

METHOD AND SYSTEM FOR HYDROGEN PRODUCTION

TECHNICAL FIELD

The present invention relates to the field of renewable energy production from biomass sources. More specifically, it concerns carbon-negative method and system for generating hydrogen gas through thermochemical conversion and downstream purification processes.

Background

The growing global demand for sustainable and renewable energy sources has brought hydrogen to the forefront as a clean and versatile energy carrier. Hydrogen has wide-ranging applications, including its use as a fuel in transportation, a feedstock in chemical industries, and a means for storing and transporting renewable energy.

Biomass, as a renewable and carbon-neutral resource, offers considerable promise as a feedstock for hydrogen production. It is abundantly available from agricultural residues, forestry by-products, solid waste, and crops. The use of biomass for hydrogen production can help mitigate waste management challenges, enhance energy security, and reduce dependency on fossil fuels.

Crucially, a key advantage of thermochemical hydrogen production from biomass is the generation of biochar as a by-product, which retains a substantial portion of the original carbon from the biomass feedstock. This biochar, when sequestered or used in long-term soil amendment applications, effectively removes carbon from the atmospheric cycle. When the system and method for hydrogen production are powered by lower-emission energy sources such as LNG or renewables such as solar or recirculated excess syngas, the total carbon dioxide captured in the form of biochar can significantly exceed the emissions produced during the process. As such, the hydrogen production system disclosed herein can be characterized as carbon-negative, meaning it results in a net reduction of atmospheric carbon dioxide rather than contributing to it.

However, hydrogen production from biomass poses technical and operational challenges. Most existing methods rely on batch or discontinuous processes such as pyrolysis, gasification, and hydrothermal liquefaction, which typically operate under non-ideal conditions and yield gas mixtures with low hydrogen content and high levels of impurities.

- 5 Furthermore, controlling these processes to maintain consistent gas composition, purity, and throughput remains a complex endeavor, especially under varying feedstock quality and moisture levels.

- To address these limitations, there exists a need for an integrated and continuous biomass-to-
10 hydrogen processing system capable of maintaining precise control over thermochemical reaction conditions along a defined processing pathway. Such a system should enable tandem operation of primary and secondary thermochemical processes, ensure high hydrogen yield and purity, and offer modular compatibility with downstream gas conversion technologies. Moreover, advancements in sensor integration, process automation, and catalyst deployment
15 can enable real-time optimization of key parameters such as temperature, pressure, and gas composition, thereby improving system responsiveness and efficiency.

- The present disclosure addresses these needs by providing a method and system for continuously converting biomass into hydrogen-rich product gas through coordinated
20 primary and secondary thermochemical processes along a controlled processing pathway. The disclosed technology further incorporates temperature sensing and control, integrated purification steps, and modular compatibility with downstream catalytic reactors for producing ammonia or methanol from the hydrogen-rich stream. In addition to improving hydrogen output and system efficiency, the system's production of sequesterable biochar
25 enables long-term carbon storage, rendering the overall process carbon-negative. This integrated approach not only enhances the hydrogen output and purity but also improves system scalability, efficiency, and adaptability across a range of biomass types and industrial applications.

Summary

The present invention provides a method and system for hydrogen production from biomass in a continuous and thermally optimized manner to improve hydrogen yield and purity while enabling integration with downstream conversion processes for generating ammonia and methanol. The methanol can be paired with current or future technologies for producing biofuels, such as sustainable aviation fuel (SAF), therefrom.

In one aspect, there is provided a method of hydrogen production from biomass, the method comprising: introducing biomass into a reaction chamber that defines a processing pathway; subjecting the biomass to a primary thermochemical process within the reaction chamber to generate an intermediate gas comprising hydrogen, carbon monoxide, and first vapor components; and subjecting at least the first vapor components to a secondary thermochemical process to obtain a product gas comprising hydrogen, carbon monoxide, and second vapor components. The method includes controlling at least one of temperature and residency duration along the processing pathway for optimizing hydrogen production from each of the primary and secondary thermochemical processes, thereby increasing the hydrogen purity of the product gas. The primary and secondary thermochemical processes occur continuously and substantially in tandem while displacing along the processing pathway.

