, syngas can be piped into the extraction beds and combusted to provide heat in situ.

[0664] It is also contemplated that the syngas can be used for the generation of carbon dioxide, which can be used in enhanced oil recovery (EOR) or methane recovery processes. Syngas can also be used in chemical processes, such as Fischer-Tropsch process to produce light oils, which can be used as diluents in the unconventional oil source extraction process.

[0665] FIG. 116 provides an exemplary embodiment of the invention in which the Gasification System is used to generate several intermediates, which are used in different processes of a tar sands processing operation. In the embodiment represented by FIG. 116, carbonaceous feedstock 4 is fed into a converter 2 and solid residue generated in the converter 2 from the gasification of the carbonaceous feedstock 4 is processed to slag in a solid residue conditioner 6. Syngas from the converter can be cooled in an optional step in an air to gas heat exchanger 8, prior to being conditioned in a gas conditioning system (GQCS) 10. The conditioned syngas that exits the GQCS 10 can be stored in a gas storage or regulation system 12 for later use. Alternatively or in addition, the syngas can be fed to a gas turbine 60 or to a fuel cell 30 to generate electricity. The conditioned syngas from the GQCS 10 can also be used to run a coking oven 40 for upgrading bitumen or it can be used to produce hydrogen by passing the syngas through a water-gas shift reactor 50 or hydrogen separator 52.

[0666] Steam can also be generated from the system depicted in FIG. 116 as follows. The syngas stored in the gas storage or regulation system 12 is regulated to a combustible gas which is used to power steam generators 20, which generate steam that can be used in SAGD operations 24 to extract bitumen from tar sands. Steam that is generated in the converter 2 can also be used directly for the SAGD process 24.

[0667] The Gasification System in the embodiment of the invention depicted in FIG. 116 comprises a gasifier, a melting chamber, a GQCS and a gas storage tank, where the Gasification System is integrated with additional equipment or components for producing energy and/or reagents that can be used in the processing of oil from tar sands. The Gasification System can, however, include additional components depending on the feedstock to be consumed/or and the energy or reagents to be produced.
Non-limiting, exemplary uses of the various intermediates produced by the Gasification System of the invention are described in more detail below.

Steam Generation

Steam is required in various aspects of oil or bitumen extraction from tar sands or extraction of oil shale deposits. For example, steam is used in in situ processes to increase the temperature of the heavy oil, tar and bitumen in a natural reservoir, such as tar sands or extra-heavy oil deposits, which results in reduced viscosity, separation of the oil, tar or bitumen from the deposit, and ensures a pressure flow that allows transportation by pipeline or other means.

One such in situ recovery method is Steam Assisted Gravity Drainage (SAGD), as described in U.S. Pat. No. 4,344,485 (Butler), which requires two horizontal wells to be drilled into the reservoir. In this method, two spaced apart wells are first drilled vertically to different depths within the reservoir. Thereafter, using directional drilling technology, the two wells are extended in the horizontal direction that result in two horizontal wells, vertically spaced from, but otherwise vertically aligned with the other. Ideally, the production well is located above the base of the reservoir and as close as practical to the bottom of the reservoir, and the injection well is placed above or nearly above the production well.

The upper horizontal well is utilized as an injection well and is supplied with steam from the surface. The steam rises from the horizontal injection well, permeating the reservoir to form a vapour chamber that grows over time towards the reservoir top, thereby increasing the temperature within the reservoir. The steam (and its condensate), by soaking for a period of time, will rise the temperature and consequently reduce the viscosity of the semi-solid bitumen or heavy oil in the reservoir. It will also partially replace the bitumen in the pores of the sand. The bitumen and condensed steam will then drain downward through the reservoir under the action of gravity and flow into the lower production well, whereby these liquids can be pumped to the surface. At the surface of the well, the condensed steam and bitumen are separated, and the bitumen is diluted with appropriate light hydrocarbons to transport the bitumen by pipeline to a refinery or an upgrader.

