CLAIMS

1. A process for cracking a hydrocarbon-containing feedstock, comprising:
providing a hydrocarbon-containing feedstock to a mixing zone, where the hydrocarbon-containing feedstock is selected to contain at least 20 wt.% hydrocarbons having a boiling point of greater than 538°C as determined in accordance with ASTM Method D5307
providing at least one metal-containing catalyst to the mixing zone, wherein any metal-containing catalyst provided to the mixing zone has an acidity as measured by ammonia chemisorption of at most 200 μmol ammonia per gram of catalyst;
providing hydrogen to the mixing zone and mixing the hydrogen, the hydrocarbon-containing feedstock, and the catalyst(s) in the mixing zone at a temperature of from 375°C to 500°C and at a total pressure of from 6.9 MPa to 27.5 MPa to produce:
a) a vapor comprised of hydrocarbons that are vaporizable at the temperature and the total pressure within the mixing zone; and
b) a hydrocarbon-depleted feed residuum comprising hydrocarbons that are liquid at the temperature and total pressure within the mixing zone;
continuously or intermittently separating at least a portion of the vapor from the mixing zone while retaining at least a portion of the hydrocarbon-depleted feed residuum and at least a portion of the catalyst(s) in the mixing zone.

2. The process of claim 1 further comprising the step of, apart from the mixing zone, condensing at least a portion of the vapor separated from the mixing zone to produce a liquid hydrocarbon-containing product separate from the mixing zone.

3. The process of claim 1 wherein the vapor separated from the mixing zone is hydroprocessed by contacting the vapor with a hydroprocessing catalyst and hydrogen at a temperature of from 260°C to 425°C and a total pressure of from 3.4 MPa to 27.5 MPa.

4. The process of claim 1 wherein the hydrocarbon-containing feedstock is continuously or intermittently provided to the mixing zone.

5. The process of claim 1 or any of claims 2-4 further comprising the steps of: providing hydrogen sulfide to the mixing zone and mixing the hydrogen sulfide with the hydrocarbon-containing feedstock, the catalyst, and hydrogen in the mixing zone, wherein hydrogen sulfide is provided to the mixing zone at a mole ratio of hydrogen sulfide to hydrogen of at least 0.5:9.5 up to 1:1, where hydrogen and hydrogen sulfide are provided for mixing such that the combined hydrogen and hydrogen sulfide partial pressures provide at least 60% of the total pressure.

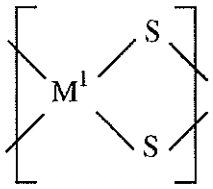
6. The process of claim 1 or any of claims 2-5 wherein the combined volume of the hydrocarbon-depleted feed residuum, the catalyst(s), and the hydrocarbon-containing feedstock in the mixing zone defines a mixture volume, and wherein the hydrocarbon-containing feedstock is provided to the mixing zone at a flow rate of at least 350, or at least 400, or at least 500, or at least 700, or at least 800, or at least 900, or at least 1000 kg/hr per m^3 of the mixture volume in the mixing zone.

7. The process of claim 1 or any of claims 2-6 wherein:
the mixing zone is located in a reactor;
the reactor has a reactor volume;
the combined volume of the hydrocarbon-depleted feed residuum, the catalyst(s), and the hydrocarbon-containing feedstock in the mixing zone defines a mixture volume;
the hydrocarbon-containing feedstock and the catalyst(s) initially provided to the mixing zone define an initial mixture volume, where the initial mixture volume is from 5% to 97% of the reactor volume; and
where the mixture volume of the catalyst(s), the hydrocarbon-depleted feed residuum, and the hydrocarbon-containing feed is maintained at a level of at least at least 10%, or at least 25%, or at least 40%, or at least 50%, or within 70%, or within 50%, or from 10% to 1940%, or from 15% to 1000%, or from 20% to 500%, or from 25% to 250% of the initial mixture volume.

8. The process of claim 7 wherein the vapor separated from the mixing zone is separated from the reactor.

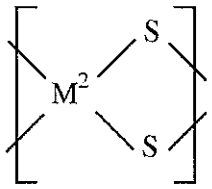
9. The process of claim 1 or any of claims 2-8 wherein any metal-containing catalyst provided to the mixing zone has an acidity as measured by ammonia chemisorption of at most 100, or at most 50, or at most 25, or at most 10, or at most 1 μmol ammonia per gram of catalyst.