In some embodiments, the first vapor components comprise hydrocarbons and carbon oxides, which are substantially reduced upon conversion to the second vapor components during the secondary thermochemical process. The method may further include sensing temperatures at a plurality of segments along the processing pathway via a plurality of sensors in communication with a controller, and regulating heating of the pathway using a heater assembly comprising a plurality of heating modules, such as electric heaters, combustion burners, or induction coils, to maintain reference temperatures at each segment.

The method may also include subjecting the product gas to one or more purification steps, including oxygen removal using a transition metal catalyst (e.g., nickel, cobalt, or platinum),

sulfur and sulfide removal using a sorbent-based sulfur trap, and hydrogen enrichment through a water-gas shift reaction catalyzed by transition metals. Furthermore, the product gas may be processed through a pressure swing adsorption (PSA) separator to isolate hydrogen for discharge to a buffer tank, pressure vessel, storage facility, or downstream
5 process.

In further embodiments, the hydrogen-rich product gas may be processed into ammonia by increasing temperature and pressure to approximately 450 °C and 250 bars, respectively, and reacting with an iron-based catalyst, with additional nitrogen introduced as required.
10 Alternatively, the hydrogen-rich gas may be reacted with a copper-based, nickel-based, or palladium-based catalyst to obtain methanol.

In another aspect, there is provided a system for hydrogen production from biomass, the system comprising: a reaction chamber configured to receive and process biomass along a
15 defined processing pathway; a heating assembly disposed along the processing pathway for subjecting the biomass to a primary thermochemical process to generate intermediate gas, and for subjecting at least the first vapor components to a secondary thermochemical process to generate a product gas; and a control system for regulating temperature or residency duration along the pathway to optimize hydrogen production and increase purity. The
20 primary and secondary thermochemical processes occur continuously and substantially in tandem along the processing pathway.

The system may further include a plurality of temperature sensors and a controller operatively coupled to a plurality of heating modules to maintain reference temperatures
25 along the pathway. Additional modules may include an oxygen-removal reactor, a sulfur trap, a water-gas shift reactor, a PSA separator, a VOCs processor or separator and one or more downstream reactors configured for ammonia or methanol synthesis.

The disclosed method and system offer a robust, modular, and scalable approach to hydrogen
30 production from biomass, enabling real-time thermal control, continuous operation, and

integration with downstream applications. The invention overcomes limitations of conventional batch or discontinuous processes and provides significant improvements in hydrogen yield, purity, and energy efficiency.

- 5 Further, the carbon dioxide sequestered from biochar generated during processing of the biomass through the hydrogen production system and method far exceeds the carbon emission of systems, for example LNG-to-electricity systems, powering the hydrogen production system. This therefore renders the hydrogen production system a carbon-negative system and the hydrogen production method 100 a carbon-negative process.

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Brief Description of the Drawings

FIG. 1 shows an exemplary process flow diagram of a method for hydrogen production in accordance with one aspect of the invention;

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FIG. 2 shows an exemplary system flow diagram of a system for hydrogen production in accordance with one aspect of the invention and utilizing the method for hydrogen production of FIG. 1;

- 20 FIG. 3 shows an exemplary partial front sectional view of a reaction chamber of the system for hydrogen production in FIG. 2; and

FIG. 4 shows a system diagram of a controller utilized in the system for hydrogen production in FIG. 2.

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Detailed Description

An exemplary embodiment of the present invention, a method for hydrogen production from biomass (“production method 100”), implementable with a system for hydrogen production from biomass (“production system 20”), is described hereinafter with reference to FIG. 1 to FIG. 4.

In the production system 20, biomass 22, for example cellulosic material, is introduced into a reaction chamber 24 in a step 110. The reaction chamber 24 defines a processing pathway 26 along which the biomass 22 and its products are displaced during processing thereof. The reaction chamber 24 is preferably cylindrical or tubular in shape and can be constructed from materials resistant to both thermal stress and chemical corrosion, such as stainless-steel alloys or ceramic composites, to ensure structural integrity under extreme conditions.

Next, the biomass 22 is subjected to a primary thermochemical process in the reaction chamber 24 to generate an intermediate gas 28 in a step 112 with the intermediate gas 28 comprising hydrogen, carbon monoxide and first vapor components. This initial process typically occurs in a temperature range between 0 °C and 1100 °C depending on the moisture content and composition of the biomass 22. The heating rate and residence time at this stage are critical parameters for maximizing the yield of intermediate gas 28.