The theoretical and design concepts required to conduct successful SAGD have been published and have been extensively discussed in technical and related industry literature. A major component of the capital and operating costs of commercial SAGD operations are the facilities to: a) generate steam, b) separate hydrocarbons from condensed steam, and c) treat and recycle water to the steam generators. Current steam generators require large amounts of water, which is heated by boilers fired by natural gas to produce steam. The volume of water handled in SAGD operations is reflected in steam-to-oil ratios (e.g. CWE m3 steam/m3 bitumen) of about 2 and above for active or anticipated projects.

As is known in the art, a particular quality of steam is required for in situ processing of bitumen from tar sands. For example, ultra-high pressure steam is used for in situ processing of bitumen from tar sands. Suitable ultra-high pressure steam is a 100% quality steam at pressure of between 3 and 10 MPa. As is known in the art, the selected pressure is dependent upon how deep the bitumen is that needs to be extracted.

The Gasification System of the invention can be used to provide steam for use in in situ methods of recovering heavy oil or bitumen deposits. In one embodiment, steam provided by the Gasification System is used in SAGD processes. The steam can be directed, for example, to the upper horizontal well of a SAGD operation using steam directing means. As described above, the steam be provided from a steam generator powered by syngas from the gasification and/or by steam recovered from the gasification process itself.

An exemplary configuration of a gasification reactor and steam generator combination is shown in FIG. 117. In this configuration, a once-through steam boiler is used to produce 75% quality steam which is subsequently converted to 100% steam in water or dirt are separated from the steam in a gas/liquid separator.

In a once-through steam generator, the heating of steam generator tubes provides as evaporator tubes leads to an evaporation of the flow medium in the steam generator tubes in a single pass. In contrast thereto, in a natural- or forced-circulation steam generator, the circulating water is only partly evaporated when passing through the evaporator tubes. The water which is not evaporated in the process is fed again to the same evaporator tubes for a further evaporation after separation of the generated steam.

A once-through steam generator, in contrast to a natural- or forced-circulation steam generator, is not subject to any pressure limit, so that live-steam pressures are possible well above the critical pressure of water (Pcr approximately 221 bar) where there is only a slight difference in density between a medium similar to a liquid and a medium similar to steam. A high live-steam pressure promotes a high thermal efficiency and thus low CO2 emissions of a fossil-fired power plant. In addition, a once-through steam generator has a simple type of construction compared with a circulation steam generator and can therefore be manufactured at low cost.

As is known in the art, when a once through steam boiler designed for use with natural gas as fuel source is used to generate steam using syngas as a fuel, components of the boiler can be reconfigured to allow for the differences in gas characteristics between syngas and natural gas such as the lower heating value of syngas compared to natural gas. For example, the injection ports of the boiler can be reconfigured to be bigger than the injection ports for use with natural gas.

As shown in FIG. 117, syngas transferred from a gasification reactor can be fed into a once-through steam generator and syngas combustion is then used to heat process water or recovered water which is supplied to the steam generator. This process water or recovered water may contain impurities such as sand, other particulate matter, slats, and dissolved organic and inorganic compounds. The resulting steam is of 75% quality, and is then fed into a two phase separator in order to generate 100% quality steam. Suitable two phase separator systems are known in the art. The 100% quality steam generated can then be transferred to in situ processing equipment for extracting heavy oil or bitumen from the tar sands as described following.

It is also possible to use a multiple pass steam boiler to produce steam using syngas from the Gasification System. An alternate process for generating steam from syngas includes passing an ultra-high steam (or thermal fluid) through the gasifier and looped it through a steam generator to produce steam from water as shown in FIG. 118.

In one embodiment, intermediates from the Gasification System are used to generate electricity and steam for extracting bitumen from tar sands. An example of a Gasifica-
tion System in accordance with this embodiment is shown in FIG. 116. In this embodiment, a Heat Recovery Steam Generator (HRSG) is used to generate steam from the latent heat in syngas and electrical output as shown in FIG. 119. In this embodiment, syngas from the gasifier 100 is passed into a HRSG 120 and the generated steam is used in the extraction process at the oil field. The cooled syngas from the HRSG 120 is purified in by passage through a scrubber 160 and baghouse 140, with subsequent hydrogen sulphide removal 150 and transferred to a storage tank 160. The syngas intermediate is then used in a gas turbine 170 to provide on-site electricity. Gas from the turbine is passed to a second HRSG 180 which can be used to generate additional steam for use in the extraction process.

