Claims

1. A process for forming a bio-derived hydrogen gas from a biomass feedstock
   using a non-food crop biomass feedstock, the method comprising the steps of:
   a. ensuring the moisture content of the biomass feedstock is 10% or less by weight of the biomass feedstock;
   b. pyrolysing the low moisture biomass feedstock at a temperature of at least 950 °C to form a mixture of biochar, hydrocarbon feedstock, non-condensable light gases, such as hydrogen, carbon monoxide, carbon dioxide and methane, and water;
   c. separating the non-condensable light gases from the mixture formed in step b.;
   d. separating hydrogen gas from the remaining non-condensable light gases using a hydrogen separation membrane.

2. A process according to Claim 1, wherein the non-food crop biomass feedstock is selected from miscanthus, switchgrass, garden trimmings, straw, such as rice straw or wheat straw, cotton gin trash, municipal solid waste, palm fronds/empty fruit bunches (EFB), palm kernel shells, bagasse, wood, such as hickory, pine bark, Virginia pine, red oak, white oak, spruce, poplar, and cedar, grass hay, mesquite, wood flour, nylon, lint, bamboo, paper, corn stover, or a combination thereof.

3. A process according to any one of Claims 1 to 2, wherein the biomass feedstock is in the form of pellets, chips, particulates or a powder, preferably the pellets, chips, particulates or powder have a diameter of from 5µm to 10 cm, such as from 5µm to 25mm, preferably from 50µm to 18mm, more preferably from 100µm to 10mm, preferably

   wherein the pellets, chips, particulates or powder have a diameter of at least 1mm, such as from 1mm to 25mm, 1mm to 18mm or 1mm to 10mm; and/or

   wherein initial moisture content of the biomass feedstock is up to 50% by weight of the biomass feedstock, such as up to 45% by weight of the biomass feed stock, or for example up to 30% by weight of the biomass feedstock.

4. A process according to any preceding claim, wherein the moisture content of the biomass feedstock is reduced to 7% or less by weight, such as 5% or less by weight of the biomass feedstock.

5. A process according to any preceding claim, wherein the step of ensuring the moisture content of the biomass feedstock is 10% or less by weight of the biomass feedstock comprises reducing the moisture content of the biomass feedstock, such as

   wherein the moisture content of the biomass feedstock is reduced by use of a vacuum oven, a rotary dryer, a flash dryer or a heat exchanger, such as a continuous belt dryer, preferably wherein the moisture content of the biomass feedstock is reduced through the use of indirect heating, for example by using an indirect heat belt dryer, an indirect heat fluidised bed or an indirect heat contact rotary steam-tube dryer.

6. A process according to any preceding claim, wherein the low moisture biomass feedstock is pyrolysed at temperature of at least 1000°C, more preferably at a temperature of at least 1100°C.

7. A process according to any preceding claim, wherein heat is provided to the pyrolysis step by means of convection heating, microwave heating, electrical heating or supercritical heating, preferably

   wherein the heat source comprises microwave assisted heating, a heating jacket, a solid heat carrier, a tube furnace or an electric heater, preferably the heating source is a tube furnace; or

   wherein the heat source is positioned inside the reactor, preferably the heat source comprises one or more electric spiral heaters, such as a plurality of electric spiral heaters.

8. A process according to any preceding claim, wherein the low moisture biomass is pyrolysed at atmospheric pressure or the low moisture biomass is pyrolysed under a pressure of from 850 to 1000 Pa, preferably from 900 to 950 Pa and, optionally, wherein the pyrolysis gases formed are separated through distillation; and/or

   wherein the low moisture biomass feedstock is pyrolysed for a period of from 10 seconds to 2 hours, preferably, from 30 seconds to 1 hour, more preferably from 60 seconds to 30 minutes, such as 100 seconds to 10 minutes.

9. A process according to any preceding claim, wherein the pyrolysis reactor is arranged such that the low moisture biomass is conveyed in a counter-current direction to any pyrolysis gases formed, and optionally wherein biochar formed as a result of the pyrolysis step leaves pyrolysis reactor separate to the pyrolysis gases, and optionally

   wherein the pyrolysis gases are subsequently cooled, for example through the use of a venturi, to condense the hydrocarbon feedstock product.

