Claims

1. A process for forming a biomass derived hydrocarbon feedstock suitable for forming bio-diesel, using a biomass feedstock having a moisture content of 10% or less by weight of the biomass feedstock;

    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; and
    b. separating the hydrocarbon feedstock from the mixture formed in step a.

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, such as wherein 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, for example, wherein 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 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, further comprising a step of ensuring the moisture content of the biomass feedstock is 10% or less by weight of the biomass feedstock comprising 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, for example, 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, for example, wherein the heat source is positioned inside the reactor, such as 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.

11. A process according to any one of claims 1 to 10, 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.

12. 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 second to 30 minutes, such as 100 seconds to 10 minutes.

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

14. A process according to any preceding claim, wherein step b. comprises at least partially separating water from the hydrocarbon feedstock product, preferably the water at least partially separated from the hydrocarbon feedstock product further comprises organic contaminants, more preferably the water at least partially separated from the hydrocarbon feedstock product is a pyroligneous acid, and optionally wherein water is at least partially separated from the hydrocarbon feedstock product by gravity oil separation, centrifugation, cyclone or microbubble separation.

15. A process according to any preceding claim, wherein step b. comprises at least partially separating non-condensable light gases from the hydrocarbon feedstock product, and optionally wherein non-condensable light gases are at least partially separated from the hydrocarbon feedstock product by use of flash distillation or fractional distillation, and optionally wherein the separated non-condensable light gases are recycled and optionally combined with the low moisture biomass feedstock in step a.

16. 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, and optionally wherein the filtration step comprises the use of a membrane filter to remove larger contaminants, for example, wherein the filtration step comprises fine filtration to remove smaller contaminants, for example by using a Nutsche filter.

17. A process according to claim 16, 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, and optionally wherein the active carbon compound and/or crosslinked organic hydrocarbon resin is contacted with the hydrocarbon feedstock product under ambient conditions; 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.

18. A process according to any one of claims 16 to 17, wherein the tar removed from the hydrocarbon feedstock is recycled and optionally combined with the low moisture biomass feedstock in step a.

19. A biomass derived hydrocarbon feedstock obtainable by the process according to any one of claims 1 to 18.

20. A hydrocarbon feedstock according to claim 19, wherein the hydrocarbon feedstock comprises at least 0.1% by weight of one or more C_8 compounds, at least 0.5% by weight of one or more C_{10} compounds, at least 5% by weight of one or more C_{12} compounds, at least 5% by weight of one or more C_{16} compounds and at least 30% by weight of at least one or more C_{18} compounds, preferably wherein the hydrocarbon feedstock comprises at least 0.5% by weight of one or more C_8 compounds, at least 2% by weight of one or more C_{10} compounds, at least 6% by weight of one or more C_{12} compounds; at least 6% by weight of one or more C_{16} compounds and/or at least 33% by weight of one or more C_{18} compounds.

21. A hydrocarbon feedstock according to any one of claims 19 to 20, wherein the hydrocarbon feedstock has a pour point of -10°C or less, preferably -15°C or less, such as -16°C or less.

22. A hydrocarbon feedstock according to any one of claims 19 to 21, wherein the hydrocarbon feedstock comprises 70 ppmw or less of sulphur.

23. A process of forming a bio-derived diesel fuel

using the biomass derived hydrocarbon feedstock according to Claim 19 or comprising at least 0.1% by weight of one or more C_8 compounds, at least 0.5% by weight of one or more C_{10} compounds, at least 5% by weight of one or more C_{12} compounds, at least 5% by weight of one or more C_{16} compounds and at least 30% by weight of one or more C_{18} compounds; the method comprising:

A. processing the hydrocarbon feedstock to produce a refined bio-oil, wherein the process comprises the steps of:

i. at least partially removing sulphur containing components from the hydrocarbon feedstock;
ii. hydro-treating the hydrocarbon feedstock; and
iii. hydro-isomerising the hydrocarbon feedstock; and

B. fractionating the resulting refined bio-oil to obtain a bio-derived diesel fuel fraction.

24. A process according to claim 23, wherein the hydrocarbon feedstock comprises at least 0.5% by weight of one or more C_8 compounds, at least 2% by weight of one or more C_{10} compounds, at least 6% by weight of one or more C_{12} compounds, at least 6% by weight of one or more C_{16} compounds and at least 33% by weight of one or more C_{18} compounds.

25. A process according to claim 23 or 24, wherein the sulphur removal step comprises a catalytic hydro-desulphurisation step, for example, 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, such as 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.