At least the first vapour components are then subjected to a secondary thermochemical process to obtain a product gas 32 comprising hydrogen, carbon monoxide and second vapor components in a step 114. For the avoidance of doubt, the product gas 32 may further comprise the hydrogen generated from the first thermochemical process. The secondary thermochemical process is typically a reforming stage, which may include steam reforming. This stage often uses internally recycled heat to facilitate endothermic reactions.

Preferably, the biomass 22 comprises at least one of woodchips, wood pellets and biowaste. An example of the at least one of woodchips and wood pellets is woody biomass 22.

Examples of biowaste includes food waste, plant fibre, rice husks, agricultural biomass 22 and the like cellulose-containing and hemicellulose-containing materials and articles. In an exemplary implementation, biomass 22 is heated in the reaction chamber 24 to a high temperature with by-products of, for example, biochar, bio-oil and wood vinegar before
5 being subsequently cooled. Biochar may also be separated and collected for use as a soil amendment or activated carbon precursor.

At least one of temperature and residency duration along the processing pathway 26 is controlled for optimizing production of hydrogen from each of the primary thermochemical
10 process and the secondary thermochemical process to thereby increase hydrogen purity of the product gas 32. Preferably, the primary thermochemical process and the secondary thermochemical process occurs continuously and substantially in tandem while displacing along the processing pathway 26. Continuous tandem operation is enabled through precise coordination between heat input, material flow, and catalytic surface exposure, ensuring
15 uninterrupted reaction kinetics and minimizing thermal cycling effects that can degrade process efficiency.

The first vapour components comprises hydrocarbons and carbon oxides which are substantially reduced during the secondary thermochemical process and upon obtaining the
20 second vapour components. Examples of hydrocarbons include methane, which are energetically favorable to crack into lighter molecules under elevated temperatures.

In one exemplary embodiment of the invention, the primary thermochemical process sees the biomass 22 being subjected to high temperatures to pyrolyse the biomass 22 into volatile
25 gases, such as hydrogen, carbon monoxide and methane, tars, volatile organic compounds, char and ash. As different biomass types contain different ratios of cellulose, lignin, moisture, and inorganic elements, the yield and composition of the volatile gases. Therefore, through sustained but controlled heating at high temperatures, at least a portion of the volatile gases continue to be cracked into the intermediate gas 28 with the first vapor components
30 comprising methane. During the sustained high temperature along the processing pathway

26, the first vapor components are reformed into the product gas 32 where more hydrogen and carbon monoxide are produced.

Preferably, the production system 20 comprises a plurality of sensors 38 and a heater assembly 40 formed integral with or coupled to the reaction chamber 24. The plurality of
5 sensors 38 and the heater assembly 40 are in signal communication with a controller 42 for providing or transducing temperature data thereto and for receiving temperature set-point and/or control signals therefrom. The production method 100 further comprises sensing temperature at a plurality of segments 44 along the processing pathway 26 by the plurality of
10 sensors 38 in a step 120, and heating of the plurality of segments 44 along the processing pathway 26 is by the heater assembly 40 in a step 122. The heating of the plurality of segments 44 along the processing pathway 26 is by the heater assembly 40 is regulated based on the sensed temperatures for achieving a reference temperature at each thereat to thereby regulate the primary thermochemical process and the secondary thermochemical process, the
15 heater assembly 40 being in signal communication with the controller 42.

Advanced temperature control may involve use of PID or model predictive control (MPC) algorithms within the controller 42, enabling dynamic adjustments in response to process fluctuations. These intelligent controls allow real-time optimization, accommodating changes
20 in composition of the biomass 22 used.

Regulation and control of the residency duration of the biomass 22 and the product gas 32 along the processing pathway 26 is further facilitated by a displacement means 45, for example an auger, in signal communication with the controller for regulating displacement
25 speed of at least one of the biomass 22, the intermediate gas 28 and the product gas 32 along the processing pathway 26. The displacement means 45 is preferably coupled to or formed integral with the reaction chamber 24. The displacement means 45 is further aligned and configured with the heater assembly 40 to enable regulation of temperature at the plurality of segments 44 of the processing pathway 26 during displacement of at least one of the biomass
30 22, the intermediate gas 28 and the product gas 32 therealong. Feedback from the plurality

of sensors 38 also assists in modulating auger speed to prevent thermal overshoot or underexposure. In some implementations, the displacement means 45, for example the auger, may be coated with or formed from a material which contains a catalytic material. In such an implementation, the catalytic material contributes to, for example, one or both of the primary
5 thermochemical process and the secondary thermochemical process. The catalytic material may be formed from one or more of at least one of Nickle (Ni), Molybdenum (Mo), Platinum (Pt), Ruthenium (Ru), Cobalt/Molybdenum (CoMo), Nickel/Molybdenum (NiMo) and Nickle Oxide (NiO) to, for example, facilitate reforming of methane or the first vapour components.

