

**CATALYST SYSTEMS AND PROCESSES
FOR MAKING AND USING SAME**

CROSS-REFERENCE TO RELATED APPLICATION

- 5 [0001] This application claims priority to and the benefit of U.S. Provisional Application No. 63/485,956 having a filing date of February 20, 2023, the disclosure of which is incorporated herein by reference in its entirety.

FIELD

- 10 [0002] This disclosure relates to catalyst systems and processes for making and using same. More particularly, this disclosure relates to catalyst systems that include a plurality of catalytic particles and a plurality of catalytically inert particles and processes for making and using same.

BACKGROUND

- 15 [0003] Catalytic reforming or dehydrogenation, dehydroaromatization, and/or dehydrocyclization of alkane and/or alkyl aromatic hydrocarbons are industrially important chemical conversion processes that are endothermic and equilibrium-limited. The reforming or dehydrogenation, dehydroaromatization, and/or dehydrocyclization of alkanes, *e.g.*, C₁-C₁₂ alkanes, and/or alkyl aromatics, *e.g.*, ethylbenzene, can be done through a variety of different catalyst compositions such as the Pt-based, Ni-based, Pd-based, Ru-based, Re-based, Cr-based, Ga-based, V-based, Zr-based, In-based, W-based, Mo-based, Zn-based, and Fe-based systems.

- 20 [0004] Preparation of the catalyst requires synthesis and processing steps, *e.g.*, forming a catalyst support, *e.g.*, via spray drying, calcination of the support, and application of the precious metal(s) at some point during the making of the catalyst. The amount of catalyst used in a commercial scale process is quite large and the cost of applying the precious metal(s) to the catalyst can be a significant aspect in the overall cost in making the catalyst. There is a need, therefore, for improved catalyst systems and processes for making and using same. This disclosure satisfies this and other needs.

SUMMARY

- 30 [0005] Catalyst systems and processes for making and using same are provided. In some embodiments, the catalyst system can include a plurality of catalytic particles and a plurality of catalytically inert particles configured to be mixed with one another or mixed with one another. The catalytic particles can include a Group 8-10 element and a first

promoter that can include Sn, Cu, Au, Ag, Ga, a combination thereof, or a mixture thereof disposed on a support. The catalytic particles can include 0.001 wt% to 6 wt% of the Group 8-10 element, up to 10 wt% of the first promoter, and the support can include Al and at least 0.5 wt% of a Group 2 element, based on the weight of the support. The catalytically inert particles can be free of a Group 8-10 element. A composition of the catalytically inert particles and a composition of the support can be the same or different.

[0006] In some embodiments, a process for upgrading a hydrocarbon can include contacting a hydrocarbon-containing feed with a catalyst system that can include a mixture of catalytic particles and catalytically inert particles to effect one or more of dehydrogenation, dehydroaromatization, and dehydrocyclization of at least a portion of the hydrocarbon-containing feed to produce a coked catalyst system and an effluent that can include one or more upgraded hydrocarbons and molecular hydrogen. The hydrocarbon-containing feed can include one or more of C₂-C₁₆ linear or branched alkanes, or one or more of C₄-C₁₆ cyclic alkanes, or one or more C₈-C₁₆ alkyl aromatics, or a mixture thereof. The one or more upgraded hydrocarbons can include at least one of a dehydrogenated hydrocarbon, a dehydroaromatized hydrocarbon, and a dehydrocyclized hydrocarbon. The catalytic particles can include a Group 8-10 element and a first promoter that can include Sn, Cu, Au, Ag, Ga, a combination thereof, or a mixture thereof disposed on a support. The catalytic particles can include 0.001 wt% to 6 wt% of the Group 8-10 element, up to 10 wt% of the first promoter, and the support can include Al and at least 0.5 wt% of a Group 2 element, based on the weight of the support. The catalytically inert particles can be free of a Group 8-10 element. A composition of the catalytically inert particles and a composition of the support can be the same or different.

DETAILED DESCRIPTION

[0007] Various specific embodiments, versions and examples of the invention will now be described, including preferred embodiments and definitions that are adopted herein for purposes of understanding the claimed invention. While the following detailed description gives specific preferred embodiments, those skilled in the art will appreciate that these embodiments are exemplary only, and that the invention may be practiced in other ways. For purposes of determining infringement, the scope of the invention will refer to any one or more of the appended claims, including their equivalents, and elements

or limitations that are equivalent to those that are recited. Any reference to the “invention” may refer to one or more, but not necessarily all, of the inventions defined by the claims.

[0008] In this disclosure, a process is described as comprising at least one “step.” It should be understood that each step is an action or operation that may be carried out once or multiple times in the process, in a continuous or discontinuous fashion. Unless specified to the contrary or the context clearly indicates otherwise, multiple steps in a process may be conducted sequentially in the order as they are listed, with or without overlapping with one or more other steps, or in any other order, as the case may be. In addition, one or more or even all steps may be conducted simultaneously with regard to the same or different batch of material. For example, in a continuous process, while a first step in a process is being conducted with respect to a raw material just fed into the beginning of the process, a second step may be carried out simultaneously with respect to an intermediate material resulting from treating the raw materials fed into the process at an earlier time in the first step. Preferably, the steps are conducted in the order described.

[0009] Unless otherwise indicated, all numbers indicating quantities in this disclosure are to be understood as being modified by the term “about” in all instances. It should also be understood that the precise numerical values used in the specification and claims constitute specific embodiments. Efforts have been made to ensure the accuracy of the data in the examples. However, it should be understood that any measured data inherently contains a certain level of error due to the limitation of the technique and/or equipment used for acquiring the measurement.

[0010] Certain embodiments and features are described herein using a set of numerical upper limits and a set of numerical lower limits. It should be appreciated that ranges including the combination of any two values, e.g., the combination of any lower value with any upper value, the combination of any two lower values, and/or the combination of any two upper values are contemplated unless otherwise indicated.

[0011] The indefinite article “a” or “an”, as used herein, means “at least one” unless specified to the contrary or the context clearly indicates otherwise. Thus, embodiments using “a reactor” or “a conversion zone” include embodiments where one, two or more reactors or conversion zones are used, unless specified to the contrary or the context clearly indicates that only one reactor or conversion zone is used.

[0012] The term “hydrocarbon” means (i) any compound consisting of hydrogen and carbon atoms or (ii) any mixture of two or more such compounds in (i). The term “C_n hydrocarbon,” where n is a positive integer, means (i) any hydrocarbon compound

comprising carbon atom(s) in its molecule at the total number of n , or (ii) any mixture of two or more such hydrocarbon compounds in (i). Thus, a C2 hydrocarbon can be ethane, ethylene, acetylene, or mixtures of at least two of these compounds at any proportion. A “C m to C n hydrocarbon” or “C m -C n hydrocarbon,” where m and n are positive integers and $m < n$, means any of C m , C $m+1$, C $m+2$, ..., C $n-1$, C n hydrocarbons, or any mixtures of two or more thereof. Thus, a “C2 to C3 hydrocarbon” or “C2-C3 hydrocarbon” can be any of ethane, ethylene, acetylene, propane, propene, propyne, propadiene, cyclopropane, and any mixtures of two or more thereof at any proportion between and among the components. A “saturated C2-C3 hydrocarbon” can be ethane, propane, cyclopropane, or any mixture thereof of two or more thereof at any proportion. A “C n + hydrocarbon” means (i) any hydrocarbon compound comprising carbon atom(s) in its molecule at the total number of at least n , or (ii) any mixture of two or more such hydrocarbon compounds in (i). A “C n - hydrocarbon” means (i) any hydrocarbon compound comprising carbon atoms in its molecule at the total number of at most n , or (ii) any mixture of two or more such hydrocarbon compounds in (i). A “C m hydrocarbon stream” means a hydrocarbon stream consisting essentially of C m hydrocarbon(s). A “C m -C n hydrocarbon stream” means a hydrocarbon stream consisting essentially of C m -C n hydrocarbon(s).

[0013] For the purposes of this disclosure, the nomenclature of elements is pursuant to the version of the Periodic Table of Elements (under the new notation) as provided in Hawley's Condensed Chemical Dictionary, 16th Ed., John Wiley & Sons, Inc., (2016), Appendix V. For example, a Group 2 element includes Mg, a Group 8 element includes Fe, a Group 9 element includes Co, a Group 10 element includes Ni, and a Group 13 element includes Al. The term “metalloid”, as used herein, refers to the following elements: B, Si, Ge, As, Sb, Te, and At. In this disclosure, when a given element is indicated as present, it can be present in the elemental state or as any chemical compound thereof, unless it is specified otherwise or clearly indicated otherwise by the context.

[0014] The term “alkane” means a saturated hydrocarbon. The term “cyclic alkane” means a saturated hydrocarbon comprising a cyclic carbon ring in the molecular structure thereof. An alkane can be linear, branched, or cyclic.

[0015] The term “aromatic” is to be understood in accordance with its art-recognized scope, which includes alkyl substituted and unsubstituted mono- and polynuclear compounds.

[0016] The term “rich” when used in phrases such as “X-rich” or “rich in X” means, with respect to an outgoing stream obtained from a device, e.g., a conversion zone, that

the stream comprises material X at a concentration higher than in the feed material fed to the same device from which the stream is derived. The term “lean” when used in phrases such as “X-lean” or “lean in X” means, with respect to an outgoing stream obtained from a device, e.g., a conversion zone, that the stream comprises material X at a concentration
 5 lower than in the feed material fed to the same device from which the stream is derived.

[0017] The term “mixed metal oxide” refers to a composition that includes oxygen atoms and at least two different metal atoms that are mixed on an atomic scale. For example, a “mixed Mg/Al metal oxide” has O, Mg, and Al atoms mixed on an atomic scale and is substantially the same as or identical to a composition obtained by calcining
 10 an Mg/Al hydrotalcite that has the general chemical formula $[Mg_{(1-x)}Al_x(OH)_2](A_{\frac{x}{n}}^{\frac{n}{n}}) \cdot mH_2O$, where A is a counter anion of a negative charge n. A material consisting of nm sized MgO particles and nm sized Al_2O_3 particles mixed together is not a mixed metal oxide because the Mg and Al atoms are not mixed on an atomic scale but are instead mixed on a nm scale.