10. The process of claim 1 or any of claims 2-9 wherein at least one catalyst provided to the mixing zone and blended with the hydrocarbon-containing feedstock and hydrogen comprises a material comprised of a first metal and a second metal where the first metal comprises a metal selected from the group consisting of Cu, Ni, Co, Fe, Ag, Mn, Zn, Sn, Ru, La, Ce, Pr, Sm, Eu, Yb, Lu, Dy, Pb, Sb, and Bi, where the second metal comprises a metal selected from the group consisting of Mo, W, V, Sn, and Sb, where the second metal is not the same as the first metal, and wherein the material is comprised of at least three linked chain elements, the chain elements comprising a first chain element including the first metal and having a structure according to formula (I) and a second chain element including the second metal and having a structure according to formula (II)



(I)

where M^1 is the first metal



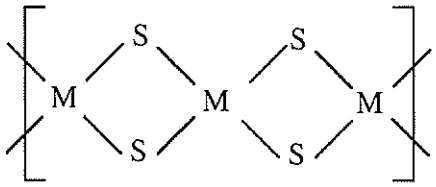
(II)

where M^2 is the second metal

where at least one chain element in the material is a first chain element and at least one chain element in the material is a second chain element, where chain elements in the material are linked by bonds between two sulfur atoms of a chain element and the metal of an adjacent chain element.

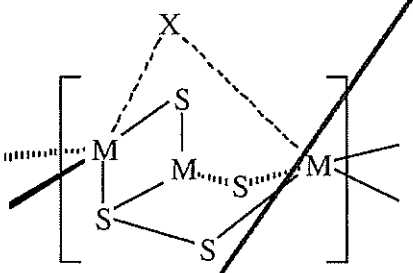
11. The process of claim 1 or any of claims 2-9 wherein the catalyst is comprised of a material comprised of a first metal and a second metal where the first metal comprises a metal selected from the group consisting of Cu, Ni, Co, Fe, Ag, Mn, Zn, Sn, Ru, La, Ce, Pr, Sm, Eu, Yb, Lu, Dy, Pb, Sb, and Bi where the second metal comprises a metal selected from the group consisting of Mo, W, V, Sn and Sb, where the second metal is not the same as the first metal, and wherein at least a

portion of the material of the catalyst has a structure according to a formula selected from the group consisting of formula (VII), formula (IX), formula (XII), and formula (XIV):



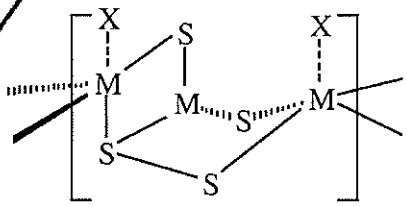
(VII)

where M is either the first metal or the second metal, and at least one M is the first metal and at least one M is the second metal;



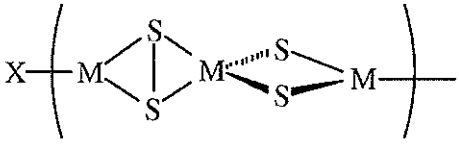
(IX)

where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3;



(XII)

where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3;



(XIV)

where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3.

12. The process of claim 1 or any of claims 2-11 wherein at least one catalyst is a solid particulate material having a particle size distribution having a median article size or a mean particle size of from 50 nm to 5 μm.

13. The process of claim 1 or any of claims 2-12 wherein the hydrocarbon-containing feedstock contains at least 30 wt.%, or least 40 wt.%, or at least 50 wt.% of hydrocarbons having a boiling point of 538°C or less as determined in ccordance with ASTM Method D5307.

14. The process of claim 1 or any of claims 2-13 wherein the temperature in the mixing zone is selected and controlled to be at least 430°C or at least 450°C.

15. The process of claim 1 or any of claims 2-14 further comprising the steps of separating a stream containing liquids and solids from the mixing zone; separating solids from the stream containing solids and liquids to produce a liquid stream and a solid material; and providing the liquid stream to the mixing zone.