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The heater assembly 40 comprises a plurality of heating modules 46 for heating the plurality of segments 44 of the processing pathway 26. Each of the plurality of heating modules is at least one of an electric heater, a combustion burner, and an induction coil, and the reference temperature being at least 1050 °C. Induction-based heating modules 46 may also be
15 implemented due to rapid heating rates with precise spatial control, whereas electric resistive elements provide steady-state heating suitable for downstream segments of the processing pathway 26.

Prior to being discharged therefrom, at least a portion of the product gas 32 may be filtered of
20 impurities such as tar and soot within the reaction chamber 24. Once the product gas 32 has been obtained or discharged from the reaction chamber 24, the product gas 32 has to be purified by removing impurities such as oxygen and sulfur. At this point prior to the processing of the product gas 32, the product gas 32 has an exemplary composition comprising a hydrogen concentration ranging of 29.69 volume percent on a dry basis, a
25 carbon monoxide concentration of 27.79 volume percent on a dry basis, a carbon dioxide concentration ranging of 6.38 volume percent on a dry basis, and a methane concentration of 6.81 volume percent on a dry basis.

Oxygen Removal

The production method 100 further comprises a step 130 of reacting at least a portion of the product gas 32 with a first catalyst in an oxygen-removal reactor 54 to substantially remove oxygen from the product gas 32. It is preferred that the catalyst comprises one or more transition metals selected from the group consisting of nickel, cobalt, and platinum. In some
5 implementations, the step 130 of oxygen removal may be excluded if oxygen content is relatively low.

Sulfur Trapping and VOC Removal

The production method 100 further comprises a step 134 of passaging at least a portion of the
10 product gas 32 through a sulfur trap 56 to substantially remove sulfur and sulfide therefrom. It is preferred that the sulfur trap 56 uses a sorbent for substantially trapping sulfur and sulfide from the product gas 32.

Additionally or alternatively, the product gas 32 is subjectable to a catalytic reaction with a
15 sulfur-recovery catalyst to convert at least a portion of organic sulfur content in the product gas into inorganic sulfur in the step 134. If implemented in conjunction with the sulfur trap, at least a portion of the organic sulfur is converted into inorganic sulfur prior to being passaged through the sulfur trap. An example of conversion from organic sulfur into inorganic sulfur is hydrogen sulfide and sulfur dioxide into elemental sulfur with the sulfur-
20 recovery catalyst being activated alumina or titanium dioxide.

The production method 100 further comprises a step 136 of passaging at least a portion of the product gas 32 through a volatile organic compounds (VOCs) processor 57 for substantially removing VOCs from at least a portion of the product gas 32, the VOCs comprising at least
25 one of chloride and benzene, toluene, ethylbenzene and xylenes (BTEX) with the VOCs processor removing the VOCs from the product gas 32 by at least one of adsorption, absorption and oxidation

Water-Gas Shift

The production method 100 further comprises a step 138 of reacting at least a portion of the product gas 32 in a water-gas shift reactor 58 in the presence of a second catalyst for substantially converting at least a portion of the product gas 32 into carbon dioxide and hydrogen to thereby further increase hydrogen purity of the product gas 32. It is preferred
5 that the second catalyst comprises one or more transition metals selected from the group consisting of nickel, cobalt, and platinum.

Once the product gas 32 has been processed to this point, the product gas 32 has an exemplary composition comprising a hydrogen concentration ranging of 95.09 volume
10 percent on a dry basis, a carbon monoxide concentration of 0 volume percent, a carbon dioxide concentration ranging of 2.08 volume percent on a dry basis, and a methane concentration of 0 volume percent.