15 [0018] The terms “calcination” and “calcining” refer to heating a material, e.g., a synthesized catalyst or a support, to a temperature of 350°C or more under any atmosphere, e.g., an oxidizing atmosphere, an inert atmosphere, or a reducing atmosphere. The term “calcined” refers to a material, e.g., a synthesized catalyst or a support, that has been subjected to calcination/calcining.

20 [0019] The term “selectivity” refers to the production (on a carbon mole basis) of a specified compound in a catalytic reaction. As an example, the phrase “an alkane hydrocarbon conversion reaction has a 100% selectivity for an olefin hydrocarbon” means that 100% of the alkane hydrocarbon (carbon mole basis) that is converted in the reaction is converted to the olefin hydrocarbon. When used in connection with a specified reactant,
 25 the term “conversion” means the amount of the reactant consumed in the reaction. For example, when the specified reactant is propane, 100% conversion means 100% of the propane is consumed in the reaction. In another example, when the specified reactant is propane, if one mole of propane converts to one mole of methane and one mole of ethylene, the selectivity to methane is 33.3% and the selectivity to ethylene is 66.7%.

30 Yield (carbon mole basis) is conversion times selectivity.

[0020] As used herein, “sccm” means standard cubic centimeters per minute, which is a flow measurement used to indicate the cubic centimeters (cm^3) of a gas at standard temperature and pressure passing a given point within one minute. Standard temperature and pressure

(STP) refers to a temperature of 273.15 K (0°C, 32°F) and an absolute pressure of 10^5 Pa (100 kPa, 1 bar).

[0021] In this disclosure, “A, B, ... or a combination thereof” means “A, B, ... or any combination of any two or more of A, B, ...” “A, B, ..., or a mixture thereof” means “A, B, ..., or any mixture of any two or more of A, B, ...”

Catalyst System

[0022] In some embodiments, the catalyst system can include a plurality of catalytic particles and a plurality of catalytically inert particles configured to be mixed with one another or mixed with one another. The catalytic particles can include a Group 8-10 element disposed on a support. In some embodiments, the catalytic particles can include 0.001 wt%, 0.002 wt%, 0.003 wt%, 0.004 wt%, 0.005 wt%, 0.006 wt%, 0.007 wt%, 0.008 wt%, 0.009 wt%, 0.01 wt%, 0.015 wt%, 0.02 wt%, 0.025 wt%, 0.03 wt%, 0.05 wt%, 0.07 wt%, 0.09 wt%, 0.1 wt%, 0.2 wt%, 0.3 wt%, 0.4 wt%, 0.5 wt%, 0.6 wt%, 0.7 wt%, 0.8 wt%, 0.9 wt%, or 1 wt% to 1.3 wt%, 1.5 wt%, 1.7 wt%, 2 wt%, 2.3 wt%, 2.5 wt%, 2.7 wt%, 3 wt%, 3.3 wt%, 3.5 wt%, 3.7 wt%, 4 wt%, 4.3 wt%, 4.5 wt%, 4.7 wt%, 5 wt%, 5.3 wt%, 5.5 wt%, 5.7 wt%, or 6 wt% of the Group 8-10 element.

[0023] In some embodiments, the Group 8-10 element can be Fe, Ru, Os, Co, Rh, Ir, Ni, Pd, Pt, any combination thereof, or any mixture thereof. In some embodiments, the Group 8-10 element can be Pt. In some embodiments, the Group 8-10 element can be present in its elemental form, in the form of a compound that includes one or more of the Group 8-10 elements, or a combination or mixture thereof.

[0024] In some embodiments, the Group 8-10 element in the catalytic particles can include two or more Group 8-10 elements. In such embodiments, the catalytic particles can include 0.001 wt%, 0.002 wt%, 0.003 wt%, 0.004 wt%, 0.005 wt%, 0.006 wt%, 0.007 wt%, 0.008 wt%, 0.009 wt%, 0.01 wt%, 0.015 wt%, 0.02 wt%, 0.025 wt%, 0.03 wt%, 0.035 wt%, 0.04 wt%, 0.045 wt%, 0.05 wt%, 0.055 wt%, 0.06 wt%, 0.065 wt%, 0.07 wt%, 0.08 wt%, 0.085 wt%, 0.09 wt%, 0.095 wt%, 0.1 wt%, 0.2 wt%, 0.3 wt%, 0.4 wt%, 0.5 wt%, 0.6 wt%, 0.7 wt%, 0.8 wt%, 0.9 wt%, or 1 wt% to 2 wt%, 3 wt%, 4 wt%, 5 wt%, or 6 wt% of a combined amount of the two or more Group 8-10 elements.

[0025] The catalytic particles can also include a promoter or “first promoter” that can include Sn, Cu, Au, Ag, Ga, a combination thereof, or a mixture thereof disposed on the support. In some embodiments, the catalytic particles can include 0.01 wt%, 0.05 wt%, 0.1 wt%, 0.2 wt%, 0.25 wt%, 0.3 wt%, 0.4 wt%, 0.5 wt%, 0.6 wt%, 0.7 wt%, 0.8 wt%, 0.9 wt%, or 1 wt% to 2 wt%, 3 wt%, 4 wt%, 5 wt%, 6 wt%, 7 wt%, 8 wt%, 9 wt%, or 10

wt% of the promoter or first promoter disposed on the support, based on the weight of the support. In some embodiments, the promoter or first promoter can be associated with the Group 8-10 element. For example, the promoter and Pt disposed on the support can form Pt-promoter clusters that can be dispersed on the support. The promoter or first promoter can improve the selectivity/activity/longevity of the catalyst system for a given upgraded hydrocarbon. In some embodiments, the promoter or first promoter can improve the propylene selectivity of the catalyst composition when the hydrocarbon-containing feed includes propane.

[0026] In some embodiments, the catalytic particles can optionally include one or more alkali metal elements or first alkali metal element(s) in an amount of up to 5 wt% disposed on the support, based on the weight of the support. In some embodiments the catalytic particles can include 0.01 wt%, 0.1 wt%, 0.2 wt%, 0.3 wt%, 0.4 wt%, 0.5 wt%, 0.6 wt%, 0.7 wt%, 0.8 wt%, 0.9 wt%, or 1 wt% to 2 wt%, 3 wt%, 4 wt%, or 5 wt% of the alkali metal element disposed on the support, based on the weight of the support. The alkali metal element, if present, can be or can include, but is not limited to, Li, Na, K, Rb, Cs, or a combination thereof, or a mixture thereof. In at least some embodiments, the alkali metal element can be or can include K and/or Cs. In some embodiments, the alkali metal element, if present, can improve the selectivity of the catalyst composition for a given upgraded hydrocarbon.

[0027] In some embodiments, the support can be or can include, but is not limited to, one or more Group 2 elements and aluminum (Al). The Group 2 element can be or can include, Be, Mg, Ca, Sr, Ba, a combination thereof, or a mixture thereof. In some embodiments, the Group 2 element and/or the Al can be present in its elemental form. In other embodiments, the Group 2 element and/or the Al can be present in the form of a compound. For example, the Group 2 element and/or the Al can be present as an oxide, a phosphate, a halide, a borate, a sulfate, a sulfide, a borate, a nitride, a carbide, an aluminate, a carbonate, metaphosphate, a selenide, a tungstate, a molybdate, a chromite, a chromate, or a dichromate. In some embodiments, a mixture of any two or more compounds that include the Group 2 element and/or the Al can be present in different forms.

[0028] In some embodiments, the support can include ≥ 0.5 wt%, ≥ 1 wt%, ≥ 2 wt%, ≥ 3 wt%, ≥ 4 wt%, ≥ 5 wt%, ≥ 10 wt%, or ≥ 20 wt%, ≥ 40 wt%, ≥ 80 wt%, or ≥ 90 wt% of the Group 2 element, based on the weight of the support. In some embodiments, the

support can include the Group 2 element in a range of from 0.5 wt%, 3 wt%, 5 wt%, or 10 wt% to 30 wt%, 50 wt%, 70 wt%, or 90 wt%, based on the weight of the support.

- [0029] In some embodiments, the support can be or can include, but is not limited to, one or more of the following compounds: $Mg_wAl_2O_{3+w}$, where w is a positive number; $Ca_xAl_2O_{3+x}$, where x is a positive number; $Sr_yAl_2O_{3+y}$, where y is a positive number; $Ba_zAl_2O_{3+z}$, where z is a positive number. BeO, MgO, CaO, BaO, SrO, BeCO₃, MgCO₃, CaCO₃, SrCO₃, BaCO₃, CaZrO₃, Ca₇ZrAl₆O₁₈, CaTiO₃, Ca₇Al₆O₁₈, Ca₇HfAl₆O₁₈, BaCeO₃, one or more magnesium chromates, one or more magnesium tungstates, one or more magnesium molybdates, combinations thereof, and/or mixtures thereof.
- [0030] The $Mg_wAl_2O_{3+w}$, where w is a positive number, if present as the support or as a component of the support can have a molar ratio of Mg to Al in a range from 0.5, 1, 2, 3, 4, or 5 to 6, 7, 8, 9, or 10. In some embodiments, the $Mg_wAl_2O_{3+w}$ can include MgAl₂O₄, Mg₂Al₂O₅, or a mixture thereof. The $Ca_xAl_2O_{3+x}$, where x is a positive number, if present as the support or as a component of the support can have a molar ratio of Ca to Al in a range from 1:12, 1:4, 1:2, 2:3, 5:6, 1:1, 12:14, or 1.5:1. In some embodiments, the $Ca_xAl_2O_{3+x}$ can include tricalcium aluminate, dodecacalcium hepta-aluminate, monocalcium aluminate, monocalcium dialuminate, monocalcium hexa-aluminate, dicalcium aluminate, pentacalcium trialuminate, tetracalcium trialuminate, or any mixture thereof. The $Sr_yAl_2O_{3+y}$, where y is a positive number, if present as the support or as a component of the support can have a molar ratio of Sr to Al in a range from 0.05, 0.3, or 0.6 to 0.9, 1.5, or 3. The $Ba_zAl_2O_{3+z}$, where z is a positive number, if present as the support or as a component of the support can have a molar ratio of Ba to Al 0.05, 0.3, or 0.6 to 0.9, 1.5, or 3.

