Claims

1. A process for forming a bio-gasoline fuel using a biomass feedstock having a moisture content of 10% or less by weight of the biomass feedstock comprising:
    a. 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;
    b. separating the hydrocarbon feedstock from the mixture formed in step a.;
    c. cracking the hydrocarbon feedstock of step b. using a fluidised catalytic cracking (FCC) process to produce a bio-oil; and
    d. fractionating the resulting bio-oil to obtain a bio-derived gasoline fuel fraction.

2. A process according to claim 1, wherein the biomass feedstock comprises cellulose, hemicellulose or lignin-based feedstocks.

3. A process according to claim 1 or claim 2, wherein the biomass feedstock is a non-food crop biomass feedstock, preferably the non-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.

4. A process according to any one of claims 1 to 3, 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, for example 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.

5. A process according to any preceding claim, wherein the 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.

6. 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.

7. 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.

8. 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.

9. 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, for example 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; and/or wherein the heat source is positioned inside the reactor, preferably wherein the heat source comprises one or more electric spiral heaters, such as a plurality of electric spiral heaters.

10. A process according to any preceding claim, wherein the low moisture biomass is pyrolysed at atmospheric pressure or wherein 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.

11. A process according to any preceding claim, 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.

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

13. A process according to any preceding claim, wherein step b. comprises at least partially separating biochar from the hydrocarbon feedstock product, preferably wherein biochar is at least partially separated by filtration (such as by use of a ceramic filter), centrifugation, or cyclone or gravity separation; and/or

    wherein step b. comprises at least partially separating water from the hydrocarbon feedstock product, preferably the water at least partially separated further comprises organic contaminants, more preferably the water at least partially separated from the hydrocarbon feedstock product is a pyroligneous acid, even more preferably wherein water is at least partially separated from the hydrocarbon feedstock product by gravity oil separation, centrifugation, cyclone or microbubble separation; and /or

    wherein step b. comprises at least partially separating non-condensable light gases from the hydrocarbon feedstock product, preferably wherein non-condensable light gases are at least partially separated from the hydrocarbon feedstock product by use of flash distillation or fractional distillation.

14. A process according to claim 13, wherein the separated non-condensable light gases are recycled and optionally combined with the low moisture biomass feedstock in step a.; and/or

    wherein carbon monoxide present in the non-condensable light gases is contacted with steam in a water gas shift reaction to produce carbon dioxide and a bio-derived hydrogen gas, preferably wherein the water gas shift reaction is performed at a temperature of from 205 °C to 482 °C, more preferably a temperature of from 205 °C to 260 °C, and optionally 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.

15. A process according to any preceding claim, further comprising the step of filtering the hydrocarbon feedstock product to at least partially remove contaminants, such as carbon, graphene, polyaromatic compounds and/or tar, contained therein, preferably the filtration step comprises the use of a membrane filter to remove larger contaminants and/or fine filtration to remove smaller contaminants, for example by using a Nutsche filter, for example wherein the filtration step comprises contacting the hydrocarbon feedstock product with an active carbon compound and/or a crosslinked organic hydrocarbon resin and subsequently separating the hydrocarbon feedstock product from the active carbon and/or crosslinked organic hydrocarbon resin compound though filtration, such as wherein the active carbon compound and/or crosslinked organic hydrocarbon resin is contacted with the hydrocarbon feedstock product at around atmospheric pressure; and/or

    wherein the active carbon compound and/or crosslinked organic hydrocarbon resin is contacted with the hydrocarbon feedstock product for at least 15 minutes before separation, preferably at least 20 minutes, more preferably at least 25 minutes; and/or

    wherein the step of filtering the hydrocarbon feedstock is performed once or is repeated one or more times.

16. A process according to claim 15, wherein the tar removed from the hydrocarbon feedstock is recycled and optionally combined with the low moisture biomass feedstock in step a.

17. A process for forming a bio-gasoline fuel using the bio-derived hydrocarbon feedstock produced according to any one of claims 1 to 16 comprising:
    i. cracking the hydrocarbon feedstock of step i. using a fluidised catalytic cracking (FCC) process to produce a bio-oil; and
    ii. fractionating the resulting bio-oil to obtain a bio-derived gasoline fuel fraction.