Pressure Swing Adsorption

15 The production method 100 further comprises a step 140 of processing the product gas 32 by a pressure swing adsorption separator 64 for separating hydrogen 65 from the product gas 32. The product gas 32 is then discharged to a downstream process, for example to a gas generator, while the separated hydrogen discharges to one of a buffer tank, a pressure vessel, a storage facility and a downstream process. The production method further comprises a step
20 142 of storing the separated hydrogen 65 in a metal hydride storage system 66. Alternatively, the hydrogen 65 may be compressed to a pressure ranging between 15 bars and 200 bars, or preferably to substantially 200 bars, to obtain pressurized hydrogen therefrom.

Ammonia Production

25 The production method 100 further comprises a step 150 increasing temperature and pressure of at least a portion of the product gas 32 to respectively substantially 450° C by a compressor 70 and substantially 250 bars by a heater 72. Next, the production method 100 further comprises a step 152 of reacting the at least a portion of the product gas 32 in a nitrogen reactor 74 with an iron-based catalyst one of subsequent and during the temperature

and pressure increase to obtain ammonia therefrom. Additional nitrogen is introducible to the product gas 32 during reaction thereof with the iron-based catalyst to obtain the ammonia.

Methanol Production

- 5 The production method 100 further comprises a step 160 of reacting at least a portion of the product gas 32 with a third catalyst in a carbon dioxide reactor 82 to obtain one of methanol 84 therefrom. Preferably, the third catalyst being one of copper-based, nickel-based and palladium-based.
- 10 Direct hydrogenation of CO₂ with hydrogen over a heterogeneous catalyst through a one-step process can convert CO₂ directly to methanol or the like liquid fuels. Liquid methanol is formed from CO₂ with the aid of a unique catalyst material consisting of sulfur and molybdenum.
- 15 Several alternatives for CO₂ reduction to methanol involving homogeneous, enzymatic catalysis, photocatalysis, and electrocatalysis may also be utilized to address the harsh operating condition issues, for example high temperatures, of methanol synthesis from CO₂ over heterogeneous catalysts.
- 20 The temperatures and pressures prescribed in the hydrogen production method 100 and the various embodiments may vary during operations and are subject to changes based on operating and system configuration requirements. Flowrates of the intermediates gas 28 and the product gas 32 through the hydrogen production system 20 will also vary and is subjected to, among other factors, the density of the biomass 22. To adapt to the amount of biomass 22
- 25 that can be processed, for example, within a day, the hydrogen production system 20 and the various embodiments thereof is scalable. For example, the number of reaction chamber 24 may be scaled or increased to meet the processing demands of the biomass which in turn requires elements of the hydrogen production system 20 to be scaled, increased or multiplied to match up or harmonized with output flowrate of the product gas 32 from the reaction
- 30 chamber 24.

The carbon dioxide sequestered from biochar generated during processing of the biomass 22 through the hydrogen production system 20 and method 100 far exceeds the carbon emission of systems, for example LNG-to-electricity systems, powering the hydrogen production system 20. This therefore renders the hydrogen production system 20 a carbon-negative system and the hydrogen production method 100 a carbon-negative process.

Further, the biochar obtained from the hydrogen production system 20 and method 100 may be further converted into hard carbon for battery anodes with better electrical characteristics, for example, better electrical cycling characteristics. Furthermore, the graphitic biochar obtained from the hydrogen production system 20 and method 100 can be further converted into hard carbon for use in battery applications such as the material for the anode of a sodium ion battery which has been demonstrated to be of a better quality in charge capacity and columbic efficiency than existing commercial grade products.

15 Sustainable Aviation fuel

Given the high hydrogen purity of the product gas 32 from where the methanol 84 is derived and the carbon-negative system and the carbon-negative process employed enables a methanol-to-jetfuel (MTJ) pathway to obtain sustainable aviation fuel (SAF) from the methanol.

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One such MTJ pathway utilises the Fisher-Tropsch process which involves a series of reactions where methanol molecules are linked together to form longer hydrocarbon chains, which are then refined into SAF. One techniques, processes and future technologies may be employed independently or in tandem to increase the yield of the green methanol.

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Due to the superior hydrogen yield from biomass 22 based on the above described processes, 1 BDT of the biomass 22 should effectively yield 320 liters of SAF, assuming a claimed yield of 0.5 from 1 ton of the methanol 84 from existing or future MTJ pathways.