[0682] As noted above, the steam generated by the Gasification System can be used in situ methods requiring steam for recovering heavy oil or bitumen. The steam is supplied to these recovery operations using steam directing means that transfer the steam to a required location. Steam directing means are known in the art and include various pipes and conduits that are in compliance with the appropriate requirements for conducting steam at high temperature and appropriate pressure.

Electricity

[0683] Syngas produced in the Gasification System can be used as a fuel for various energy generating components such as gas engines, gas turbines, steam generators, steam engines, steam turbines, fuel cells and the like, to produce electricity required to power various components of the unconventional oil source processing facility. Syngas acts as a suitable fuel for these systems if it exhibits the required characteristics of pressure, LHV, composition and lack of impurities required for the operation of these energy generating components. As discussed above, a syngas exhibiting these characteristics can be generated by the Gasification System through optimisation of the reformulating stage to provide a syngas with a desired composition, in combination with one or more syngas conditioning or processing components, such as a GQCS, cooling units, gas storage tanks, gas shift reactors, pressure regulator valves and the like.

[0684] Electricity can also be produced by using combined cycle technology, which employs the syngas in an Integrated Gasification Combined Cycle (IGCC) system. Syngas produced from fossil fuel based feedstocks (such as coal, bitumen, peat coke, and the like) is particularly useful in this type of system.

[0685] An IGCC system generally comprises a combustion turbine/generator, a heat recovery steam generator, and a steam turbine/generator. The syngas produced from the Gasification System, which contains high concentrations of carbon monoxide and hydrogen, is used in the combustion turbine. Exhaust heat from the combustion turbine is recovered in the heat recovery steam generator to produce steam. This steam then passes through a steam turbine to power another generator, which produces more electricity. Combined cycle is frequently more efficient than conventional power generating systems because it re-uses waste heat to produce more electricity.

[0686] In one embodiment of the invention, intermediates (syngas) from the Gasification System are used to produce electricity via an IGCC system.

Hydrogen Generation

[0687] Hydrogen (H₂) can be used in unconventional oil source processing for hydrotreating bitumen or oil extracted from the unconventional oil source. H₂ can also be used in a fuel cell system to generate electricity and water on-site. [0688] Hydrogen can be separated from the syngas produced by the Gasification System via a number of commercially available technologies as is known in the art, including for example, using a commercially available membrane technology such as a membrane separator, a water-gas shift reactor, adsorption or absorption techniques fuel cells, ion transfer membranes, cryogenic separation, molecular sieves, or combinations thereof. The clean H₂ gas, thus separated, can be stored and transported/piped to the region of the processing operation where it is required. The hydrogen-depleted syngas which is rich in CO can be used to generate additional electricity through a turbine generator or other gas-fired engine via conventional heat engine technology.

Carbon Dioxide Generation

[0689] Carbon dioxide (CO₂) can be used in unconventional oil source processing for enhanced oil recovery (EOR) and/or methane recovery processes. EOR using CO₂ involves injecting CO₂ into a reservoir containing oil to be recovered. Once in the reservoir, the CO₂ expands and, in doing so, pushes additional oil to a production wellbore. In addition, CO₂ dissolves in the oil to lower its viscosity and improve the flow rate of the oil making it more amenable to pumping.

[0690] Methane recovery from subterranean coal beds using CO₂ is carried out by similar methods. CO₂ is continuously injected via injection wells into the coal bed to produce methane from one or more recovery wells spaced from the injection wells. The produced methane includes both free methane displaced by the injection gas and methane that is desorbed from the coal surface by differential adsorption of carbon dioxide on the coal surface.