18. A process according to any preceding claim, wherein the hydrocarbon feedstock of step b. as defined in any one of claims 1 to 16 or the hydrocarbon feedstock as defined in claim 17 undergoes FCC at a temperature of from 400 °C to 800 °C, preferably at a temperature of from 450 °C to 750 °C, more preferably a temperature of from 500 °C to 700 °C.

19. A process according to any preceding claim, wherein the hydrocarbon feedstock of step b. as defined in any one of claims 1 to 16 or the hydrocarbon feedstock as defined in claim 17

undergoes FCC at a pressure of from 0.05 MPa to 10 MPa, preferably from 0.1 MPa to 8 MPa, more preferably from 0.5 MPa to 6 MPa.

20. A process according to any preceding claim, wherein the hydrocarbon feedstock is contacted with the fluidised cracking catalyst at a weight ratio of from 1:1 to 1: 150, preferably from 1:2 to 1:100, more preferably from 1:5 to 1:50.

21. A process according to any preceding claim, wherein the FCC process is performed in a fluidised catalytic cracking reactor, such as a fluidised dense bed reactor or a riser reactor, preferably the FCC reactor is a riser reactor, more preferably the riser reactor is selected from an internal riser reactor or an external riser reactor, optionally wherein the hydrocarbon feedstock and the fluidised cracking catalyst are supplied at an inlet at or near the base of the FCC reactor, and wherein the bio-oil formed and de-activated catalyst are extracted from an outlet at or near the top of the FCC reactor, optionally wherein the hydrocarbon feedstock is atomised prior to or upon entry into the FCC reactor, preferably the hydrocarbon feedstock is atomised to a droplet size of from 10 μm to 60 μm, more preferably a droplet size of from 20 μm to 50 μm.

22. A process according to claim 21, wherein a lift gas is supplied to the FCC reactor through an inlet at or near the base of the reactor, preferably the lift gas is selected from steam, nitrogen, or vaporised oil; and/or

    wherein the hydrocarbon is in contact with the fluidised cracking catalyst in the FCC reactor for a period of from 0.5 seconds to 15 seconds, preferably from 1 second to 10 seconds, more preferably from 2 seconds to 5 seconds.

23. A process according to any preceding claim, wherein the fluidised cracking catalyst is in the form of particulates or a powder, preferably the fluidised cracking catalyst is in the form of a fine powder, such as wherein the particulates or powder have a diameter of from 10 μm to 300 μm, preferably 15 μm to 200 μm, more preferably a diameter of from 20 μm to 150 μm.

24. A process according to any preceding claim, wherein the fluidised cracking catalyst comprises a zeolite or high activity crystalline alumina silicate, and optionally further comprises an amorphous binder compound and/or a filler, preferably the amorphous binder compound is selected from silica, alumina, titania, zirconia and magnesium oxide, or combinations thereof and/or the filler is selected from a clay, such as kaolin, such as wherein the zeolite is a large pore zeolite, preferably the large pore zeolite is selected from FAU or faujasite, preferably synthetic faujasite, for example, zeolite Y or X, ultra-stable zeolite Y (USY), Rare Earth zeolite Y (REY) and Rare Earth USY (REUSY), more preferably the large pore zeolite is selected from an ultra-stable zeolite Y (USY); and/or

    wherein the zeolite is a large pore zeolite, preferably selected from a natural large-pore zeolite, such as gmelinite, chabazite, dachiardite, clinoptilolite, faujasite, heulandite, analcite, levynite, erionite, sodalite, cancrinite, nepheline, lazurite, scolecite, natrolite, offretite, mesolite, mordenite, brewsterite, and ferrierite and/or a synthetic large pore zeolite, such as zeolites X, Y, A, L. ZK-4, ZK-5, B, E, F, H, J, M, Q, T, W, Z, alpha and beta, omega, REY and USY zeolites, preferably the large pore zeolite is preferably selected from faujasites, particularly zeolite Y, USY, and REY; and/or

wherein the large pore zeolite comprises internal pores having a pore diameter of from 0.62 nm to 0.8 nm.