- [0031] In some embodiments, the Group 2 element can include Mg and at least a portion of the Group 2 element can be in the form of MgO or a mixed metal oxide that includes Mg. In some embodiments, the support can be or can include, but is not limited to, a mixed Mg/Al metal oxide. In some embodiments, the support can be or can include a mixed Mg/Al metal oxide produced or obtained by calcining hydrotalcite. In some embodiments, the support can be or can include a mixed Mg/Al metal oxide having the same or similar structure of the compound produced or obtained by calcining hydrotalcite but made via an alternative process.

[0032] In some embodiments, a weight ratio of the Group 2 element to the Al in the support can be in a range from 0.001, 0.005, 0.01, 0.05, 0.1, 0.15, 0.2, 0.3, 0.5, 0.7, or 1 to 3, 6, 12.5, 25, 50, 75, 100, 200, 300, 400, 500, 600, 700, 800, 900, or 1,000. In some

embodiments, when the support is a mixed Mg/Al metal oxide, the support can have a weight ratio of Mg to Al in a range of from 0.001, 0.005, 0.01, 0.05, 0.1, 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, or 5 to 6, 10, 12.5, 25, 50, 75, 100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, or 1,000. In some embodiments, the support can include ≥ 0.5 wt%, ≥ 1 wt%, ≥ 2 wt%, ≥ 2.1 wt%, ≥ 2.5 wt%, ≥ 3 wt%, ≥ 3.5 wt%, ≥ 4 wt%, ≥ 4.5 wt%, ≥ 5 wt%, ≥ 5.5 wt%, ≥ 6 wt%, ≥ 6.5 wt%, ≥ 7 wt%, ≥ 8 wt%, ≥ 9 wt%, ≥ 10 wt%, ≥ 11 wt%, ≥ 12 wt%, ≥ 13 wt%, ≥ 14 wt%, ≥ 15 wt%, ≥ 16 wt%, ≥ 17 wt%, ≥ 18 wt%, ≥ 19 wt%, ≥ 20 wt%, ≥ 21 wt%, ≥ 22 wt%, ≥ 23 wt%, ≥ 24 wt%, ≥ 25 wt%, ≥ 26 wt%, ≥ 27 wt%, ≥ 28 wt%, ≥ 29 wt%, ≥ 30 wt%, ≥ 35 wt%, ≥ 40 wt%, ≥ 45 wt%, ≥ 50 wt%, ≥ 55 wt%, ≥ 60 wt%, ≥ 65 wt%, ≥ 70 wt%, ≥ 75 wt%, ≥ 80 wt%, ≥ 85 wt%, or ≥ 90 wt% of the Group 2 element, based on the weight of the support. In some embodiments, the support can include the Group 2 element in a range from 0.5 wt%, 1 wt%, 1.5 wt%, 2 wt%, 2.1 wt%, 2.3 wt%, 2.5 wt%, 2.7 wt%, 3 wt%, 4 wt%, 5 wt%, 6 wt%, 7 wt%, 8 wt%, 9 wt%, 10 wt%, 11 wt%, 13 wt%, 15 wt%, 17 wt%, 19 wt%, 21 wt%, 23 wt%, or 25 wt% to 30 wt%, 35 wt%, 40 wt%, 45 wt%, 50 wt%, 55 wt%, 60 wt%, 65 wt%, 70 wt%, 75 wt%, 80 wt%, 85 wt%, 90 wt%, or 92.34 wt% based on the weight of the support. In some embodiments, the support can include Al in a range from 0.5 wt%, 1 wt%, 1.5 wt%, 2 wt%, 2.1 wt%, 2.3 wt%, 2.5 wt%, 2.7 wt%, 3 wt%, 4 wt%, 5 wt%, 6 wt%, 7 wt%, 8 wt%, 9 wt%, 10 wt%, or 11 wt% to 15 wt%, 20 wt%, 25 wt%, 30 wt%, 40 wt%, 45 wt%, or 50 wt%, based on the weight of the support.

[0033] In some embodiments, the support can be or can include a first quantity of the Group 2 element and the Al in the form of a mixed Group 2 element/Al metal oxide and a second quantity of the Group 2 element in the form of an oxide of the Group 2 element. In such embodiment, the mixed Group 2 element/Al metal oxide and the oxide of the Group 2 element can be mixed on the nm scale and the Group 2 element and Al in the mixed Group 2 element/Al metal oxide can be mixed on the atomic scale.

[0034] In other embodiments, the support can be or can include Group 2 element and a first quantity of the Al in the form of a mixed Group 2 element/Al metal oxide and a second quantity of Al in the form of Al_2O_3 . In such embodiment, the mixed Group 2 element/Al metal oxide and the Al_2O_3 can be mixed on the nm scale and the Group 2 element and Al in the mixed Group 2 element/Al metal oxide can be mixed on the atomic scale.

[0035] In still other embodiments, the support can be or can include a first quantity of the Group 2 element and a first quantity of the Al in the form of a mixed Group 2

element/Al metal oxide, a second quantity of the Group 2 element in the form of an oxide of the Group 2 element, and a second quantity of the Al in the form of Al_2O_3 . In such embodiment, the mixed Group 2 element/Al metal oxide, the oxide of the Group 2 element, and the Al_2O_3 can be mixed on a nm scale and the Group 2 element and Al in the mixed
 5 Group 2 element/Al metal oxide can be mixed on the atomic scale.

[0036] In some embodiments, a molar ratio of the Group 2 element to a total amount of any Group 8-10 element present in the catalytic particles can be in a range from 0.24, 0.5, 1, 10, 50, 100, 300, 450, 600, 800, 1,000, 1,200, 1,500, 1,700, or 2,000 to 3,000, 3,500, 4,000, 4,500, 5,000, 5,500, 6,000, 6,500, 7,000, 7,500, 8,000, 8,500, 9,000, 9,500, 10,000,
 10 15,000, 20,000, 25,000, 30,000, 35,000, 40,000, 45,000, 50,000, 55,000, 60,000, 65,000, 70,000, 75,000, 80,000, 85,000, 90,000, 95,000, 100,000, 200,000, 300,000, 400,000, 500,000, 600,000, 700,000, 800,000, or 900,000.

[0037] In some embodiments, the catalytic particles can be free of any Si. In other embodiments, the catalytic particles can include < 0.5 wt %, < 0.45 wt %, < 0.4 wt %, <
 15 0.35 wt %, < 0.3 wt %, < 0.25 wt %, < 0.2 wt %, < 0.15 wt %, < 0.1 wt %, < 0.09 wt %, < 0.08 wt %, < 0.07 wt %, < 0.06 wt %, < 0.05 wt %, < 0.04 wt %, < 0.03 wt %, 0.02 wt %, < 0.01 wt %, < 0.007 wt %, < 0.005 wt %, < 0.003 wt %, < 0.001 wt %, < 0.0007 wt %, < 0.0005 wt %, < 0.0003 wt %, or < 0.0001 wt % of Si, based on the weight of the support.

[0038] In some embodiments, the catalytic particles can have a median particle size in
 20 a range of from 1 μm , 5 μm , 10 μm , 20 μm , 40 μm , or 60 μm to 80 μm , 100 μm , 115 μm , 130 μm , 150 μm , 200 μm , 300 μm or 400, or 500 μm . In some embodiments, the catalytic particles can have an apparent loose bulk density in a range from 0.3 g/cm³, 0.4 g/cm³, 0.5 g/cm³, 0.6 g/cm³, 0.7 g/cm³, 0.8 g/cm³, 0.9 g/cm³, or 1 g/cm³ to 1.1 g/cm³, 1.2 g/cm³, 1.3 g/cm³, 1.4 g/cm³, 1.5 g/cm³, 1.6 g/cm³, 1.7 g/cm³, 1.8 g/cm³, 1.9 g/cm³, or 2 g/cm³, as
 25 measured according to ASTM D7481-18 modified with a 10, 25, or 50 mL graduated cylinder instead of a 100 or 250 mL graduated cylinder. In some embodiments, the catalytic particles can have an attrition loss after one hour of ≤ 5 wt %, ≤ 4 wt %, ≤ 3 wt %, ≤ 2 wt %, ≤ 1 wt %, ≤ 0.7 wt %, ≤ 0.5 wt %, ≤ 0.4 wt %, ≤ 0.3 wt %, ≤ 0.2 wt %, ≤ 0.1 wt %, ≤ 0.07 wt %, or ≤ 0.05 wt %, as measured according to ASTM D5757-11(2017). The
 30 morphology of the catalytic particles can be largely spherical so that they are suitable to run in a fluid bed reactor. In some embodiments, the catalytic particles can have a size and density that is consistent with a Geldart A or Geldart B definition of a fluidizable solid.

[0039] In some embodiments, the catalytic particles can have a surface area in a range from 0.1 m²/g, 1 m²/g, 10 m²/g, or 100 m²/g to 500 m²/g, 800 m²/g, 1,000 m²/g, or 1,500

m²/g. The surface area of the catalytic particles can be measured according to the Brunauer-Emmett-Teller (BET) method using adsorption-desorption of nitrogen (temperature of liquid nitrogen, 77 K) with a Micromeritics 3flex instrument after degassing of the powders for 4 hrs at 350°C. More information regarding the method can be found, for example, in “Characterization of Porous Solids and Powders: Surface Area, Pore Size and Density,” S. Lowell et al., Springer, 2004.

Catalytically Inert Particles

[0040] In some embodiments, the catalytically inert particles can be or can include, but are not limited to, aluminum oxide, magnesium oxide, a second mixed Mg/Al metal oxide, quartz, silicon carbide, or a mixture thereof. In some embodiments, a composition of the catalytically inert particles and a composition of the support in the catalytic particles can be the same or different with respect to one another. In some embodiments, the catalytically inert particles can be the same as the catalytic particles except the catalytically inert particles can be free of any Group 8-10 element.