[0691] Syngas from the gasification reaction can be used to generate CO₂ using methods known in the art. These methods include, for example, electrochemical pumps, membranes, and chemical looping approaches to CO₂ separation. Electrochemical pumps include carbonate and proton conductors. Selective membranes for hydrogen separation can be used as a method for carbon dioxide concentration in fuel gas streams. The selective membranes include mixed ionic-electronic (solid electrolyte-metal) films as well as palladium-based materials. The CO₂ produced in this way can be used in enhanced oil recovery (EOR) and methane recovery processes.

Light Oils Generation

[0692] Light oils can be used in unconventional oil source processing as diluents in the processing and transport of bitumen or heavy oils from the unconventional oil source. Syngas can be used to produce light oils, for example, using the Fischer-Tropsch process, which produces liquid hydrocarbons of various forms via a chemical reaction typically catalyzed by iron and cobalt. Examples of methods for conversion of syngas to hydrocarbons in a Fischer-Tropsch process are illustrated in U.S. Pat. No. 4,096,163 to Chang et al., U.S. Pat. No. 6,085,512 to Agee et al., and U.S. Pat. No. 6,172,124.

[0693] The Fischer-Tropsch synthesis process is an exothermic process and may generate steam, which can be utilized in various processes in the unconventional oil source processing facility, as described above.

[0694] Light oils may also be produced by the Gasification System when it comprises a cooler and tar separator, which
functions to remove tar from the gas exiting the gasifier (see, for example, the embodiment of the Gasification System depicted in FIG. 120). The tar can then be distilled by conventional techniques to produce light oils that can be used as diluents in the processing and transport of bitumen from the tar or oil sands. As shown in FIG. 120, the gas exiting the cooler and tar separator is then reformulated in a gas reformulating zone prior to entering a GCS. In one embodiment, this gas reformulating zone is a secondary gas reformulating zone, with the primary gas reformulating zone being located upstream of the cooler and tar separator. In one embodiment, the Gasification System according to the invention comprises a cooler and tar separator. In another embodiment, the Gasification System comprises a secondary gas reformulating zone. In another embodiment, the Gasification System comprises both a cooler and tar separator and a secondary gas reformulating zone.

Standalone or Retrofitting the Gasification System and Gas Reformulating Systems onto Existing Facilities

It is contemplated that the system of the invention may be provided as described above, or alternatively the system may be modified to be integrated with existing systems that rely on conventional energy sources, for example, natural gas to improve the overall cost effectiveness of the existing system and/or reduce the requirement for other energy sources, such as natural gas. Such modifications include, for example, modifications to the gas transfer means to permit transfer of the syngas to an existing steam generator or other component of the facility. The design and scope of such modifications are within the knowledge of a worker skilled in the art.

As would be evident to one of skill in the art, the Gasification System of the invention may require design changes in order to allow coupling of the system to various components that utilise the intermediates produced by the system. For example, changes may be required to configurations of components, such as, nozzles, transport pipes, injection ports and/or operating conditions. Additional components may also need to be introduced to facilitate the generation or further processing of the intermediates. In one embodiment, specialized energy producing components such as gas engines or gas turbines, or special once through boiler systems can be used. In another embodiment, the energy producing component is similar to those used when natural gas is the fuel used to power the energy producing component.

To gain a better understanding of the invention described herein, the following examples are set forth. It will be understood that these examples are intended to describe illustrative embodiments of the invention and are not intended to limit the scope of the invention in any way.

EXAMPLES

Example 1

Plasma Gasification System Integrated with an IGCC

This example describes a plasma Gasification System integrated with an IGCC. The plasma Gasification System comprises a converter, solid residue conditioner, a GCS, and a gas storage or regulation system, integrated with use of a combined-cycle to produce electricity.

As shown in FIG. 119, coal 106 is combined with oxygen from an oxygen plant 185 in the converter 100 to produce syngas, which is mainly hydrogen and carbon monoxide. The syngas is then cooled in a heat recovery steam generator (HRSG) 120 and then cleaned by a gas cleanup process in a GCS which includes the steps of scrubbing the syngas in a scrubber 130, removing particulate matter and heavy metals from the syngas in a baghouse 140, and H_{2}S removal in an H_{2}S removal system 150. The cleaned or conditioned gas is then stored or regulated in a gas storage or regulation system 160 prior to being fed to a gas turbine 170 for the production of electricity.

