Claims

1. A method of producing linear alkanes comprising 7 to 28 carbon atoms, from ethanol and/or linear alkanoic acids comprising 2 to 5 carbon atoms, the method comprising

(a) contacting ethanol and/or a linear alkanoic acid comprising 2 to 5 carbon atoms or any salts thereof with at least one microorganism capable of carrying out two-carbon chain elongation to produce as an intermediate a linear alkanoic acid comprising 4 to 7 carbon atoms and/or a salt thereof and/or an ester thereof;

(b) extracting the intermediate, its salt and/or ester thereof from (a) using at least one extractant, wherein the extractant comprises at least one alkyl-phosphine oxide and optionally at least one alkane comprising at least 12 carbon atoms; or at least one trialkylamine and at least one alkane comprising at least 12 carbon atoms; or a branched higher alcohol like 2-octyl-dodecanol;

(c) contacting the extracted intermediate and/or ester thereof from (b) and optionally a further linear alkanoic acid comprising 1 to 22 carbon atoms with at least one ketonization catalyst to a linear alkanone comprising 7 to 28 carbon atoms;

(d) contacting the linear alkanone comprising 7 to 28 carbon atoms from step (c) with at least one hydrogenation metal catalyst for catalytic hydrogenation of the linear alkanone comprising 7 to 28 carbon atoms to a corresponding secondary linear alkanol comprising 7 to 28 carbon atoms;

(e) dehydration of the secondary linear alkanol comprising 7 to 28 carbon atoms in the presence of an acidic heterogeneous catalyst to form a corresponding linear alkene comprising 7 to 28 carbon atoms; and

(f) contacting the linear alkene comprising 7 to 28 carbon atoms obtained in step (e) with at least one hydrogenation metal catalyst for catalytic hydrogenation to a corresponding secondary linear alkane comprising 7 to 28 carbon atoms;

or combining step (e) and (f) into one single step using a catalyst or catalyst mixture providing dehydrating and hydrogenating properties, thus hydrogenolysing the secondary linear alkanol comprising 7 to 28 carbon atoms obtained in step (d) directly to the corresponding linear alkane comprising 7 to 28 carbon atoms and

wherein the alkyl-phosphine oxide is selected from the group consisting of trioctylphosphine oxide, octylphosphine oxide and mixtures thereof and the alkane is selected from the group consisting of pentadecane, hexadecane, heptadecane, octadecane, tetradecane and mixtures thereof.

2. The method according to claim 1, wherein the ketonization catalyst of (c) is a metal oxide catalyst or mixtures thereof.

3. The method according to claim 2, wherein the metal oxide catalyst or mixtures thereof is selected from the group consisting of heteropoly acid ($H_3PW_{12}O_{40}$) catalyst, titanium oxide

(TiO2) catalyst, cerium oxide (CeO2) catalyst, zinc-chromium (Zn–Cr) mixed oxide catalyst, manganese oxide (MnO2) catalyst, lanthanum oxide (La2O3) catalyst, magnesium oxide (MgO) catalyst, iron oxide (FeO, FeO2, Fe2O3, Fe3O4, Fe4O5, Fe5O6, Fe5O7), silicon-aluminium (Si–Al) mixed oxide catalyst and zirconia (ZrO2) catalyst.

4. The method according to any one of the preceding claims, wherein the ketonization catalyst in step (c) is manganese oxide (MnO2) catalyst, or magnesium oxide (MgO) catalyst,.

5. The method according to any one of the preceding claims, wherein the suitable reaction conditions of step (c) comprises reaction temperatures of 150°C – 350 °C.

6. The method according to any one of the preceding claims, wherein the microorganism in (a) is selected from the group consisting of *Clostridium carboxidivorans* and *Clostridium kluyveri*.

7. The method according to any one of the preceding claims, wherein the alkyl-phosphine oxide is Trioctylphosphine oxide (TOPO) and the alkane is a mixture of pentadecane, hexadecane, heptadecane, octadecane, and tetradecane.

8. The method according to claim 7, wherein the weight ratio of TOPO to mixture of alkanes is between 1:100 to 1:10.

9. The method according to any one of the preceding claims, wherein the pH of the aqueous medium in (b) is maintained between 5.5 and 8.

10. The method according to any one of the preceding claims, wherein the hydrogenation metal catalyst of step (d) is selected from the group consisting of ruthenium (Ru) catalyst, rhenium (Re) catalyst, nickel (Ni) catalyst, iron (Fe), cobalt (Co) and platinum (Pt) catalyst.

11. The method according to any one of the preceding claims, wherein the acidic heterogeneous catalyst of step (e) is a catalyst comprising an aluminosilicate zeolite.

12. The method according of claim 11, wherein the acidic heterogeneous catalyst of step (e) comprises ZSM-5.

13. The method according to any one of the preceding claims, wherein the catalyst of step (e) further comprises a transition metal.