10. A process according to any preceding claim, wherein step c. comprises at least partially separating the non-condensable light gases from the mixture formed in step b. by use of flash distillation or fractional distillation.

11. A process according to any preceding claim, wherein the hydrogen separation membrane is selected from a polymeric membrane, a metal organic framework (MOF) or a metallic membrane, preferably

    wherein the metallic membrane comprises a single metal, a metal alloy and/or a metallic complex; or

    wherein the polymeric membrane is selected from the group consisting of cellulose acetate, polysulfone, polyethersulfone, polyimide or a polyetherimide-based polymeric membrane; or

    wherein the MOF membrane comprises a metal selected from Zn, Cu, Co, Fe, Cr, Mn, Ti, Zr, Cd, Mg, Al, Ni, Ag, Mo and W and at least one organic ligand selected from the group consisting of formic acid, MIM (methylimidazole), BIM (benzimidazole), BDC (1,4-dicarboxylic acid benzene), BTC (1,2,4-tricarboxylic acid benzene) 1,4-NDC (1,4-naphthalene dicarboxylic acid), 2,6-NDC (2.6-naphthalene dicarboxylic acid), BBIM (bisbenzimidazole), bpy (4,4'-bipyridine), pym_2S_2 (dithiopyridine), IN (Isonicotinic acid), pshz (N-propionic salicylhydrazine) or a combination thereof, such as

wherein the MOF membrane is selected from the group consisting of CuBDC, In(OH)hfipbb, $Zn_2(BIM)_4$, $Zn_2(BIM)_3(OH)(H_2O)$, Zn(BIM)OAc, $Zn_2(MIM)_4(HMIM)(H_2O)_3$, CoBDC, Cu(1,4-NDC), Cu(2,6-NDC), or $Mn_6(pshz)_6(bpea)_2(dma)_2$.

12. A process according to Claim 11, wherein the metallic membrane is selected from palladium or a palladium alloy, preferably

    wherein the palladium alloy comprises one or more transition metals selected from Ag, Au, Ni and Pt.

13. A process according to Claim 11, wherein the metallic membrane comprises a palladium complex comprising one or more ligands, preferably the one or more ligands are selected from ethylene diamine, diethylene diamine, tetraammonia and diammonia, preferably

    wherein the palladium complex is in the form of an alloy with one or more transition metals, such as

    wherein the one or more transition metals are selected from Group IB, IVB, VB, VIB, or VIII of the periodic table.

14. A process according to Claim 13, wherein the one or more transition metals are selected from Group IB of the periodic table, preferably the one or more transition metals are selected from Cu, Ag and Au; or

    wherein the one or more transition metals are selected from Group IVB of the periodic table, preferably the one or more transition metals are selected from Ti or Zr; or

    wherein the one or more transition metals are selected from Group VB of the period table, preferably the one or more transition metals are selected from Ta, Nb and V; or

    wherein the one or more transition metals are selected from Group VIB of the periodic table, preferably the one or more transition metals are selected from Cr, Mo and W; or

    wherein the one or more transition metals are selected from Group VIII of the periodic table, preferably the one or more transition metals are selected from Pt, Rh, Ir, Fe, Co and Ni, more preferably the transition metal is selected from Ni.

15. A process according to any one of Claims 12 to 14, wherein the palladium alloy or palladium complex comprises palladium in an amount of at least 50% by weight, preferably in an amount of from 55% to 90% by weight based on the total weight of the palladium alloy or palladium complex.

16. A process according to any one of Claims 12 to 15, wherein the metallic membrane is formed from two or more layers of palladium, palladium alloy or a palladium complex, preferably

    wherein the metallic membrane is selected from a palladium alloy and wherein each layer comprises a palladium/transition metal alloy or wherein the palladium alloy comprises alternating layers of palladium and one or more transition metals.

17. A process according to any preceding claim, wherein the hydrogen separation membrane further comprises a porous support, preferably the porous support is selected from porous stainless steel, porous ceramic, porous glass or porous nickel, more preferably the support is selected from a porous ceramic material or porous stainless steel, preferably

    wherein the pores of the porous support have a diameter of from 0.5 nm to 5 µm, preferably 0.6 nm to 2 µm, more preferably from 0.6 nm to 10 nm.