Combined-Cycle

This design consists of a combustion turbine/generator 170, and a heat recovery steam generator 180. The exhaust heat from the combustion turbine 170 is recovered in the heat recovery steam generator 180 to produce steam. Combined cycle is more efficient than conventional power generating systems because it re-uses waste heat to produce more electricity.

Example 2

Configurations of Gasifiers Suitable for Use

FIG. 121A to D depicts various examples of gasifiers that can be used in the system of the invention.

Example 3

Design of a GCS for Use in the System of the Invention

FIG. 122 depicts an example of a GCS that is designed for use in tar sands applications. As shown in FIG. 122, gas from the gasifier is cooled, particulates are removed, as is heavy metal and H_{2}S. The conditioned gas is then fed to a gas boiler for the production of steam.

Example 4

Overview of a System in which Bitumen is Partially Gasified

The technology is the process of converting low-value feedstocks (Bitumen & others) using plasma gasification (and supporting technologies) into valuable end-products (Light Oils, Power, Steam). This process will reduce/remove the need for higher value fuels such as Natural Gas from being used to produce heat & hydrogen which is currently the norm in the field of tar sands extraction.

Example 5

The process surrounds the following equipment (Optional variations do not include all pieces of equipment into every design):

A plasma gasifier of fluid feedstocks for bitumen and others

A Cooler & Tar Remover from syngas

Other Supporting equipment

A plasma gasifier for Solid feedstocks

A Distillation Column for Heavy Oils

Residue Chamber

Reformation Chamber

GCS with optional H2 & CO2 removal and Gas shift equipment.

Power Generation Technology (Engines, Turbines)

Chemical Plants (Fischer-Tropsch, etc) for light oil production

An example of one possible design of the Gasification System is shown in FIG. 120. In this example, bitumen is
partially gasified to produce a syngas. The syngas is then sent to a cooler and tar separator where longer chain molecules are separated and sent to be diluents. The syngas now free of most heavy tars is reformed further into $H_2+CO$ syngas which is then cleaned further in a GCS (CO$_2$ can be optionally removed for EOR/sequestering projects) and sent to a chemical plant (such as, for example one that carries out a Fischer-Tropsch process) to produce diluents (such as light oils).

Example 5
Overview of a Simplified System

[0716] FIG. 123 depicts an overview of an example of a simplified system. In this example of the gasification facility syngas is to be produced from bitumen to be used in downstream processes. A tar separator is optionally used for diluents production if that process is required. Residue from the reaction (Coke, Carbon, & Ash) is sent to a residue chamber for vitrification.

Example 6
Overview of a System in which Multiple Co-Products are Generated

[0717] FIG. 124 depicts an overview of an example of a system of the invention in which light oil production is maximized upstream with syngas being used to produce $H_2$, CO$_2$, Power, and Steam downstream from the bitumen gasification. As shown in FIG. 124, a distillation system is added where the system extracts the lighter portion of bitumen (and tars) to avoid gasifying the lighter fraction into syngas when it is fed into the gasifier; instead the lighter fraction (light oils) are sent to become diluents for bitumen transportation (or other application). Residues from the gasifier & distillation system (Coke, Carbon, & Ash) are sent to a residue chamber for vitrification; or combusted further to provide heat for the gasification reaction or other process.

Example 7
Overview of a System in which Feedstock is Used to Produce Steam

[0718] FIG. 125 depicts an example of a system in which bitumen/coal/ coke etc. is used to produce steam (and optionally extract and use CO$_2$) for use in processing tar sands. The steam can be used, for example in EOR or SAGD processes.