14. The method of claim 13, wherein the transition metal is molybdenum.

Claims

1. A method of producing linear alkanes comprising 7 to 28 carbon atoms, from ethanol and/or linear alkanoic acids comprising 2 to 5 carbon atoms, the method comprising

(a) contacting ethanol and/or a linear alkanoic acid comprising 2 to 5 carbon atoms or any salts thereof with at least one microorganism capable of carrying out two-carbon chain elongation to produce as an intermediate a linear alkanoic acid comprising 4 to 7 carbon atoms and/or a salt thereof and/or an ester thereof;

(b) extracting the intermediate, its salt and/or ester thereof from (a) using at least one extractant, wherein the extractant comprises at least one alkyl-phosphine oxide and optionally at least one alkane comprising at least 12 carbon atoms; or at least one trialkylamine and at least one alkane comprising at least 12 carbon atoms; or a branched higher alcohol like 2 octyl-dodecanol;

(c) contacting the extracted intermediate and/or ester thereof from (b) and optionally a further linear alkanoic acid comprising 1 to 22 carbon atoms with at least one ketonization catalyst to a linear alkanone comprising 7 to 28 carbon atoms;

(d) contacting the linear alkanone comprising 7 to 28 carbon atoms from step (c) with at least one hydrogenation metal catalyst for catalytic hydrogenation of the linear alkanone comprising 7 to 28 carbon atoms to a corresponding secondary linear alkanol comprising 7 to 28 carbon atoms;

(e) dehydration of the secondary linear alkanol comprising 7 to 28 carbon atoms in the presence of an acidic heterogeneous catalyst to form a corresponding linear alkene comprising 7 to 28 carbon atoms; and

(f) contacting the linear alkene comprising 7 to 28 carbon atoms obtained in step (e) with at least one hydrogenation metal catalyst for catalytic hydrogenation to a corresponding secondary linear alkane comprising 7 to 28 carbon atoms;

or combining step (e) and (f) into one single step using a catalyst or catalyst mixture providing dehydrating and hydrogenating properties, thus hydrogenolysing the secondary linear alkanol comprising 7 to 28 carbon atoms obtained in step (d) directly to the corresponding linear alkane comprising 7 to 28 carbon atoms.

2. The method according to claim 1, wherein the ketonization catalyst of (c) is a metal oxide catalyst or mixtures thereof.

3. The method according to claim 2, wherein the metal oxide catalyst or mixtures thereof is selected from the group consisting of heteropoly acid ($H_3PW_{12}O_{40}$) catalyst, titanium oxide (TiO_2) catalyst, cerium oxide (CeO_2) catalyst, zinc-chromium (Zn−Cr) mixed oxide catalyst, manganese oxide (MnO_2) catalyst, lanthanum oxide (La_2O_3) catalyst, magnesium oxide (MgO) catalyst, iron oxide (FeO, FeO_2, Fe_2O_3, Fe_3O_4, Fe_4O_5, Fe_5O_6, Fe_5O_7), silicon-aluminium (Si−Al) mixed oxide catalyst and zirconia (ZrO_2) catalyst.

4. The method according to any one of the preceding claims, wherein the ketonization catalyst in step (c) is manganese oxide (MnO_2) catalyst, or magnesium oxide (MgO) catalyst.

5. The method according to any one of the preceding claims, wherein the suitable reaction conditions of step (c) comprises reaction temperatures of 150°C – 350 °C.

6. The method according to any one of the preceding claims, wherein the microorganism in (a) is selected from the group consisting of *Clostridium carboxidivorans* and *Clostridium kluyveri*.

7. The method according to any one of the preceding claims, wherein the alkyl-phosphine oxide is selected from the group consisting of trioctylphosphine oxide, octylphosphine oxide and mixtures thereof and the alkane is selected from the group consisting of pentadecane, hexadecane, heptadecane, octadecane, tetradecane and mixtures thereof.

8. The method according to claim 7, wherein the weight ratio of TOPO to mixture of alkanes is between 1:100 to 1:10.

9. The method according to any one of the preceding claims, wherein the pH of the aqueous medium in (b) is maintained between 5.5 and 8.

10. The method according to any one of the preceding claims, wherein the hydrogenation metal catalyst of step (d) is selected from the group consisting of ruthenium (Ru) catalyst, rhenium (Re) catalyst, nickel (Ni) catalyst, iron (Fe), cobalt (Co) and platinum (Pt) catalyst.

11. The method according to any one of the preceding claims, wherein the acidic heterogeneous catalyst of step (e) is a catalyst comprising an aluminosilicate zeolite.

12. The method according of claim 11, wherein the acidic heterogeneous catalyst of step (e) comprises ZSM-5.

13. The method according to any one of the preceding claims, wherein the catalyst of step (e) further comprises a transition metal.

14. The method of claim 13, wherein the transition metal is molybdenum.