[0041] In some embodiments, the catalytically inert particles can also include a promoter or “second promoter” that can include Sn, Cu, Au, Ag, Ga, a combination thereof, or a mixture thereof disposed on the catalytically inert particles. In some embodiments, the catalytically inert particles can include 0.01 wt%, 0.05 wt%, 0.1 wt%, 0.2 wt%, 0.25 wt%, 0.3 wt%, 0.4 wt%, 0.5 wt%, 0.6 wt%, 0.7 wt%, 0.8 wt%, 0.9 wt%, or 1 wt% to 2 wt%, 3 wt%, 4 wt%, 5 wt%, 6 wt%, 7 wt%, 8 wt%, 9 wt%, or 10 wt% of the second promoter disposed thereon, based on the weight of the catalytically inert particles.

[0042] In some embodiments, the catalytically inert particles can optionally include one or more alkali metal elements or “second” alkali metal element(s) in an amount of up to 5 wt% disposed on the catalytically inert particles, based on the weight of the catalytically inert particles. In some embodiments the catalytically inert particles can include 0.01 wt%, 0.1 wt%, 0.2 wt%, 0.3 wt%, 0.4 wt%, 0.5 wt%, 0.6 wt%, 0.7 wt%, 0.8 wt%, 0.9 wt%, or 1 wt% to 2 wt%, 3 wt%, 4 wt%, or 5 wt% of the alkali metal element disposed on the catalytically inert particles, based on the weight of the catalytically inert particles. The alkali metal element, if present, can be or can include, but is not limited to, Li, Na, K, Rb, Cs, or a combination thereof, or a mixture thereof. In at least some embodiments, the alkali metal element can be or can include K and/or Cs.

[0043] In some embodiments, the catalytically inert particles can be free of any Si. In other embodiments, the catalytically inert particles can include < 0.5 wt %, < 0.45 wt%, < 0.4 wt%, < 0.35 wt%, < 0.3 wt%, < 0.25 wt%, < 0.2 wt%, < 0.15 wt%, < 0.1 wt%, <

0.09 wt%, < 0.08 wt%, < 0.07 wt%, < 0.06 wt%, < 0.05 wt%, < 0.04 wt%, < 0.03 wt%,
0.02 wt%, < 0.01 wt%, < 0.007 wt%, < 0.005 wt%, < 0.003 wt%, < 0.001 wt%, < 0.0007
wt%, < 0.0005 wt%, < 0.0003 wt%, or < 0.0001 wt% of Si, based on the weight of the
catalytically inert particles.

5 [0044] In some embodiments, the catalytically inert particles can have a median particle
size in a range of from 1 μm , 5 μm , 10 μm , 20 μm , 40 μm , or 60 μm to 80 μm , 100 μm ,
115 μm , 130 μm , 150 μm , 200 μm , 300 μm or 400, or 500 μm . In some embodiments, the
catalytically inert particles can have an apparent loose bulk density in a range from 0.3
g/cm³, 0.4 g/cm³, 0.5 g/cm³, 0.6 g/cm³, 0.7 g/cm³, 0.8 g/cm³, 0.9 g/cm³, or 1 g/cm³ to 1.1
10 g/cm³, 1.2 g/cm³, 1.3 g/cm³, 1.4 g/cm³, 1.5 g/cm³, 1.6 g/cm³, 1.7 g/cm³, 1.8 g/cm³, 1.9
g/cm³, or 2 g/cm³, as measured according to ASTM D7481-18 modified with a 10, 25, or
50 mL graduated cylinder instead of a 100 or 250 mL graduated cylinder. In some
embodiments, the catalytic particles can have an attrition loss after one hour of ≤ 5 wt%,
 ≤ 4 wt%, ≤ 3 wt%, ≤ 2 wt%, ≤ 1 wt%, ≤ 0.7 wt%, ≤ 0.5 wt%, ≤ 0.4 wt%, ≤ 0.3 wt%, ≤ 0.2
15 wt%, ≤ 0.1 wt%, ≤ 0.07 wt%, or ≤ 0.05 wt%, as measured according to ASTM D5757-
11(2017). The morphology of the catalytically inert particles can be largely spherical so
that the catalytically inert particles can be suitable to run in a fluid bed reactor. In some
embodiments, the catalytically inert particles can have a size and density that is consistent
with a Geldart A or Geldart B definition of a fluidizable solid.

20 [0045] In some embodiments, the catalytically inert particles can have a surface area in
a range from 0.1 m²/g, 1 m²/g, 10 m²/g, or 100 m²/g to 500 m²/g, 800 m²/g, 1,000 m²/g,
or 1,500 m²/g. The surface area of the catalytically inert particles can be measured
according to the Brunauer-Emmett-Teller (BET) method using adsorption-desorption of
nitrogen (temperature of liquid nitrogen, 77 K) with a Micromeritics 3flex instrument after
25 degassing of the powders for 4 hrs at 350°C.

[0046] In some embodiments, the catalyst system can include the catalytic particles and
the catalytically inert particles at any suitable weight ratio. In some embodiments, the
weight ratio of the catalytic particles to the catalytically inert particles can be in a range
from 0.01:1, 0.03:1, 0.05:1, 0.07:1, 0.1:1, 0.3:1, 0.5:1, 0.7:1, or 1:1 to 1:0.7:1, 1:0.5:1,
30 1:0.3:1, 1:0.1, 1:0.07, 1:0.5, 1:0.3, or 1:0.1, 1:0.07, 1:0.05, 1:0.03, or 1:0.01.

First Process for Making the Catalytic Particles

[0047] The process for making the catalytic particles can include preparing a slurry or
gel that can include, milling, mixing, blending, combining, or otherwise contacting, but is
not limited to, a compound containing a Group 2 element and a liquid medium. In some

embodiments, preparation of the slurry or gel can also include contacting, but is not limited to, the compound containing a Group 2 element, the liquid medium, and one or more additives.

[0048] The compound containing a Group 2 element can be in the form of an oxide, a hydroxide, a hydrated carbonate, a salt, a clay containing a Group 2 element, a layered double hydroxide, a phosphate, a halide, a halate, a sulfate, a sulfide, a borate, a nitride, a carbide, an aluminate, an aluminosilicate, a silicate, a carbonate, metaphosphate, a selenide, a tungstate, a molybdate, a chromite, a chromate, a dichromate, a silicide, or a mixture thereof. In some embodiments, the Group 2 element can be or can include Mg and the compound containing the Group 2 element can be in the form of a magnesium oxide, a magnesium hydroxide, hydromagnesite (a hydrated magnesium carbonate mineral, $\text{Mg}_3(\text{CO}_3)_4(\text{OH})_2 \cdot 4\text{H}_2\text{O}$), a magnesium salt, a magnesium-containing clay, hydrotalcite (a layered double hydroxide), an organo-magnesium compound or a mixture thereof.

[0049] The liquid medium can be or can include, but is not limited to, water, alcohols, acetone, chloroform, methylene chloride, dimethyl formamide, dimethyl sulfoxide, glycerin, ethyl acetate, or any mixture thereof. Illustrative alcohols can be or can include, but are not limited to methanol, ethanol, isopropanol, or any mixture thereof. The one or more additives, if present, can be or can include, but is not limited to, acids such as formic acid, lactic acid, citric acid, acetic acid, HNO_3 , HCl , oxalic acid, stearic acid, carbonic acid, etc.; bases such as ammonia solution, NaOH , KOH , etc.; inorganic salts such as nitrates, carbonates, bicarbonates, chlorides, etc.; organic salts such as acetates, oxalates, formates, citrates, etc.; polymers such as a polyvinyl alcohol, a polysaccharide, etc., a binder and/or binder precursory, or any mixture thereof. The additives can help to improve the chemical/physical property of the spray dried material and/or to improve the rheological property of the slurry/gel to facilitate spray drying.

[0050] In some embodiments, the binder, if present, can be or can include one or more of the following: B_2O_3 , AlBO_3 , Al_2O_3 , ZrO_2 , TiO_2 , zinc aluminate, ZnO , VO , V_2O_3 , VO_2 , V_2O_5 , Ga_2O_3 , In_2O_3 , Mn_2O_3 , Mn_3O_4 , MnO , one or more molybdenum oxides, one or more tungsten oxides, one or more zeolites, where s, t, u, and v are positive numbers and mixtures and combinations thereof. If the Group 2 element is in the form of a mixed metal oxide, e.g., a mixed Mg/Al metal oxide, the additional metal(s) in the mixed metal oxide is/are not considered to be part of a binder. For example, the support may include a mixed Mg/Al metal oxide, such as those obtained by calcining an Mg/Al hydrotalcite and such

Al would not be considered as part of the binder, but the support could also include Al_2O_3 that is mixed on a nm scale with the mixed Mg/Al metal oxide and the Al_2O_3 would be considered as a binder. The binder precursor, if present, can be or can include, but is not limited to, $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ (Kaolin clay), aluminum chlorohydrate, boehmite, pseudoboehmite, gibbsite, bayerite, aluminum nitrate, aluminum chloride, sodium aluminate, alumina sol, silica sol, or any mixture thereof. It is known that in literature, some of the compounds herein referred to as “binders” may also be referred to as a filler, a matrix, etc.

[0051] The slurry or gel can be spray dried to produce spray dried particles that include the Group 2 element. Spray drying refers to the process of producing a dry particulate solid product from the slurry or the gel. The process can include spraying or atomizing the slurry or gel, e.g., forming small droplets, into a temperature-controlled gas stream to evaporate the liquid medium from the atomized droplets and produce the particulate solid product. For example, in the spray drying process, the slurry or gel can be atomized to small droplets and mixed with hot air or a hot inert gas, e.g., nitrogen, to evaporate the liquid from the droplets. The temperature of the slurry or gel during the spray drying process can usually be close to or greater than the boiling temperature of the liquid. An outlet air temperature of about 60°C to about 120°C can be common.

[0052] The slurry or gel can be atomized with one or more pressure nozzles (e.g., a fluid nozzle atomizer), one or more pulse atomizers, one or more high speed spinning discs (e.g., centrifugal or rotary atomizer), or any other known process. The median particle size, liquid (e.g., water) concentration, apparent loose bulk density, or any combination thereof, of the particulate solid product prepared via spray drying can be controlled, adjusted, or otherwise influenced by one or more operating conditions and/or parameters of the spray dryer. Illustrative operating conditions can include, but are not limited to, the feed rate and temperature of the gas stream, the atomizer velocity, the feed rate of the slurry or gel via the atomizer, the temperature of the slurry or gel, the size and/or solids concentration of the droplets, the spray dryer dimensions, or any combination thereof. It is well-known in the art that the various operating conditions will vary depending on the particular spray drying apparatus that is used and can be readily determined by persons having ordinary skill in the art.