Aspects of particular embodiments of the present disclosure address at least one aspect, problem, limitation, and/or disadvantage associated with existing hydrogen production approaches. While features, aspects, and/or advantages associated with certain embodiments have been described in the disclosure, other embodiments may also exhibit such features, aspects, and/or advantages, and not all embodiments need necessarily exhibit such features, aspects, and/or advantages to fall within the scope of the disclosure. It will be appreciated by a person of ordinary skill in the art that several of the above-disclosed structures, components, or alternatives thereof, can be desirably combined into alternative structures, components, and/or applications. In addition, various modifications, alterations, and/or improvements may be made to various embodiments that are disclosed by a person of ordinary skill in the art within the scope of the present disclosure, which is limited only by the following claims.

Claims

1. A method of hydrogen production from biomass, the method comprising:
introducing biomass into a reaction chamber defining a processing pathway;
5 subjecting the biomass to a primary thermochemical process in the reaction chamber to generate an intermediate gas comprising hydrogen, carbon monoxide and first vapor components; and
 subjecting at least the first vapour components to a secondary thermochemical process to obtain a product gas comprising hydrogen, carbon monoxide and second
10 vapor components,
 wherein at least one of temperature and residency duration along the processing pathway is controlled for optimizing production of hydrogen from each of the primary thermochemical process and the secondary thermochemical process to thereby increase hydrogen purity of the product gas, and
15 wherein the primary thermochemical process and the secondary thermochemical process occurs continuously and substantially in tandem while displacing along the processing pathway.
2. The method as in claim 1, the first vapour components comprising hydrocarbons and
20 carbon oxides which are substantially reduced upon obtaining the second vapour components.
3. The method as in claim 1, further comprising:
 sensing temperature at a plurality of segments along the processing pathway
25 by a plurality of sensors in signal communication with a controller; and
 regulating heating of the plurality of segments along the processing pathway by a heater assembly based on the sensed temperatures for achieving a reference temperature at each thereat to thereby regulate the primary thermochemical process and the secondary thermochemical process, the heater assembly being in signal
30 communication with the controller,

wherein the heater assembly comprises a plurality of heating modules for heating the plurality of segments of the processing pathway, each of the plurality of heating modules being at least one of an electric heater, a combustion burner, and an induction coil, and the reference temperature being at least 1050 °C.

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4. The method as in claim 1, further comprising:

reacting at least a portion of the product gas with a catalyst to substantially remove oxygen from the product gas,

wherein the catalyst comprises one or more transition metals selected from the group consisting of nickel, cobalt, and platinum.

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5. The method as in claim 1, further comprising at least one of:

subjecting the product gas to a catalytic reaction with a sulfur-recovery catalyst to convert at least a portion of organic sulfur content in the product gas into inorganic sulfur;

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passaging at least a portion of the product gas through a sulfur trap to substantially remove sulfur and sulfide therefrom; and

passaging at least a portion of the product gas through a volatile organic compounds (VOCs) processor for substantially removing VOCs therefrom, the VOCs comprising at least one of chloride and benzene, toluene, ethylbenzene and xylenes (BTEX) with the VOCs processor removing the VOCs from the product gas by at least one of adsorption, absorption and oxidation,

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wherein the sulfur trap uses a sorbent for substantially trapping sulfur and sulfide from the product gas.

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6. The method as in claim 1, further comprising:

reacting at least a portion of the product gas in a water-gas shift reactor in the presence of a catalyst for substantially converting at least a portion of the product gas into carbon dioxide and hydrogen to thereby further increase hydrogen purity of the product gas,

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wherein the catalyst comprises one or more transition metals selected from the group consisting of nickel, cobalt, and platinum.

7. The method as in claim 1, further comprising:
5 processing the product gas by a pressure swing adsorption separator for separating hydrogen from the product gas for discharge to one of a buffer tank, a pressure vessel, a storage facility and a downstream process.
8. The method as in claim 7, further comprising one of:
10 storing the separated hydrogen in a metal hydride storage system.
9. The method as in claim 1, further comprising:
 increasing temperature and pressure of at least a portion of the product gas to respectively substantially 450° C and 250 bars; and
15 reacting the at least a portion of the product gas with an iron-based catalyst one of subsequent and during the temperature and pressure increase to obtain ammonia therefrom,
 wherein additional nitrogen is introducible to the product gas during reaction thereof with the iron-based catalyst to obtain the ammonia.
- 20 10. The method as in claim 1, further comprising:
 reacting at least a portion of the product gas with a catalyst to obtain methanol therefrom,
 wherein the catalyst being one of copper-based, nickel-based and palladium-based.
25 11. A system of hydrogen production from biomass, the system comprising:
 a reaction chamber for receiving and processing biomass along a processing pathway defined thereby;