26. A process according to claim 25, 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.

27. A process according to any one of claims 23 to 26, wherein the desulphurised hydrocarbon feedstock comprises at least 0.5% by weight of one or more C_8 compounds, at least 2% by weight of one or more C_{10} compounds, at least 4% by weight of one or more C_{12} compounds, at least 10% by weight of one or more C_{16} compounds and at least 25% by weight of one or more C_{18} compounds, such as wherein the desulphurised hydrocarbon feedstock comprises at least 1% by weight of one or more C_8 compounds, at least 3% by weight of one or more C_{10} compounds, at least 5% by weight of one or more C_{12} compounds, at least 12% by weight of one or more C_{16} compounds and/or at least 27% by weight of one or more C_{18} compounds.

28. A process according to any one of claims 23 to 27, wherein the catalytic hydro-desulphurisation process further comprises the step of degassing the reduced sulphur hydrocarbon feedstock to remove hydrogen disulphide gas, such as by cooling the reduced sulphur hydrocarbon feedstock 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 degassing step removes hydrogen formed during the catalytic hydro-desulphurisation process, and optionally wherein the hydrogen is recycled to the biomass derived hydrocarbon feedstock.

29. A process according to any one of claims 23 to 28, 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.

30. A process according to any one of claims 23 to 29, 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, such as wherein 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, and optionally 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.

31. A process according to any one of claims 23 to 30, wherein the hydro-treated hydrocarbon feedstock comprises at least 0.5% by weight of one or more C_8 compounds, at least 6% by weight of one or more C_{10} compounds, at least 4% by weight of one or more C_{12} compounds, at least 3% by weight of one or more C_{16} compounds and at least 30% by weight of one or more C_{18} compounds, such as wherein the hydro-treated hydrocarbon feedstock comprises at least 1% by weight of one or more C_8 compounds, at least 7% by weight of one or more C_{10} compounds, at least 5% by weight of one or more C_{12} compounds, at least 4% by weight of one or more C_{16} compounds and/or at least 35% by weight of one or more C_{18} compounds.

32. A process according to any one of claims 23 to 31, wherein the hydro-isomerisation step is performed at a temperature of from 260°C to 370°C, preferably from 290°C to 350°C, more preferably from 310°C to 330°C; and/or wherein the hydro-isomerisation step is performed at a reaction pressure of from 4MPaG to 6MPaG, preferably from 4.5MPaG to 5.5MPaG, more preferably about 5MPaG.

33. A process according to any one of claims 23 to 32, wherein the hydro-isomerisation step further comprises a catalyst, such as catalyst as part of a fixed bed or a trickle bed reactor, preferably wherein the catalyst comprises a metal selected from Group VIII of the periodic table, such as a catalyst selected from a platinum and/or palladium catalyst, and optionally 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.

34. A process according to any one of claims 23 to 33, wherein the hydro-isomerised hydrocarbon feedstock comprises at least 0.5% by weight of one or more C_8 compounds, at least 7.5% by weight of one or more C_{10} compounds, at least 4% by weight of one or more C_{12} compounds, at least 7% by weight of one or more C_{16} compounds and at least 12% by weight of one or more C_{18} compounds, such as wherein the hydro-isomerised hydrocarbon feedstock comprises at least 1% by weight of one or more C_8 compounds, at least 10% by weight of one or more C_{10} compounds, at least 5% by weight of one or more C_{12} compounds, at least 8% by weight of one or more C_{16} compounds and/or at least 15% by weight of one or more C_{18} compounds.

35. A process according to any one of claims 23 to 34, wherein hydro-isomerisation process further comprises the step of degassing the hydro-isomerised hydrocarbon feedstock to remove light gases, such as hydrogen, methane, ethane and propane gas present, and optionally wherein the light gases are recycled to the biomass derived hydrocarbon feedstock.

36. A process according to any one of claims 23 to 35, wherein the hydro-isomerisation process further comprises the step of hydro-stabilising the hydro-isomerised hydrocarbon feedstock.

37. A process according to claim 36, wherein the hydro-stabilisation reaction is performed at a temperature of from 250°C to 350°C, preferably from 260°C to 340°C, more preferably from 280°C to 320°C and/or wherein the hydro-stabilisation process is performed at a reaction pressure of from 4MPaG to 6MPaG, preferably from 4.5MPaG to 5.5MPaG, more preferably about 5MPaG.

38. A process according to claim 36 or 37, wherein the hydro-stabilisation reaction further comprises a catalyst, such as a catalyst as part of a fixed bed or a trickle bed reactor, preferably wherein the catalyst is selected from a Ni, Pt and/or Pd-based catalyst, such as 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.