[0053] The spray dried particles can, optionally, be calcined under an oxidative atmosphere, e.g., air, to produce calcined support particles that include the Group 2 element. In some embodiments, the spray dried particles can be calcined at a temperature

in a range of from 450°C, 500°C, 525°C, 550°C, 575°C, 600°C, 625°C, 650°C, or 675°C to 700°C, 725°C, 750°C, 775°C, 800°C, 850°C, 900°C, or 950°C. In some embodiments, the spray dried particles can be calcined at a temperature of $\leq 950^{\circ}\text{C}$, $\leq 900^{\circ}\text{C}$, $\leq 850^{\circ}\text{C}$, $\leq 800^{\circ}\text{C}$, $\leq 750^{\circ}\text{C}$, $\leq 700^{\circ}\text{C}$, $\leq 650^{\circ}\text{C}$, $\leq 600^{\circ}\text{C}$, or $\leq 550^{\circ}\text{C}$, $\leq 525^{\circ}\text{C}$, $\leq 500^{\circ}\text{C}$, $\leq 475^{\circ}\text{C}$, or $\leq 460^{\circ}\text{C}$. In some embodiments, the spray dried particles can be calcined for a time period of ≤ 240 minutes ≤ 180 minutes ≤ 120 minutes ≤ 90 minutes, ≤ 60 minutes, ≤ 45 minutes, ≤ 30 minutes, ≤ 25 minutes, ≤ 20 minutes, or ≤ 15 minutes. In some embodiments, the spray dried particles can be calcined at a temperature in a range of from 550°C to 900°C or 550°C to 850°C for a time period of ≤ 240 minutes ≤ 180 minutes ≤ 120 minutes ≤ 90 minutes, ≤ 60 minutes, ≤ 45 minutes, ≤ 30 minutes, ≤ 25 minutes, ≤ 20 minutes, or ≤ 15 minutes. In other embodiments, the spray dried particles can be calcined at a temperature of $\leq 550^{\circ}\text{C}$, $\leq 540^{\circ}\text{C}$, $\leq 530^{\circ}\text{C}$, $\leq 520^{\circ}\text{C}$, $\leq 510^{\circ}\text{C}$, or $\leq 500^{\circ}\text{C}$ for a time period of ≤ 240 minutes ≤ 180 minutes ≤ 120 minutes ≤ 90 minutes, ≤ 60 minutes, ≤ 45 minutes, ≤ 30 minutes, ≤ 25 minutes, ≤ 20 minutes, or ≤ 15 minutes.

15 [0054] The Group 8-10 element present in the catalytic particles can be introduced via one or more ways. For simplicity and ease of description, preparation of the catalytic particles will be further described as including Pt as the Group 8-10 element, but any Group 8-10 element, combination thereof, or mixture thereof can be used. In some embodiments, the process for making the catalytic particles can include (i) contacting at least the compound containing the Group 2 element and the liquid medium with a Pt-containing compound such that the Pt can be present in the slurry or the gel and the catalyst system can include catalytic particles that include the calcined support particles having Pt disposed thereon. In other embodiments, the process for making the catalytic particles can include (ii) depositing Pt on the spray dried particles by contacting the spray dried particles with a Pt-containing compound to produce Pt-containing spray dried particles and the catalyst system can include catalytic particles that include the calcined support particles having Pt disposed thereon. In other embodiments, the process for making the catalytic particles can include (iii) depositing Pt on the calcined support particles if the spray dried particles are optionally calcined by contacting the calcined support particles with a Pt-containing compound to produce Pt-containing calcined support particles and the process can, optionally, further include calcining the Pt-containing calcined support particles to produce re-calcined support particles having Pt disposed thereon, where the catalyst system can include the re-calcined support particles. In some embodiments, the catalytic particles can include the Pt-containing calcined support particles without the

optional additional calcination step. In other embodiments, the process for making the catalytic particles can include option (i), (ii), (iii), (i) and (ii), (i) and (iii), (ii) and (iii), or (i), (ii), and (iii).

[0055] In some embodiments, the Pt-containing compound can be or can include, but is not limited to, chloroplatinic acid hexahydrate, tetraammineplatinum(II) nitrate, platinum(II) acetylacetonate, platinum(II) bromide, platinum(II) iodide, platinum(II) chloride, platinum(IV) chloride, platinum(II)diammine dichloride, ammonium tetrachloroplatinate(II), tetraammineplatinum(II) chloride hydrate, tetraammineplatinum(II) hydroxide hydrate, platinum (II) oxalate, or any mixture thereof.

10 Other suitable compounds that include other Group 8-10 elements that can be used to make the catalytic particles can be or can include, but are not limited to, nickel (II) chloride, palladium(II) acetate, palladium(II) nitrate, iron (II) chloride, iron (III) chloride, ruthenium(III) chloride hydrate, rhodium(III) nitrate, cobalt(II) nitrate, cobalt(II) acetate, or any mixture thereof.

15 [0056] The promoter or first promoter present in the catalytic particles can be introduced via one or more ways. In some embodiments, the process for making the catalytic particles can include (iv) contacting at least the compound containing the Group 2 element and the liquid medium with a compound that includes a promoter element such that the promoter element is present in the slurry or the gel and the catalyst system can include

20 catalytic particles that include the calcined support particles having the promoter element disposed thereon. In other embodiments, the process for making the catalytic particles can include (v) depositing a compound that includes a promoter element on the spray dried particles to produce promoter-containing spray dried particles and the catalyst system can include catalyst particles that include the calcined support particles having the promoter

25 element disposed thereon. In other embodiments, the process for making the catalytic particles can include (vi) depositing a compound that includes a promoter element on the calcined support particles if the spray dried particles are optionally calcined to produce promoter-containing calcined support particles and the process can further include, optionally, calcining the promoter-containing calcined support particles to produce re-

30 calcined support particles having the promoter element disposed thereon, where the catalyst system includes the re-calcined support particles. In some embodiments, the catalytic particles can include the promoter-containing calcined support particles without the optional additional calcination step. In other embodiments, the process for making the catalytic particles can include option (iv), (v), (vi), (iv) and (v), (iv) and (vi), (v) and (vi),

or (iv), (v), and (vi). In other embodiments, the process can include any one or more of options (i), (ii), and (iii) and any one or more of options (iv), (v), and (iv). In some embodiments, the compound that includes the promoter element can be or can include, but is not limited to, tin(IV) chloride pentahydrate, tin(II) chloride dihydrate, tin(II) bromide, tin(IV) bromide, tin(II) acetylacetonate, tin(II) acetate, tin(IV) acetate, tin(II) oxalate, tin(IV) oxalate, silver(I) nitrate, gold(III) nitrate, copper(II) nitrate, gallium(III) nitrate, or any mixture thereof.

[0057] In some embodiments, platinum (II) oxalate and tin(II) oxalate and/or tin(IV) oxalate can be used as the Pt-containing compound and the Sn-containing compound, respectively. Tin(II) oxalate and/or tin(IV) oxalate can be dissolved in an aqueous solution containing ammonium oxalate or an aqueous solution containing ammonium oxalate and platinum oxalate. The aqueous solution containing tin(II) oxalate and/or tin(IV) oxalate and ammonium oxalate or ammonium oxalate and platinum oxalate can be added to the support, followed by equilibration, drying, and/or calcination. The Sn distribution across the support can be improved by using oxalates of Sn including tin(II) oxalate and tin(IV) oxalate as the Sn-containing compounds.

[0058] The alkali metal element, if present in the catalytic particles, can be introduced via one or more ways. In some embodiments, the process for making the catalytic particles can include (vii) contacting at least the compound containing the Group 2 element and the liquid medium with a compound that includes an alkali metal element such that the alkali metal element is present in the slurry or the gel and the catalyst system can include catalyst particles that include the calcined support particles having the alkali metal element disposed thereon. In other embodiments, the process for making the catalytic particles can include (viii) depositing a compound that includes an alkali metal element on the spray dried particles to produce alkali metal element-containing spray dried particles and the catalyst system can include catalytic particles that include the calcined support particles having the alkali metal element disposed thereon. In other embodiments, the process for making the catalytic particles can include (ix) depositing a compound that includes an alkali metal element on the calcined support particles if the spray dried particles are optionally calcined to produce alkali metal element-containing calcined support particles and the process can further include, optionally, calcining the alkali metal element-containing calcined support particles to produce re-calcined support particles having the alkali metal element disposed thereon, where the catalyst system includes the re-calcined support particles. In other embodiments, the process for making

the catalytic particles can include option (vii), (viii), (ix), (vii) and (viii), (vi) and (ix), (viii) and (ix), or (vii), (viii), and (iv). In other embodiments, the process for making the catalytic particles can include any one or more of options (i), (ii), and (iii), any one or more of options (iv), (v), and (iv), and any one or more of options (vii), (viii), and (ix).

- 5 The compound that includes the alkali metal element can be or can include, but are not limited to, lithium nitrate, sodium nitrate, potassium nitrate, rubidium nitrate, cesium nitrate, or any mixture thereof.

[0059] In some embodiments, the process for making the catalytic particles can optionally include hydrating the calcined support particles to produce hydrated support
10 particles. For example, the calcined support particles can be contacted with water to produce the hydrated support particles. In such embodiment, the process can also include calcining the hydrated support particles to produce the catalytic particles that include re-calcined support particles. Hydrating the calcined support can be carried out at a temperature in a range of from 20°C, 40°C, or 60°C to 80°C, 120°C, 140°C, 160°C, 180°C,
15 or 200°C. The calcined support particles can be contacted with the water for a time period in a range of from 1 minutes, 5 minutes, or 10 minutes to 20 minutes, 40 minutes, 80 minutes, 160 minutes, 6 hours, 12 hours, 24 hours, or 48 hours. In some embodiments, an anion such as chloride, nitrate, carbonate, bicarbonate, acetate, oxalate, formate, and/or citrate can be present during hydration.