Example 8
Block Flow Diagram of CO$_2$ and Diluents Application

[0719] FIG. 126 depicts an example of a system in which lighter fractions of bitumen can be produced in addition to power or steam. In this example, the gasifier is operated with carbonaceous feedstock, additives, plasma torch(s), and bitumen to produce lighter oils, pet coke, & syngas. The light oils can be sold or mixed with heavy bitumen to make it more pumpable which increases its value and mobility to markets and the pet coke & syngas can be used to produce power, CO$_2$, and/or steam. CO$_2$ and steam can be used to improve bitumen extraction using enhanced oil recovery (EOR) methods known in the art; such methods include steam assisted gravity drainage (SAGD) and CO$_2$ sequestration in depleted oil fields. CO$_2$ could also be injected into coal mine seams for enhanced methane recovery.

Example 9
Overview of a System Design to Produce $H_2$, Electricity, and Steam for Use in Upgrading Oil

[0720] FIG. 127 depicts an example of system in which $H_2$, electricity, and steam is produced by a system of the invention for use in upgrading oil. As shown in FIG. 127, two gasifiers are used sequentially in order to produce syngas from coal, bitumen, or other carbonaceous feedstock. The syngas is then conditioned in a GCS prior to use in the generation of $H_2$, steam, or electricity.

Example 10
A Fluid Plasma Gasifier

[0721] FIG. 128 depicts a drawing of an exemplary fluid plasma gasifier that can be used in the Gasification System of the invention. The plasma gasifier is designed for fluids (at elevated temperatures bitumen is a fluid) which is designed to allow for the cracking of the feed into smaller carbon chains. These chains will break into gaseous products with the help of a plasma torch and additional additives.

[0722] For this design the feed is injected into the gasification chamber where it is acted on by temperature, and chemical reactions with additives which include CO, CO$_2$, Steam, Water, Air, Oxygen, Hydrogen, etc. To improve the cracking of long chains in the feed stock a plasma torch is added to chamber to produce high temperature zone and ionized plasma which breaks the complex bonds; optionally a hydrogen burner can be utilized if heat is only required.

[0723] The gasifier is designed to handle liquids or fine particles in entrainment that can be sprayed (heated bitumen, pulverized coal/coke, oils, sludge, liquid wastes, slurries, entrained fines, etc) where such liquids are placed in a nozzle (with optional steam/air injection) and sprayed into the chamber containing plasma torch(es) where the plasma enhanced conditions will lead to cracking of tars, pyrolysis, combustion, and gasification to produce syngas laden with tars. Additional additives can be added to the chamber though ports in the gas or oil pool as needed for maximizing syngas production/quality or Oil production/quality as required for downstream application needs.

[0724] Additional feeds can be included (such as a biomass, sawdust, or sludge) into the heated bitumen fluid to increase the hydrogen content of the feed to improve the cracking process and end products. Depending on what feed stocks are available a Gasification System can also be used as a substitute for the proposed gasifier or run in parallel where the syngas & residue of both systems could be combined to reduce equipment needs is desired. Examples of suitable designs are shown in FIG. 129 A to C. With reference to FIG. 129, each function group represents the following systems: 1. Primary Gasification Chamber; 2. Residue Chamber; 3. Reforming Chamber.

Example 11
Cooling and Removal Systems

[0725] FIG. 130 depicts exemplary cooling and removal systems that can be used in the Gasification System of the invention.

Example 12
Extraction of CO$_2$ from the Syngas

[0726] This example describes a method of extracting CO$_2$ from syngas as it is processed through the GCS of the system.
In the GCS a water-gas shift reaction could be utilized along with CO₂ capture to extract CO₂ from the syngas for the use in EOR (pumping CO₂ into the tar sands to improve oil extraction) or other downstream process. The same reaction produces higher H₂ (optionally H₂ can be extracted) to be applied in the art of oil upgrading (inside gasification facility, or exported to another processing unit) or improved power/steam production.