25. A process according to claim 24, wherein the zeolite is a medium pore zeolite, preferably the medium pore zeolite is a MFI type zeolite, for example, ZSM-5, a MFS type zeolite, a MEL type zeolites a MTW type zeolite, for example, ZSM-12, a MTW type zeolite, an EUO type zeolite, a MTT type zeolite, a HEU type zeolite, TON type zeolite, for example, theta-1, and/or a FER type zeolite, for example, ferrierite, such as wherein the medium pore zeolite is selected from ZSM-5, ZSM-12, ZSM-22, ZSM-23, ZSM-34, ZSM-35, ZSM-38, ZSM-48, ZSM-50, silicalite, and silicalite 2, preferably the medium pore zeolite is ZSM-5; and/or

    wherein the medium pore zeolite has internal pores having a diameter of from 0.45 nm to 0.62 nm.

26. A process according to any one of claims 24 to 25 wherein the zeolite catalyst comprises a blend of one or more large pore zeolites, as defined in claim 24 and one or more medium pore zeolites, as defined in claim 25, for example wherein the weight ratio of large pore zeolites to medium pore zeolites is in the range of 99:1 to 70:30, preferably from 98:2 to 85:15.

27. A process according to any preceding claim, wherein the fluidised cracking catalyst is arranged to contact the hydrocarbon feedstock of step b. as defined in any one of claims 1 to 16 or the hydrocarbon feedstock as defined in claim 17 in a counter-current flow, a co-current flow or a cross-flow configuration.

28. A process according to any preceding claim, wherein the process further comprises at least partially removing the deactivated catalyst from the bio-oil formed, preferably the deactivated catalyst is at least partially removed from the bio-oil using one or more cyclones and/or one or more swirl tubes.

29. A process according to any preceding claim, wherein the process further comprises at least partially removing sulphur containing components from the bio-oil formed and/or the bio-derived gasoline fuel fraction, preferably the sulphur removal step comprises a catalytic hydro-desulphurisation step, such as wherein the catalyst is part of a fixed bed or a trickle bed reactor, and preferably wherein the catalyst is selected from a nickel molybdenum sulphide (NiMoS), molybdenum, molybdenum disulphide (MoS_2), cobalt/molybdenum, cobalt molybdenum sulphide (CoMoS) and/or a nickel/molybdenum based catalyst, and preferably wherein the catalyst is selected from a nickel molybdenum sulphide (NiMoS) based catalyst, preferably the catalyst is a supported catalyst, such as by means of a support selected from activated carbon, silica, alumina, silica-alumina, a molecular sieve, and/or a zeolite.

30. A process according to claim 29, wherein the hydro-desulphurisation step is performed at a temperature of from 250°C to 400 °C, preferably from 300°C and 350°C; and/or wherein the hydro-desulphurisation step is performed at a reaction pressure of from 4 to 6 MPaG, preferably from 4.5 to 5.5MPaG, more preferably about 5 MPaG.

31. A process according to any one of claims 29 to 30, wherein the catalytic hydro-desulphurisation process further comprises the step of degassing the reduced sulphur bio-oil and/or gasoline fuel fraction to remove hydrogen disulphide gas, such as by cooling the reduced sulphur bio-oil and/or gasoline fuel fraction to a temperature of from 60 to 120°C, preferably from 80 to 100°C and optionally applying a vacuum pressure of less than 6KPaA, preferably less than 5KPaA, more preferably less than 4KPaA, and optionally wherein the process further comprises deoxygenating the separated hydrocarbon feedstock of step b. as defined in any one of claims 1 to 16 or the hydrocarbon feedstock as defined in claim 17, for example wherein the deoxygenation steps is a hydrodeoxygenation step performed at a temperature of from 200 °C to 450 °C, preferably from 250 °C to 400 °C, more preferably from 280 °C to 350 °C and/or wherein the hydrodeoxygenation step is performed at a pressure of from 1 MP to 30 MPa, preferably from 5 MPa to 30 MPa, and optionally wherein the hydrodeoxygenation step further comprises a catalyst, such as a catalyst as part of a fixed bed or a trickle bed reactor, preferably wherein the catalyst comprises a metal selected from Group VIII and/or Group VIB of the periodic table, preferably the catalyst comprises a metal selected from Ni, Cr, Mo, W, Co, Pt, Pd, Rh, Ru, Ir, Os, Cu, Fe, Zn, Ga, In, V, and mixtures thereof, more preferably the catalyst is a supported catalyst, such as by means of a support selected from alumina, amorphous silica-alumina, titania, silica, ceria, zirconia, carbon, silicon carbide or zeolite such as zeolite Y, zeolite beta, ZSM-5 , ZSM-12, ZSM-22, ZSM-23, ZSM-48, SAP0-11, SAP0-41, and ferrierite.