20 [0060] In some embodiments, the process for making the catalytic particles can optionally include hydrating the spray dried particles to produce hydrated spray dried particles. For example, the spray dried particles can be contacted with water to produce the hydrated spray dried particles. In such embodiment, the process can also include calcining the hydrated spray dried particles to produce the catalyst composition that
25 includes calcined support particles. Hydrating the spray dried particles can be carried out at a temperature in a range of from 20°C, 40°C, or 60°C to 80°C, 120°C, 140°C, 160°C, 180°C, or 200°C. The spray dried particles can be contacted with the water for a time period in a range of from 1 minutes, 5 minutes, or 10 minutes to 20 minutes, 40 minutes, 80 minutes, 160 minutes, 6 hours, 12 hours, 24 hours, or 48 hours. In some embodiments,
30 an anion such as chloride, nitrate, carbonate, bicarbonate, acetate, oxalate, formate, and/or citrate can be present during hydration.

[0061] In some embodiments, the process for making the catalytic particles can optionally include hydrating the spray dried particles to produce hydrated spray dried particles, calcining the hydrated spray dried particles to produce calcined support particles,

hydrating the calcined support particles to produce hydrated calcined support particles, and calcining the hydrated calcined support particles to produce re-calcined support particles. As such, the catalyst system can include the spray dried particles, the calcined support particles, the hydrated spray dried particles, the hydrated spray dried particles that
5 can be calcined, the hydrated calcined support particles, the hydrated calcined support particles that can be re-calcined, or any mixture thereof.

[0062] In some embodiments, catalytic particles produced by hydrating the calcined support particles or the spray dried particles and then calcining the hydrated calcined support particles or the hydrated spray dried particles can produce catalytic particles that
10 have an attrition loss after one hour that is less than an attrition loss after one hour of the initially calcined particles or the spray dried particles produced before the hydration step, as measured according to ASTM D5757-11(2017). In some embodiments, catalytic particles produced by hydrating the calcined support particles or the spray dried particles and then calcining the hydrated support particles or the hydrated support particles can
15 produce catalyst particles that have an attrition loss after one hour that is 10% less, 30% less, 50% less, 70% less, 90% less, or 100% less, than an attrition loss after one hour of the initially calcined particles produced before the hydration step, as measured according to ASTM D5757-11(2017).

Second Process for Making the Catalytic Particles

20 [0063] In some embodiments, the catalytic particles can be catalytic particles produced through only the spray drying step such that the slurry is prepared and spray dried particles are produced therefrom with the Pt and promoter added to the slurry, the spray dried particles, or a combination thereof. Accordingly, in some embodiments the process for making the catalytic particles, can include preparing the slurry or gel that can include the
25 compound containing a Group 2 element and a liquid medium and optionally one or more additives as described above and spray drying the slurry or the gel to produce spray dried support particles that include the Group 2 element. At least one of (i) and (ii) can be met: (i) Pt can be present in the slurry or the gel in the form of the Pt-containing compound and the catalyst system can include catalyst particles that include the spray dried support
30 particles having Pt disposed thereon, and (ii) Pt can be deposited on the spray dried support particles by contacting the spray dried support particles with the Pt-containing compound to produce Pt-containing spray dried support particles and the catalyst system can include catalytic particles that can include the spray dried support particles having Pt disposed thereon. At least one of (iii) and (iv) can also be met: (iii) the compound that includes the

- promoter element can be present in the slurry or the gel and the catalyst system can include catalyst particles that include the spray dried support particles having the promoter element disposed thereon, and (iv) the compound that can include the promoter element can be deposited on the spray dried support particles to produce promoter-containing spray
- 5 dried support particles and the catalyst system can include catalyst particles that include the spray dried support particles having the promoter element disposed thereon, where the promoter element includes Sn, Cu, Au, Ag, Ga, or a combination thereof, or a mixture thereof. In some embodiments, the optional alkali metal element(s) and/or binders can also be added during the synthesis of the catalytic particles as described above.
- 10 [0064] In some embodiments, the catalytic particles can be further processed or activated in-situ by adding the catalytic particles into a hydrocarbon upgrading process that subjects the catalytic particles to higher severity conditions to produce catalytic particles having a greater level of activation than just the spray dried particles have upon preparation thereof. In some embodiments, when the catalytic particles include catalyst
- 15 particles only subjected to the spray drying step such that the slurry is prepared and spray dried support particles are produced therefrom with the Pt and promoter added to the slurry, the spray dried support particles, or a combination thereof, the catalytic particles can be introduced into a reaction zone, a combustion zone, a reduction zone, or any other location within a fluidized hydrocarbon upgrading process some of which are further described
- 20 below.
- [0065] The preparation of the catalytic particles and processes for adding the Group 8-10 element such as Pt, the promoter(s) such as Sn, the optional alkali metal element(s), and the optional rare earth metal element(s) to the catalyst composition has been described above. In some embodiments, the preparation of the slurry or gel, spray drying the slurry,
- 25 calcination of the spray dried particles and/or the hydrated calcined particles, and/or hydration of the Group 2 metal containing calcined support particles or the spray-dried particles can also be performed using one of the known methods reported in literature, such as U.S. Patent Nos. 4,866,019; 6,028,023; 6,589,902; 6,593,265; 6,800,578; 7,361,264; and 7,417,005; U.S. Patent Application Publication Nos. 2004/0029729;
- 30 2005/000396; and 2016/0082424; WO Publication No. WO2008083563A1; and journal publications Wang et al., *Ind. Eng. Chem. Res.* 2008, 47, 5746-5750; Chubar et al., *Chem. Eng. J.* 2013, 234, 284-299; Valente et al., *Energy Environ. Sci.*, 2011, 4, 4096-4107; and Julklang et al., *Mater. Lett.* 2017, 209, 429-432.

Processes for Making the Catalytically Inert Particles

[0066] In some embodiments, the catalytically inert particles can be or can include particles produced via any of the processes suitable for producing the catalytic particles except that the addition of a Group 8-10 element can be omitted from the process. In other
5 embodiments, the catalytically inert particles can be or can include one or more oxide compounds, e.g., MgO and/or Al₂O₃, as obtained from a commercial supplier. Optionally, if the catalytically inert particles includes an oxide or other compound obtained from a commercial supplier, such compound can be subjected to calcination and/or hydration if so desired.

10 A First Process for Upgrading a Hydrocarbon

[0067] The first process for upgrading a hydrocarbon can include contacting a first hydrocarbon-containing feed with the catalyst system that can include a mixture of the catalytic particles and the catalytically inert particles to effect one or more of dehydrogenation, dehydroaromatization, and dehydrocyclization of at least a portion of
15 the first hydrocarbon-containing feed to produce a coked catalyst system and an effluent that can include one or more upgraded hydrocarbons and molecular hydrogen. The catalyst system and the first hydrocarbon-containing feed can be contacted with one another within any suitable environment such as one or more reaction or conversion zones disposed within one or more reactors to produce the effluent and the coked catalyst system.
20 The reaction or conversion zone can be disposed or otherwise located within one or more fixed bed reactors, one or more fluidized or moving bed reactors, one or more reverse flow reactors, or any combination thereof.

[0068] The first hydrocarbon-containing feed and the catalyst system can be contacted at a temperature in a range from 300°C, 350°C, 400°C, 450°C, 500°C, 550°C, 600°C,
25 620°C, 650°C, 660°C, 670°C, 680°C, 690°C, or 700°C to 725°C, 750°C, 760°C, 780°C, 800°C, 825°C, 850°C, 875°C, or 900°C. In some embodiments, the first hydrocarbon-containing feed and the catalyst system can be contacted at a temperature of at least 620°C, at least 650°C, at least 660°C, at least 670°C, at least 680°C, at least 690°C, or at least 700°C to 725°C, 750°C, 760°C, 780°C, 800°C, 825°C, 850°C, 875°C, or 900°C. The first
30 hydrocarbon-containing feed can be introduced into the reaction or conversion zone and contacted with the catalyst system therein for a time period of ≤ 3 hours, ≤ 2.5 hours, ≤ 2 hours, ≤ 1.5 hours, ≤ 1 hour, ≤ 45 minutes, ≤ 30 minutes, ≤ 20 minutes, ≤ 10 minutes, ≤ 5 minutes, ≤ 1 minute, ≤ 30 seconds, ≤ 10 seconds, ≤ 5 seconds, or ≤ 1 second or ≤ 0.5 second. In some embodiments, the first hydrocarbon-containing feed can be contacted

with the catalyst system for a time period in a range from 0.1 seconds, 0.5 seconds, 0.7 seconds, 1 second, 30 second, 1 minute, 5 minutes, or 10 minutes to 30 minutes, 50 minutes, 70 minutes, 1.5 hours, 2 hours, or 3 hours.

[0069] The first hydrocarbon-containing feed and the catalyst system can be contacted under a hydrocarbon partial pressure of at least 20 kPa-absolute, where the hydrocarbon partial pressure is the total partial pressure of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics in the first hydrocarbon-containing feed. In some embodiments, the hydrocarbon partial pressure during contact of the first hydrocarbon-containing feed and the catalyst system can be in a range from 20 kPa-absolute, 50 kPa-absolute, 100 kPa-absolute, at least 150 kPa, at least 200 kPa 300 kPa-absolute, 500 kPa-absolute, 750 kPa-absolute, or 1,000 kPa-absolute to 1,500 kPa-absolute, 2,500 kPa-absolute, 4,000 kPa-absolute, 5,000 kPa-absolute, 7,000 kPa-absolute, 8,500 kPa-absolute, or 10,000 kPa-absolute, where the hydrocarbon partial pressure is the total partial pressure of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics in the first hydrocarbon-containing feed. In other embodiments, the hydrocarbon partial pressure during contact of the first hydrocarbon-containing feed and the catalyst system can be in a range from 20 kPa-absolute, 50 kPa-absolute, 100 kPa-absolute, 150 kPa-absolute, 200 kPa-absolute, 250 kPa-absolute, or 300 kPa-absolute to 500 kPa-absolute, 600 kPa-absolute, 700 kPa-absolute, 800 kPa-absolute, 900 kPa-absolute, or 1,000 kPa-absolute, where the hydrocarbon partial pressure is the total partial pressure of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics in the first hydrocarbon-containing feed.