18. A process according to any preceding claim, wherein the hydrogen separation membrane is in the form of flat membrane or a tubular membrane, such as a generally straight tubular membrane or a helical tubular membrane.

19. A process according to any one of Claims 12 to 18, wherein the palladium, palladium alloy or palladium complex membrane has been applied to the surface of the porous support using electroless plating, chemical vapour deposition or sputtering, preferably the palladium, palladium alloy or palladium complex membrane has been applied to the surface of the porous support using electroless plating.

20. A process according to any one of Claims 17 to 18, wherein the hydrogen separation membrane is bonded to the surface of the porous support via an adhesive or welding or the hydrogen separation membrane is maintained on the surface of the porous support via mechanical means, preferably

    wherein the mechanical means are selected from pins screws, bands, such as an O-ring, rubber ring or fluoro-rubber ring, or a graphite gasket.

21. A process according to any preceding claim wherein the hydrogen separation membrane has a thickness of from 0.5 to 25 µm, preferably from 2 to 10 µm, more preferably from 3 to 8 µm.

22. A process according to any one of Claims 17 to 21, wherein the supported hydrogen separation membrane further comprises an intermediate layer positioned between the support and the hydrogen separation membrane, preferably the intermediate layer is selected from palladium, silver, copper, gold, cerium oxide and or ɣAl_2O_3 , more preferably, the intermediate layer is selected from ɣAl_2O_3, preferably

    wherein the intermediate layer is applied to the surface of the support using electroless plating, chemical vapour deposition or sputtering.

23. A process according to any preceding claim, wherein the non-condensable light gases are contacted with the hydrogen separation membrane at ambient pressure or under a pressure of from 100 KPa to 2000 KPa, preferably from 300 KPa to 1500 KPa, more preferably from 500KPa to 800 KPa.

24. A process according to any preceding claim, wherein the separated hydrogen gas is contacted with a second hydrogen separation membrane, in order to remove further impurities from the separated hydrogen gas, preferably

    wherein the second hydrogen separation membrane is as defined in any one of Claims 11 to 22.

25. A process according to any preceding claim, further comprising the step of increasing the hydrogen content of the non-condensable light gases through a water gas shift reaction before separating hydrogen gas from the remaining non-condensable light gases.

26. A process according to any preceding claim, further comprising the step of increasing the hydrogen content of the remaining non-condensable light gases through a water gas shift reaction following step d, preferably

    wherein the hydrogen formed is separated from the remaining the non-condensable light gases in accordance with any one of Claims 11 to 24.

27. A process according to any one of Claims 25 to 26, wherein the ratio of water to carbon monoxide of the non-condensable gas or remaining non-condensable gas is from 1 to 5, preferably the ratio of water to carbon monoxide is greater than 1.2, such as from 1.2 to 4.5, preferably from 1.6 to 3.5; and/or

    wherein the water gas shift reaction is performed at a temperature of from 250 °C to 450 °C, preferably a temperature of from 325 °C to 400 °C, more preferably from 350 to 385 °C; and/or

    wherein the water gas shift reaction is performed at a pressure of from 0.1 to 2 MPa, preferably from 0.3 to 1.5 MPa; and/or

    wherein the water-gas shift reaction further comprises a shift catalyst, preferably the shift catalyst is selected from a copper-zinc-aluminium catalyst or a chromium or copper promoted iron-based catalyst, more preferably the shift catalyst is a copper-zinc-aluminium catalyst.

28. A process according to any preceding claim, wherein the remaining non-condensable light gases are at least partially recycled and optionally combined with the low moisture biomass feedstock in step b.

29. A bio-derived hydrogen gas formed by the process defined in any one of Claims 1 to 28, preferably

    wherein the hydrogen gas has a purity of at least 95%, preferably at least 97% more preferably at least 98.5%,

30. Use of a bio-derived hydrogen gas as defined in claim 29 in fuel cells; or

    in petroleum refining processes; or

    in forming bio-derived ammonia or methane.