We claim:

1. A process for cracking a hydrocarbon-containing feedstock, comprising: providing a hydrocarbon-containing feedstock to a mixing zone, where the hydrocarbon-containing feedstock is selected to contain at least 20 wt. % hydrocarbons having a boiling point of greater than 538° C. as determined in accordance with ASTM Method D5307 providing at least one metal-containing catalyst to the mixing zone, wherein any metal-containing catalyst provided to the mixing zone has an acidity as measured by ammonia chemisorption of at most 200 μmol ammonia per gram of catalyst; providing hydrogen to the mixing zone and mixing the hydrogen, the hydrocarbon-containing feedstock, and the catalyst(s) in the mixing zone at a temperature of from 375° C. to 500° C. and at a total pressure of from 6.9 MPa to 27.5 MPa to produce: a) a vapor comprised of hydrocarbons that are vaporizable at the temperature and the total pressure within the mixing zone; and b) a hydrocarbon-depleted feed residuum comprising hydrocarbons that are liquid at the temperature and total pressure within the mixing zone; continuously or intermittently separating at least a portion of the vapor from the mixing zone while retaining at least a portion of the hydrocarbon-depleted feed residuum and at least a portion of the catalyst(s) in the mixing zone, wherein the vapor separated from the mixing zone comprises at most 5 wt. % solids and liquids at the temperature at which the vapor is separated from the mixing zone; and apart from the mixing zone, condensing a liquid hydrocarbon-containing product that contains at least 90% of the atomic carbon initially contained in the hydrocarbon-containing feedstock and that contains less than 5 wt. % hydrocarbons having a boiling point of at least 538° C. as determined in accordance with ASTM Method D5307 from at least a portion of the vapor separated from the mixing zone.

2. The process of claim 1 wherein the hydrocarbon-containing product condensed from the vapor separated from the mixing zone contains at least 40% of the atomic sulfur present in the hydrocarbon-containing feedstock.

3. The process of claim 1 wherein the hydrocarbon-containing product condensed from the vapor separated from the mixing zone contains at least 40% of the atomic nitrogen present in the hydrocarbon-containing feedstock.

4. The process of claim 1 wherein the hydrocarbon-containing product contains at most 0.001 wt. % vanadium and at most 0.001 wt. % nickel.

5. The process of claim 1 wherein the hydrocarbon-containing feedstock is continuously or intermittently provided to the mixing zone.

6. The process of claim 1 further comprising the steps of: providing hydrogen sulfide to the mixing zone and mixing the hydrogen sulfide with the hydrocarbon-containing feedstock, the catalyst, and hydrogen in the mixing zone, wherein hydrogen sulfide is provided to the mixing zone at a mole ratio of hydrogen sulfide to hydrogen of at least 0.5:9.5 up to 1:1, where hydrogen and hydrogen sulfide are provided for mixing such that the combined hydrogen and hydrogen sulfide partial pressures provide at least 60% of the total pressure.

7. The process of claim 1 wherein the combined volume of the hydrocarbon-depleted feed residuum, the catalyst(s), and the hydrocarbon-containing feedstock in the mixing zone defines a mixture volume, and wherein the hydrocarbon-containing feedstock is provided to the mixing zone at a flow rate of at least 350 kg/hr per m^3 of the mixture volume in the mixing zone.

8. The process of claim 1 wherein: the mixing zone is located in a reactor; the reactor has a reactor volume; the

combined volume of the hydrocarbon-depleted feed residuum, the catalyst(s), and the hydrocarbon-containing feedstock in the mixing zone defines a mixture volume; the hydrocarbon-containing feedstock and the catalyst(s) initially provided to the mixing zone define an initial mixture volume, where the initial mixture volume is from 5% to 97% of the reactor volume; and where the mixture volume of the catalyst(s), the hydrocarbon-depleted feed residuum, and the hydrocarbon-containing feed is maintained at a level of from 10% to 1940% of the initial mixture volume.

9. The process of claim 8 wherein the vapor separated from the mixing zone is separated from the reactor.

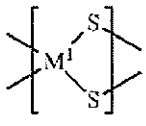
10. The process of claim 1 wherein the hydrocarbon-depleted feed residuum is blended with hydrogen, the catalyst(s), and, optionally, fresh hydrocarbon-containing feedstock in the mixing zone while separating at least a portion of the vapor from the mixing zone.

11. The process of claim 1 wherein any metal-containing catalyst provided to the mixing zone has an acidity as measured by ammonia chemisorption of at most 100 μmol ammonia per gram of catalyst.

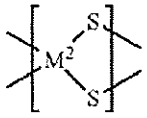
12. The process of claim 1 wherein at least one catalyst provided to the mixing zone and blended with the hydrocarbon-containing feedstock and hydrogen comprises a metal of Column 6 of the Periodic Table or a compound of a Column 6 metal.