[0070] In some embodiments, the first hydrocarbon-containing feed can include at least 60 vol%, at least 65 vol%, at least 70 vol%, at least 75 vol%, at least 80 vol%, at least 85 vol%, at least 90 vol%, at least 95 vol%, or at least 99 vol% of a single C₂-C₁₆ alkane, e.g., propane, based on a total volume of the first hydrocarbon-containing feed. The first hydrocarbon-containing feed and the catalyst system can be contacted under a single C₂-C₁₆ alkane, e.g., propane, pressure of at least 20 kPa-absolute, at least 50 kPa-absolute, at least 100 kPa-absolute, at least 150 kPa-absolute, at least 250 kPa-absolute, at least 300 kPa-absolute, at least 400 kPa-absolute, at least 500 kPa-absolute, or at least 1,000 kPa-absolute.

[0071] The first hydrocarbon-containing feed can be contacted with the catalyst system within the reaction or conversion zone at any weight hourly space velocity (WHSV) effective for carrying out the upgrading process. In some embodiments, the WHSV can be 0.01 hr⁻¹, 0.1 hr⁻¹, 1 hr⁻¹, 2 hr⁻¹, 5 hr⁻¹, 10 hr⁻¹, 20 hr⁻¹, 30 hr⁻¹, or 50 hr⁻¹ to 100 hr⁻¹,

250 hr⁻¹, 500 hr⁻¹, or 1,000 hr⁻¹. In some embodiments, when the hydrocarbon upgrading process includes a fluidized or otherwise moving catalyst system, a ratio of the catalyst system circulation mass flow rate to a combined amount of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics mass flow rate can be in a range from 1, 3, 5, 10, 15, 20, 25, 30, or 40 to 50, 60, 70, 80, 90, 100, 110, 125, or 150 on a weight to weight basis.

[0072] When the activity of the coked catalyst system decreases below a desired minimum amount, the coked catalyst system or at least a portion thereof can be subjected to a regeneration process to produce a regenerated catalyst system. More particularly, the coked catalyst system can be contacted with one or more oxidants to effect combustion of at least a portion of the coke to produce a regenerated catalyst system lean in coke and a combustion gas. Regeneration of the coked catalyst system can occur within the reaction or conversion zone or within a combustion zone that is separate and apart from the reaction or conversion zone, depending on the particular reactor configuration, to produce the regenerated catalyst system. For example, regeneration of the coked catalyst system can occur within the reaction or conversion zone when a fixed bed or reverse flow reactor is used, or within a separate combustion zone that can be separate and apart from the reaction or conversion zone when a fluidized bed reactor or other circulating or fluidized type reactor is used.

[0073] In some embodiments the process can optionally include contacting at least a portion of the regenerated catalyst system with a reducing gas to produce a regenerated and reduced catalyst system. An additional quantity of the first hydrocarbon-containing feed can be contacted with at least a portion of the regenerated catalyst system and/or at least a portion of any regenerated and reduced catalyst system to produce a re-coked catalyst system and additional effluent. Reduction of the regenerated catalyst system can occur within the reaction or conversion zone, within the regeneration zone, or within a reduction zone that is separate and apart from the reaction or conversion zone and the regeneration zone, depending on the particular reactor configuration, to produce the regenerated and reduced catalyst system. For example, reduction of the regenerated catalyst system can occur within the reaction or conversion zone when a fixed bed or reverse flow reactor is used, or within a separate reduction zone that can be separate and apart from the reaction or conversion zone and the regeneration zone when a fluidized bed reactor or other circulating or fluidized type reactor is used.

[0074] In some embodiments, a cycle time from contacting the first hydrocarbon-containing feed with the catalyst system to contacting the additional quantity of the first

hydrocarbon-containing feed with the regenerated catalyst system can be ≤ 5 hours. The first cycle begins upon contact of the catalyst system with the first hydrocarbon-containing feed, followed by contact with at least the oxidative gas to produce the regenerated catalyst system or at least the oxidative gas and the optional reducing gas to produce the regenerated catalyst system, and the first cycle ends upon contact of the regenerated catalyst system with the additional quantity of the first hydrocarbon-containing feed. If one or more additional feeds (described in more detail below) are utilized between flows of the first hydrocarbon-containing feed and the oxidative gas, between the oxidative gas and the reducing gas (if used), between the oxidative gas and the additional quantity of the first hydrocarbon-containing feed, and/or between the reducing gas (if used) and the additional quantity of the first hydrocarbon-containing feed, the period of time such stripping gas(es) is/are utilized would be included in the period included in the cycle time. As such, the cycle time from contacting the first hydrocarbon-containing feed with the catalyst system to the contacting the additional quantity of the first hydrocarbon-containing feed with the regenerated catalyst system, in some embodiments, can be ≤ 5 hours, ≤ 4 hours, ≤ 3 hours, ≤ 2 hours, ≤ 1 hour, ≤ 50 minutes, ≤ 45 minutes, ≤ 30 minutes, ≤ 15 minutes, ≤ 10 minutes, ≤ 5 minutes, ≤ 1 minute, ≤ 30 seconds, or ≤ 10 seconds.

[0075] The oxidant can be or can include, but is not limited to, O_2 , O_3 , CO_2 , H_2O , or a mixture thereof. In some embodiments, an amount of oxidant in excess of that needed to combust 100% of the coke on the catalyst system can be used to increase the rate of coke removal from the catalyst system, so that the time needed for coke removal can be reduced and lead to an increased yield in the upgraded product produced within a given period of time. The use of pure O_2 as an oxidant can facilitate the capturing and sequestration of CO_2 made during combustion in one or more downstream CO_2 recovery systems.

[0076] The coked catalyst system and oxidant can be contacted with one another at a temperature in a range from $500^\circ C$, $550^\circ C$, $600^\circ C$, $650^\circ C$, $700^\circ C$, $750^\circ C$, or $800^\circ C$ to $900^\circ C$, $950^\circ C$, $1,000^\circ C$, $1,050^\circ C$, or $1,100^\circ C$ to produce the regenerated catalyst system. In some embodiments, the coked catalyst system and oxidant can be contacted with one another at a temperature in a range from $500^\circ C$ to $1,100^\circ C$, $600^\circ C$ to $1,000^\circ C$, $650^\circ C$ to $950^\circ C$, $700^\circ C$ to $900^\circ C$, or $750^\circ C$ to $850^\circ C$ to produce the regenerated catalyst system.

[0077] The coked catalyst system and oxidant can be contacted with one another for a time period of ≤ 2 hours, ≤ 1 hour, ≤ 30 minutes, ≤ 10 minutes, ≤ 5 minutes, ≤ 1 min, ≤ 30 seconds, ≤ 10 seconds, ≤ 5 seconds, or ≤ 1 second. For example, the coked catalyst system and oxidant can be contacted with one another for a time period in a range from 2

seconds to 2 hours. In some embodiments, the coked catalyst system and oxidant can be contacted for a time period sufficient to remove ≥ 50 wt%, ≥ 75 wt%, or ≥ 90 wt% or > 99 % of any coke disposed on the catalyst system.

[0078] In some embodiments, the time period the coked catalyst system and oxidant contact one another can be less than the time period the catalyst system contacts the first hydrocarbon-containing feed to produce the effluent and the coked catalyst system. For example, the time period the coked catalyst system and oxidant contact one another can be at least 90%, at least 60%, at least 30%, or at least 10% less than the time period the catalyst system contacts the first hydrocarbon-containing feed to produce the effluent. In other embodiments, the time period the coked catalyst system and oxidant contact one another can be greater than the time period the catalyst system contacts the first hydrocarbon-containing feed to produce the effluent and the coked catalyst system. For example, in some embodiments, the coked catalyst system and oxidant can contact one another for a time period that can be at least 50%, at least 100%, at least 300%, at least 500%, at least 1,000%, at least 10,000%, at least 30,000%, at least 50,000%, at least 75,000%, at least 100,000%, at least 250,000%, at least 500,000%, at least 750,000%, at least 1,000,000%, at least 1,250,000%, at least 1,500,000%, or at least 1,800,000% greater than the time period the catalyst system contacts the first hydrocarbon-containing feed to produce the effluent.

[0079] The coked catalyst system and oxidant can be contacted with one another under an oxidant partial pressure in a range from 20 kPa-absolute, 50 kPa-absolute, 100 kPa-absolute, 300 kPa-absolute, 500 kPa-absolute, 750 kPa-absolute, or 1,000 kPa-absolute to 1,500 kPa-absolute, 2,500 kPa-absolute, 4,000 kPa-absolute, 5,000 kPa-absolute, 7,000 kPa-absolute, 8,500 kPa-absolute, or 10,000 kPa-absolute. In other embodiments, the oxidant partial pressure during contact with the coked catalyst system can be in a range from 20 kPa-absolute, 50 kPa-absolute, 100 kPa-absolute, 150 kPa-absolute, 200 kPa-absolute, 250 kPa-absolute, or 300 kPa-absolute to 500 kPa-absolute, 600 kPa-absolute, 700 kPa-absolute, 800 kPa-absolute, 900 kPa-absolute, or 1,000 kPa-absolute to produce the regenerated catalyst system.

[0080] Without wishing to be bound by theory, it is believed that at least a portion of the Group 8-10 element present in/on the coked catalytic particles can be agglomerated as compared to the catalyst system prior to contact with the first hydrocarbon-containing feed. It is believed that during combustion of at least a portion of the coke on the coked catalyst system that at least a portion of the Group 8-10 element can be re-dispersed about

the support of the catalytic particles. Re-dispersing at least a portion of any agglomerated Group 8-10 element can improve the stability of the catalyst system over many cycles.