Example 13

Multi-Chamber Gasification System

[0727] FIG. 131 depicts one embodiment of a multi-chamber carbonaceous feedstock gasification system. In the present embodiment, the feedstock and heated air inputs are introduced to the primary chamber, where the feedstock undergoes drying and volitization. The resulting char is passed into a secondary chamber, where it is subjected to further heating with heated air inputs, optionally in the presence of steam additives. The carbon in the char is converted to a gaseous product, and the residual ash is passed into a plasma heated slag chamber, where it undergoes melting and vitrification. The gaseous products of the two stages are passed into a gas reformulation chamber, where it undergoes plasma heating, optionally in the presence of process additives such as air and/or steam to produce a hot syngas product. The hot syngas is passed through a heat exchanger where the sensible heat from the syngas is removed. The cooled syngas is passed into a further cooling system, such as a heat recovery steam generator or a dry quench step. Where a heat recovery steam generator is used to cool the syngas, the resulting steam product may be used in downstream applications such as in a steam turbine for generating electricity. Activated carbon is then injected into the further cooled syngas, which then undergoes a filtration step to remove particulate matter, for example, by being passed through a baghouse filter. The particulate matter removed from the syngas product is passed into the slag chamber, where it undergoes plasma melting with the ash product of the feedstock gasification. The filtered syngas product undergoes further cleaning and conditioning steps prior to being used in downstream applications for the generation of energy or reagents for use in processing materials from tar sands.

[0728] Although the invention has been described with reference to certain specific embodiments, various modifications thereof will be apparent to those skilled in the art without departing from the spirit and scope of the invention. All such modifications as would be apparent to one skilled in the art are intended to be included within the scope of the following claims.

We claim:

1. An integrated facility for the extraction of useful fuel products from an unconventional oil source, said facility using fossil fuels as a primary source of energy and comprising:
   a. a Gasification System for converting a feedstock comprising a fossil fuel into slag, an off-gas, heat and steam;
   g. a gas formulation system operatively associated with said Gasification System for converting the off-gas to a reformulated gas and heat, said reformulated gas comprising hydrogen and carbon monoxide;
   h. a Control System operatively associated with said Gasification System and said reformulation system for monitoring and regulating said systems to ensure efficient conversion of said feedstock;
   i. one or more Gas Conversion Systems operatively associated with said gas reformulation system that use the reformulated gas to produce electricity, steam, hydrogen, carbon dioxide, or light oils, or a combination thereof, and
   j. an Extraction System operatively associated with at least one or said Gas Conversion Systems for extracting crude fuel products from the unconventional oil source using the electricity, steam, hydrogen, carbon dioxide, or light oils, or a combination thereof, produced in the one or more Gas Conversion Systems.

2. The facility according to claim 1, further comprising an upgrading system operatively associated with at least one or said Gas Conversion Systems for upgrading the crude fuel products to upgraded fuel products using the electricity, steam, hydrogen, carbon dioxide, or light oils, or a combination thereof, produced in the one or more Gas Conversion Systems.

3. The facility according to claim 2, further comprising a refining system operatively associated with at least one or said Gas Conversion Systems for refining the upgraded fuel products to purified or partially purified fuel products using the electricity, steam, hydrogen, carbon dioxide, or light oils, or a combination thereof, produced in the one or more Gas Conversion Systems.

4. The facility according to any one of claims 1, 2 or 3, wherein the unconventional oil source is tar sands, oil shales or an extra heavy oil deposit.

5. A process for producing useful fuel products from an unconventional oil source, said process comprising the steps of:
   a. gasifying a feedstock comprising a fossil fuel to produce slag, an off-gas, heat and steam;
   b. reformulating the off-gas to provide a reformulated gas comprising hydrogen and carbon monoxide;
   c. providing the reformulated gas to a Gas Conversion Systems to produce electricity, steam, hydrogen, carbon dioxide, or light oils, or a combination thereof, and
   d. providing the electricity, steam, hydrogen, carbon dioxide, or light oils, or a combination thereof, to an Extraction System for extracting crude fuel products from the unconventional oil source.

6. The process according to claim 5, further comprising the step of providing the electricity, steam, hydrogen, carbon dioxide, or light oils, or a combination thereof, to an upgrading system for upgrading said crude fuel products to upgraded fuel products.

7. The process according to claim 6, further comprising the step of providing the electricity, steam, hydrogen, carbon dioxide, or light oils, or a combination thereof, to a refining system for refining said upgraded fuel products to purified or partially purified fuel products.

* * * * *