Claims

1. A process for forming a bio-diesel 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. hydrocracking the hydrocarbon feedstock of step b. in the presence of a hydrocracking catalyst and a hydrogen containing gas to produce a bio-oil; and
    d. fractionating the resulting bio-oil to obtain a bio-derived diesel 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 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, for example, 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.

10. 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.

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, such as 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 by filtration (such as by use of a ceramic filter), centrifugation, or cyclone or gravity separation and/or

    wherein step d. 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 the 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 the non-condensable light gases are at least partially separated 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.

15. A process according to claim 13, 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 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, such as 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.

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, 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 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.

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

18. A process for forming a bio-diesel fuel from a bio-derived hydrocarbon feedstock using the bio-derived hydrocarbon feedstock produced according to any one of claims 1 to 17 comprising:
    i. hydrocracking the hydrocarbon feedstock in the presence of a hydrocracking catalyst and a hydrogen containing gas to produce a bio-oil; and
    ii. fractionating the resulting bio-oil to obtain a bio-derived diesel fuel fraction.

19. A process according to any preceding claim, wherein the hydrocracking step is performed at a temperature of from 200 °C to 700 °C, preferably from 250 °C to 550 °C, more preferably from 300 °C to 500 °C and/or under a pressure of from 1 MPa to 28 MPa, preferably from 5 MPa to 20 MPa, more preferably from 10 MPa to 17 MPa.

20. A process according to any preceding claim, wherein the hydrocarbon feedstock of step b. as defined in any one of claims 1 to 17 or the hydrocarbon feedstock of step i. as defined in claim 18 and hydrogen containing gas are contacted with the hydrocracking catalyst at a liquid hourly space velocity of from 0.1 to 30 hr^{-1}, preferably from 0.2 to 10 hr^{-1}, more preferably from 0.3 to 5 hr^{-1}.

21. A process according to any preceding claim, wherein the hydrocracking catalyst is contained in a catalytic reactor, such as a fixed bed reactor, a trickle bed reactor, a fluidised bed reactor or a tubular reactor, such as a coiled tube reactor, a U-tube reactor or a straight tube reactor; and/or

    wherein the hydrocracking catalyst is in the form of pellets, particulates or a powder, preferably the pellets, particulates or powder have a diameter of from 0.5 to 5 mm, preferably from 0.8 to 3.5 mm; and/or

    wherein the hydrocracking catalyst has a surface area of from 100 m^2/g to 800m^2/g, preferably a surface area of from 150 m^2/g to 700 m^2/g, more preferably from 200 m^2/g to 600 m^2/g.

22. A process according to any preceding claim, wherein the hydrocracking catalyst is a bi-functional catalyst comprising one or more metals selected Group VB, Group VIB, Group VIIB and/or Group VIII, of the periodic table, on an acidic support material, for example wherein the metal is present in an amount of from 0.1 to 20 wt% based on the total weight of the hydrocracking catalyst, preferably from 0.1 to 10 wt%, more preferably from 0.5 to 5 wt%, and preferably wherein the hydrocracking catalyst comprises a metal selected from the group consisting of iron, nickel, palladium, platinum, rhodium, iridium, cobalt, tungsten, molybdenum, vanadium, ruthenium, and mixtures thereof, contained on a support material, such as wherein the acidic support material is selected from a zeolite, a molecular sieve, silica-alumina, alumina, silica, silica nitride, silica borate, alumina oxide, boron nitride, zirconia, titania, ceria, carbon (such as activated carbon) boria, ferrierite and zirconia-alumina, preferably the acidic support material is selected from beta zeolite, Y zeolite, MFI zeolite, ALP0-31, SAP0-11, SAP0-31, SAP0-37, SAP0-41, SM-3, MgAPS0-31, FU-9, NU-10, NU-23, ZSM-12, ZSM-22, ZSM-23, ZSM-35, ZSM-48, ZSM-50, ZSM-57, MeAP0-11 , MeAP0-31, MeAP0-41, MeAPS0-11, MeAPS0-31, MeAPS0-41, MeAPS0-46, ELAP0-11, ELAP0-31, ELAP0-41, ELAPS0-11, ELAPS0-31, ELAPS0-41, laumontite, cancrinite, offretite, hydrogen form of stillbite, magnesium or calcium form of mordenite, and magnesium or calcium form of partheite, or combinations thereof.

23. A process according to any preceding claim, wherein the hydrocarbon feedstock of step b. as defined in any one of claims 1 to 17 or the hydrocarbon feedstock as defined in claim 18 and the hydrogen containing gas are contacted with the hydrocracking catalyst simultaneously; and/or

    wherein the hydrocarbon feedstock is preheated before contacting the hydrocracking catalyst, preferably the hydrocarbon feedstock is pre-heated to a temperature of from 150 °C to 650 °C, more preferably from 200 °C to 500 °C.

24. A process according to any preceding claim, further comprising the step of at least partially removing hydrogen gas and/or carbon dioxide contained in the bio-oil formed, preferably by use of flash distillation or fractional distillation, and preferably wherein the separated hydrogen gas is at least partially recycled to the hydrocracking process step.

25. 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 diesel fuel fraction formed, for example wherein 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.

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 25 to 26, wherein the catalytic hydro-desulphurisation process further comprises the step of degassing the reduced sulphur bio-oil and/or diesel fuel fraction to remove hydrogen disulphide gas, such as by cooling the reduced sulphur bio-oil and/or diesel 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 degassing step removes hydrogen formed during the catalytic hydro-desulphurisation process, and optionally wherein hydrogen removed is recycled to the hydrocracking process step.

28. A process according to any preceding claim, wherein the process further comprises hydro-treating the bio-oil formed, for example 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 under a pressure of from 4MPaG to 6MPaG, preferably from 4.5MPaG to 5.5MPaG.

29. A process according to claim 28, 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 a metal selected from Group VIII of the periodic table, more 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.

30. 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, and 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.

31. A process according to any preceding claim, 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.

32. A process according to claim 31, wherein the process comprises collecting the bottom stream of the bio-oil as a bio-derived diesel fuel.

33. A bio-derived LPG fuel formed by a process according to any one of claims 1 to 30 and/or

    A bio-derived gasoline fuel formed by a process according to any one of claims 1 to 30 and/or

    A bio-derived jet fuel formed by a process according to any one of claims 1 to 31 and/or

    A bio-derived diesel fuel formed by a process according to any one of claims 1 to 32, preferably the bio-derived diesel fuel is formed entirely from a biomass feedstock.