32. A process according to any preceding claim, wherein the process further comprises hydro-treating the bio-oil formed, such as wherein the hydro-treating step is performed at a temperature of from 250°C to 350°C, preferably from 270°C to 330°C, more preferably from 280°C to 320°C; and/or wherein the hydro-treating step is performed at a reaction pressure of from 4MPaG to 6MPaG, preferably from 4.5MPaG to 5.5MPaG, more preferably about 5MPaG, and optionally wherein the hydro-treating process further comprises a catalyst, such as a catalyst as part of a fixed bed or a trickle bed reactor, preferably wherein the catalyst comprises a metal selected from Group IIIB, Group IVB, Group VB, Group VIB, Group VIIB, and Group VIII, of the periodic table, preferably the catalyst comprises a metal selected from Group VIII of the periodic table, preferably the catalyst comprises Fe, Co, Ni, Ru, Rh, Pd, Os, Ir, and/or Pt, such as a catalyst comprising Ni, Co, Mo, W, Cu, Pd, Ru, Pt, and preferably wherein the catalyst is selected from CoMo, NiMo or Ni, more preferably wherein the catalyst is a supported catalyst, such as by means of a support selected from activated carbon, silica, alumina, silica-alumina, a molecular sieve, and or a zeolite.

33. A process according to any preceding claim, further comprising the step of at least partially removing LPG from the bio-oil by condensation and/or flash distillation, optionally further comprising the step of applying a vacuum pressure of less than 6KPaA to the bio-oil, preferably less than 5KPaA, more preferably less than 4KPaA, to separate LPG from the remaining bio-oil.

34. A process according to any one of claims 1 to 33, wherein the fractionation step comprises separating a first fractionation cut having a cut point of between 30 °C and 220°C , preferably between 50°C and 210°C, more preferably between 70 °C and 200 °C of the bio-oil under atmospheric pressure, wherein the separated fraction is collected as a bio-derived gasoline fuel, and optionally wherein the process further comprises performing a second fractionation cut having a cut point between 280°C and 320°C, preferably from 290°C to

310°C, more preferably about 300°C of the boil-oil under atmospheric pressure, wherein the separated fraction is collected as a bio-derived jet-fuel, and further optionally wherein the process comprises collecting the bottom stream of the bio-oil as a bio-derived diesel fuel.

35. A process according to any one of claims 28 to 34, wherein the at least partially removed catalyst undergoes regeneration, comprising the steps of:

    a. stripping the deactivated catalyst to remove bio-oil absorbed on the surface of the catalyst; and
    b. regenerating the catalyst,

    optionally wherein the stripping step comprises contacting the deactivated catalyst with a gas comprising steam at a temperature of from 400 °C to 800°C, preferably from 400 °C to 700°C, more preferably from 450 °C to 650 °C, preferably wherein the deactivated catalyst is contacted with a gas comprising steam for a period of 1 to 10 minutes, preferably 2 to 8 minutes, more preferably 3 to 6 minutes, and preferably wherein the deactivated catalyst is contacted with a gas comprising steam in a weight ratio of from 10:1 to 100:1, preferably in a weight ratio of 20:1 to 60:1; and/or

    wherein the catalyst is regenerated by contacting the stripped catalyst with an oxygen containing gas at a temperature of from 550 °C to 950 °C, preferably 575 °C to 900 °C, more preferably from 600 °C to 850 °C and/or wherein the regeneration step is performed at a pressure of from 0.05 MPa to 1 MPa, preferably a pressure of from 0.1 MPa to 0.6 MPa.

36. A process according to claim 35, wherein the regenerated catalyst is at least partly recycled to the FCC process.

37. A bio-derived LPG fuel formed by a process according to any one of claims 1 to 33; and/or

    A bio-derived gasoline fuel formed by a process according to any one of claims 1 to 33, preferably the bio-derived gasoline fuel is formed entirely from a biomass feedstock and/or

    A bio-derived jet fuel formed by a process according to any one of claims 1 to 33 and/or

    A bio-derived diesel fuel formed by a process according to any one of claims 1 to 34.