39. A process according to any one of claims 23 to 38, wherein the fractionation step comprises separating a first fractionation cut having a cut point of between 110 °C and 170°C, preferably between 130°C and 160°C , more preferably 150°C of the refined bio-oil under atmospheric pressure.

40. A process according to claim 39, wherein the method comprises forming a second fractionation cut of the refined bio-oil, with a cut point between 280°C and 320°C, preferably from 290°C to 310°C, more preferably about 300°C, wherein the bottom stream is collected as a bio-derived diesel fuel.

41. A process according to claim 40, wherein the bottom stream comprises from 10 to 30% by weight of the refined bio-oil, preferably from 15 to 25% by weight of the refined bio-oil.

42. A process according to any one of claims 23 to 41 wherein the biomass derived hydrocarbon feedstock. is produced by the process according to any one of claims 1 to 18.

43. A desulphurised hydrocarbon feedstock, obtainable by the process of any one of claims 23 to 28, wherein the feedstock comprises at least 0.5% by weight of one or more C_8 compounds, at least 2% by weight of one or more C_{10} compounds, at least 4% by weight of one or more C_{12} compounds, at least 10% by weight of one or more C_{16} compounds and at least 25% by weight of one or more C_{18} compounds, such as wherein the feedstock comprises at least 1% by weight of one or more C_8 compounds, at least 3% by weight of one or more C_{10} compounds, at least 5% by weight of one or more C_{12} compounds, at least 12% by weight of one or more C_{16} compounds and/or at least 27% by weight of one or more C_{18} compounds.

44. A hydro-treated hydrocarbon feedstock, obtainable by the process of any one of claims 23 to 31, wherein the feedstock comprises at least 0.5% by weight of one or more C_8 compounds, at least 6% by weight of one or more C_{10} compounds, at least 4% by weight of one or more C_{12} compounds, at least 3% by weight of one or more C_{16} compounds and at least 30% by weight of one or more C_{18} compounds, such as wherein the feedstock comprises at least 1% by weight of one or more C_8 compounds, at least 7% by weight of one or more C_{10} compounds, at least 5% by weight of one or more C_{12} compounds, at least 4% by weight of one or more C_{16} compounds and/or at least 35% by weight of one or more C_{18} compounds.

45. A hydro-isomerised hydrocarbon feedstock, obtainable by the process according to any one of claims 23 to 36, wherein the feedstock comprises at least 0.5% by weight of one or more C_8 compounds, at least 7.5% by weight of one or more C_{10} compounds, at least 4% by weight of one or more C_{12} compounds, at least 7% by weight of one or more C_{16} compounds and at least 12% by weight of one or more C_{18} compounds, such as wherein the feedstock comprises at least 1% by weight of one or more C_8 compounds, at least 10% by weight of one or more C_{10} compounds, at least 5% by weight of one or more C_{12} compounds, at least 8% by weight of one or more C_{16} compounds and/or at least 15% by weight of one or more C_{18} compounds.

46. A refined bio-oil, obtainable by a process according to any one of claims 23 to 38, wherein the refined bio-oil formed comprises at least 7.5% by weight of one or more C_{10} compounds, at least 4% by weight of one or more C_{12} compounds, at least 7% by weight of one or more C_{16} compounds and at least 12% by weight of one or more C_{18} compounds, such as wherein the

refined bio-oil comprises at least 10% by weight of one or more C_{10} compounds, at least 5% by weight of one or more C_{12} compounds, at least 8% by weight of one or more C_{16} compounds and/or at least 15% by weight of one or more C_{18} compounds.

47. A refined bio-oil according to claim 46, wherein the refined bio-oil has a pour point of -45°C or less, preferably -50°C or less, more preferably -54°C or less.

48. A bio-derived diesel fuel formed by a process according to anyone of claims 23 to 42, preferably wherein the bio-derived diesel fuel is formed entirely from a biomass feedstock.

49. A bio-derived diesel fuel according to claim 48, wherein the bio-derived diesel fuel exceeds the Euro 5 and Euro 6 standards for diesel fuel.

50. A bio-derived diesel fuel according to any one of claims 48 to 49, wherein the bio-derived diesel fuel has one or more, and preferably at least, the following properties:

    a. a cetane number of at least 60, preferably at least 65, more preferably a cetane number of at least 70;
    b. 10 ppmw or less of sulphur, preferably 5 ppmw or less of sulphur, more preferably 1ppmw or less of sulphur; and
    c. a pour point of fuel is -40°C or less, preferably -42°C or less, more preferably -45°C or less.