13. The process of claim 1 wherein at least one catalyst provided to the mixing zone and blended with the hydrocarbon-containing feedstock and hydrogen comprises a metal of Column 6, 14, or 15 of the Periodic Table or a compound of a metal of Column 6, 14, or 15 of the Periodic Table and a metal of Column(s) 3 or 7-15 of the Periodic Table or a compound of a metal of Column(s) 3 or 7-15 of the Periodic Table.

14. The process of claim 1 wherein at least one catalyst provided to the mixing zone and blended with the hydrocarbon-containing feedstock and hydrogen comprises a material comprised of a first metal and a second metal where the first metal comprises a metal selected from the group consisting of Cu, Ni, Co, Fe, Ag, Mn, Zn, Sn, Ru, La, Ce, Pr, Sm, Eu, Yb, Lu, Dy, Pb, Sb, and Bi, where the second metal comprises a metal selected from the group consisting of Mo, W, V, Sn, and Sb, where the second metal is not the same as the first metal, and wherein the material is comprised of at least three linked chain elements, the chain elements comprising a first chain element including the first metal and having a structure according to formula (I) and a second chain element including the second metal and having a structure according to formula (II)



(I)

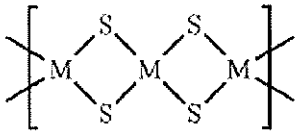


(II)

where M^1 is the first metal where M^2 is the second metal where at least one chain element in the material is a first chain element and at least one chain element in the material is a second chain element, where chain elements in the material are linked by bonds between two sulfur atoms of a chain element and the metal of an adjacent chain element.

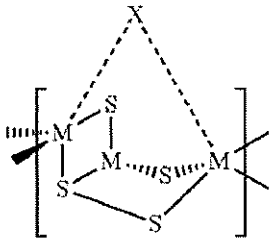
15. The process of claim 1 wherein the catalyst is comprised of a material comprised of a first metal and a second metal where the first metal comprises a metal selected from the group consisting of Cu, Ni, Co, Fe, Ag, Mn, Zn, Sn, Ru, La, Ce, Pr, Sm, Eu, Yb, Lu, Dy, Pb, Sb, and Bi where the second metal comprises a metal selected from the group consisting of Mo, W, V, Sn and Sb, where the second metal is not the same as the first metal, and wherein at least a portion of the material of the catalyst has a structure according to a formula selected from the group consisting of formula (VII), formula (IX), formula (XII), and formula (XIV):

(VII)



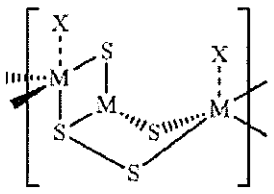
where M is either the first metal or the second metal, and at least one M is the first metal and at least one M is the second metal;

(IX)



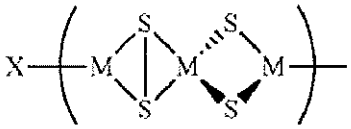
where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3;

(XII)



where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3;

(XIV)



where M is either the first metal or the second metal, at least one M is the first metal and at least one M is the second metal, and X is selected from the group consisting of SO_4, PO_4, oxalate (C_2O_4), acetylacetonate, acetate, citrate, tartrate, Cl, Br, I, ClO_4, and NO_3.

16. The process of claim 1 wherein at least one catalyst is a solid particulate material having a particle size distribution having a median particle size or a mean particle size of from 50 nm to 5 μm.

17. The process of claim 1 wherein the hydrocarbon-containing feedstock contains at least 30 wt. % of hydrocarbons having a boiling point of greater than 538° C. as determined in accordance with ASTM Method D5307.

18. The process of claim 1 wherein the hydrocarbon-containing feedstock contains at least 30 wt. % of hydrocarbons having a boiling point of 538° C. or less as determined in accordance with ASTM Method D5307.

19. The process of claim 1 wherein the temperature in the mixing zone is selected and controlled to be at least 430° C.

20. The process of claim 1 wherein the hydrocarbon-depleted feed residuum contains less than 0.02 grams of substances insoluble in toluene as determined in accordance with ASTM Method 4072, excluding the catalyst(s), per gram of hydrocarbon-containing feedstock and provided to the mixing zone.

21. The process of claim 1 further comprising the steps of separating a stream containing liquids and solids from the mixing zone; separating solids from the stream containing solids and liquids to produce a liquid stream and a solid material; and providing the liquid stream to the mixing zone.