a heating assembly configured with the processing pathway for subjecting the biomass to a primary thermochemical process to generate an intermediate gas comprising hydrogen, carbon monoxide and first vapor components, and for subjecting at least the first vapour components to a secondary thermochemical process to obtain a product gas comprising hydrogen, carbon monoxide and second vapor components,

wherein at least one of temperature and residency duration along the processing pathway is controlled for optimizing production of hydrogen from each of the primary thermochemical process and the secondary thermochemical process to thereby increase hydrogen purity of the product gas, and

wherein the primary thermochemical process and the secondary thermochemical process occurs continuously and substantially in tandem while displacing along the processing pathway.

12. The system as in claim 11, the first vapour components comprising hydrocarbons and carbon oxides which are substantially reduced upon obtaining the second vapour components.

13. The system as in claim 11, further comprising:
a plurality of sensors disposed for sensing temperature at a plurality of segments along the processing pathway; and
a controller in signal communication with the heating assembly and the plurality of sensors for regulating heating of the plurality of segments along the processing pathway based on the sensed temperatures for achieving a reference temperature at each thereat to thereby regulate the primary thermochemical process and the secondary thermochemical process,

wherein the heater assembly comprises a plurality of heating modules for heating the plurality of segments of the processing pathway, each of the plurality of heating modules being at least one of an electric heater, a combustion burner, and an induction coil, and the reference temperature being at least 1100 °C.

14. The system as in claim 11, further comprising:
an oxygen-removal reactor for reacting at least a portion of product gas received from the reaction chamber with a catalyst to substantially remove oxygen from the product gas,
5 wherein the catalyst comprises one or more transition metals selected from the group consisting of nickel, cobalt, and platinum, and
wherein the product gas is subjectable to a catalytic reaction with a sulfur-recovery catalyst to convert at least a portion of organic sulfur content in the product gas into inorganic sulfur prior to passing through the sulfur trap.
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15. The system as in claim 11, further comprising at least one of:
a sulfur-recovery catalyst to convert at least a portion of organic sulfur content in the product gas into inorganic sulfur;
15 a sulfur trap for substantially remove sulfur and sulfide from the product gas passing therethrough; and
a volatile organic compounds (VOCs) processor for substantially removing VOCs from at least a portion of the product gas, the VOCs comprising at least one of chloride and benzene, toluene, ethylbenzene and xylenes (BTEX) with the VOCs processor removing the VOCs from the product gas by at least one of adsorption, absorption and oxidation,
20 wherein the sulfur trap uses a sorbent for substantially trapping sulfur and sulfide from the product gas.
- 25 16. The system as in claim 11, further comprising:
a water-gas shift reactor for reacting at least a portion of the product gas for substantially converting at least a portion of the product gas into carbon dioxide and hydrogen to thereby further increase hydrogen purity of the product gas,
wherein the catalyst comprises one or more transition metals selected from the group consisting of nickel, cobalt, and platinum.
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17. The system as in claim 11, further comprising:
a pressure swing adsorption separator for separating hydrogen from the
product gas for discharge to one of a buffer tank, a pressure vessel, a storage facility
5 and a downstream process.
18. The system as in claim 17, further comprising one of:
a metal hydride storage system for storing the hydrogen separated from the
product gas.
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19. The system as in claim 11, further comprising:
a compressor for increasing pressure of the product gas to substantially 250
bars;
a heater for increasing temperature of the product gas to substantially 450° C;
15 and
a nitrogen reactor for reacting the product gas with an iron-based catalyst one
of subsequent and during the temperature and pressure increase to obtain ammonia
therefrom,
wherein additional nitrogen is introducible to the product gas during reaction
20 thereof with the iron-based catalyst to obtain the ammonia.
20. The system as in claim 11, further comprising:
a carbon dioxide reactor for reacting the product gas with a catalyst to obtain
methanol therefrom,
25 wherein the catalyst being one of copper-based, nickel-based and palladium-
based.