[0081] In some embodiments, at least a portion of the Group 8-10 element in the regenerated catalyst system can be at a higher oxidized state as compared to the Group 8-10 element in the catalyst system contacted with the first hydrocarbon-containing feed and as compared to the Group 8-10 element in the coked catalyst system. As such, as noted above, in some embodiments the process can optionally include contacting at least a portion of the regenerated catalyst system with a reducing gas to produce a regenerated and reduced catalyst system. Suitable reducing gases (reducing agent) can be or can include, but are not limited to, H₂, CO, CH₄, C₂H₆, C₃H₈, C₂H₄, C₃H₆, steam, or a mixture thereof. In some embodiments, the reducing agent can be mixed with an inert gas such as Ar, Ne, He, N₂, CO₂, H₂O or a mixture thereof. In such embodiments, at least a portion of the Group 8-10 element in the regenerated and reduced catalyst system can be reduced to a lower oxidation state, e.g., the elemental state, as compared to the Group 8-10 element in the regenerated catalyst system. In this embodiment, the additional quantity of the first hydrocarbon-containing feed can be contacted with at least a portion of the regenerated catalyst system and/or at least a portion of the regenerated and reduced catalyst system.

[0082] In some embodiments, the regenerated catalyst system and the reducing gas can be contacted at a temperature in a range from 400°C, 450°C, 500°C, 550°C, 600°C, 620°C, 650°C, or 670°C to 720°C, 750°C, 800°C, or 900°C. The regenerated catalyst system and the reducing gas can be contacted for a time period in a range from 1 second, 5 seconds, 10 seconds, 20 seconds, 30 seconds, or 1 minute to 10 minutes, 30 minutes, or 60 minutes. The regenerated catalyst system and reducing gas can be contacted at a reducing agent partial pressure of 20 kPa-absolute, 50 kPa-absolute, or 100 kPa-absolute, 300 kPa-absolute, 500 kPa-absolute, 750 kPa-absolute, or 1,000 kPa-absolute to 1,500 kPa-absolute, 2,500 kPa-absolute, 4,000 kPa-absolute, 5,000 kPa-absolute, 7,000 kPa-absolute, 8,500 kPa-absolute, or 10,000 kPa-absolute. In other embodiments, the reducing agent partial pressure during contact with the regenerated catalyst system can be in a range from 20 kPa-absolute, 50 kPa-absolute, 100 kPa-absolute, 150 kPa-absolute, 200 kPa-absolute, 250 kPa-absolute, or 300 kPa-absolute to 500 kPa-absolute, 600 kPa-absolute, 700 kPa-absolute, 800 kPa-absolute, 900 kPa-absolute, or 1,000 kPa-absolute to produce the regenerated catalyst system.

[0083] At least a portion of the regenerated catalyst system, the regenerated and reduced catalyst system, new or fresh catalyst system, or a mixture thereof can be contacted with

- an additional quantity of the first hydrocarbon-containing feed within the reaction or conversion zone to produce additional effluent and additional coked catalyst system. As noted above, in some embodiments, the cycle time from the contacting the first hydrocarbon-containing feed with the catalyst system to the contacting the additional quantity of the first hydrocarbon-containing feed with at least a portion of the regenerated catalyst system, and/or the regenerated and reduced catalyst system, and optionally with new or fresh catalyst system can be ≤ 5 hours, ≤ 4 hours, ≤ 3 hours, ≤ 2 hours, ≤ 1 hour, ≤ 50 minutes, ≤ 45 minutes, ≤ 30 minutes, ≤ 15 minutes, ≤ 10 minutes, ≤ 5 minutes, ≤ 1 minute, ≤ 30 seconds, or ≤ 10 seconds.
- 10 [0084] In some embodiments, as noted above, one or more additional feeds, e.g., one or more sweep fluids, can be utilized between flows of the first hydrocarbon-containing feed and the oxidant, between the oxidant and the optional reducing gas if used, between the oxidant and the additional first hydrocarbon-containing feed, and/or between the reducing gas and the additional first hydrocarbon-containing feed. The sweep fluid can, among
- 15 other things, purge or otherwise urge undesired material from the reactors, such as non-combustible particulates including soot. In some embodiments, the additional feed(s) can be inert under the dehydrogenation, dehydroaromatization, and dehydrocyclization, combustion, and/or reducing conditions. Suitable sweep fluids can be or can include, but are not limited to, N_2 , He, Ar, CO_2 , H_2O , CO , CH_4 , or a mixture thereof. In some
- 20 embodiments, if the process utilizes a sweep fluid the duration or time period the sweep fluid is used can be in a range from 1 second, 5 seconds, 10 seconds, 20 seconds, 30 seconds, or 1 minute to 10 minutes, 30 minutes, or 60 minutes.
- [0085] In some embodiments, the catalyst system can remain sufficiently active and stable after many cycles, e.g., at least 15, at least 20, at least 30, at least 40, at least 50, at
- 25 least 60, at least 70, at least 100 cycles, at least 125 cycles, at least 150 cycles, at least 175 cycles, or at least 200 cycles with each cycle time lasting for ≤ 5 hours, ≤ 4 hours, ≤ 3 hours, ≤ 2 hours, ≤ 1 hour, ≤ 50 minutes, ≤ 45 minutes, ≤ 30 minutes, ≤ 15 minutes, ≤ 10 minutes, ≤ 5 minutes, ≤ 1 minute, ≤ 30 seconds, or ≤ 10 seconds. In some embodiments, the cycle time can be from 5 seconds, 30 seconds, 1 minute or 5 minutes to 10 minutes,
- 30 20 minutes, 30 minutes, 45 minutes, 50 minutes, 70 minutes, 2 hours, 3 hours, 4 hours, or 5 hours. In some embodiments, after the catalyst performance stabilizes (sometimes the first few cycles can have a relatively poor or a relatively good performance, but the performance can eventually stabilize), the process can produce a first upgraded hydrocarbon product yield, e.g., propylene when the first hydrocarbon-containing feed

includes propane, at an upgraded hydrocarbon selectivity, e.g., propylene, of $\geq 75\%$, $\geq 80\%$, $\geq 85\%$, $\geq 90\%$, $\geq 93\%$, or $\geq 95\%$ when initially contacted with the first hydrocarbon-containing feed, and can have a second upgraded hydrocarbon product yield upon completion of the last cycle (at least 15 cycles total) that can be at least 90%, at least 93%,
 5 at least 95%, at least 97%, at least 98%, at least 99%, at least 99.5%, or at least 100% of the first upgraded hydrocarbon product yield at an upgraded hydrocarbon selectivity, e.g., propylene, of $\geq 75\%$, $\geq 80\%$, $\geq 85\%$, or $\geq 90\%$, $\geq 93\%$, or $\geq 95\%$.

[0086] In some embodiments, when the first hydrocarbon-containing feed includes propane and the upgraded hydrocarbon includes propylene, contacting the first
 10 hydrocarbon-containing feed with the catalyst system can produce a propylene yield of $\geq 52\%$, $\geq 53\%$, $\geq 55\%$, $\geq 57\%$, $\geq 60\%$, $\geq 62\%$, $\geq 63\%$, $\geq 64\%$, $\geq 65\%$, or $\geq 66\%$ at a propylene selectivity of $\geq 75\%$, $\geq 80\%$, $\geq 85\%$, $\geq 90\%$, $\geq 93\%$, or $\geq 95\%$ for at least 15, at least 20, at least 30, at least 40, at least 50, at least 60, at least 70, at least 100 cycles, at least 125 cycles, at least 150 cycles, at least 175 cycles, or at least 200 cycles. In other
 15 embodiments, when the first hydrocarbon-containing feed includes at least 70 vol% of propane, based on a total volume of the first hydrocarbon-containing feed, is contacted under a propane partial pressure of at least 20 kPa-absolute, a propylene yield of $\geq 52\%$, $\geq 53\%$, $\geq 55\%$, $\geq 57\%$, $\geq 60\%$, $\geq 62\%$, $\geq 63\%$, $\geq 64\%$, $\geq 65\%$, or $\geq 66\%$ at a propylene selectivity of $\geq 75\%$, $\geq 80\%$, $\geq 85\%$, $\geq 90\%$, $\geq 93\%$, or $\geq 95\%$ can be obtained for at least
 20 15, at least 20, at least 30, at least 40, at least 50, at least 60, at least 70, at least 100 cycles, at least 125 cycles, at least 150 cycles, at least 175 cycles, or at least 200 cycles. It is believed that the propylene yield can be further increased to $\geq 67\%$, $\geq 68\%$, $\geq 70\%$, $\geq 72\%$, $\geq 75\%$, $\geq 77\%$, $\geq 80\%$, or $\geq 82\%$ at a propylene selectivity of $\geq 75\%$, $\geq 80\%$, $\geq 85\%$, $\geq 90\%$, $\geq 93\%$, or $\geq 95\%$ for ≥ 15 cycles, ≥ 20 cycles, ≥ 30 cycles, ≥ 40 cycles, ≥ 50 cycles,
 25 ≥ 60 cycles, ≥ 70 cycles, ≥ 100 cycles, ≥ 125 cycles, ≥ 150 cycles, ≥ 175 cycles, or ≥ 200 cycles by further optimizing the composition of the support and/or adjusting one or more process conditions. In some embodiments, the propylene yield can be obtained when the catalyst system is contacted with the first hydrocarbon-containing feed at a temperature of $\geq 620^\circ\text{C}$, $\geq 630^\circ\text{C}$, $\geq 640^\circ\text{C}$, $\geq 650^\circ\text{C}$, $\geq 655^\circ\text{C}$, $\geq 660^\circ\text{C}$, $\geq 670^\circ\text{C}$, $\geq 680^\circ\text{C}$, $\geq 690^\circ\text{C}$,
 30 $\geq 700^\circ\text{C}$, or $\geq 750^\circ\text{C}$ for ≥ 15 cycles, ≥ 20 cycles, ≥ 30 cycles, ≥ 40 cycles, ≥ 50 cycles, ≥ 60 cycles, ≥ 70 cycles, ≥ 100 cycles, ≥ 125 cycles, ≥ 150 cycles, ≥ 175 cycles, or ≥ 200 cycles.

[0087] In some embodiments, when a fluidized bed reactor or other circulating or fluidized type reactor is used, the catalytic system that includes the mixture of the catalytic

particles and the catalytically inert particles can be introduced into any location or combination of locations of the reactor system. In some embodiments, the catalyst system can be introduced into the reaction or conversion zone, the regeneration zone, if present, the reduction zone, any location located between any two of the zones or any combination thereof. In some embodiments, when a fluidized bed reactor or other circulating or fluidized type reactor is used, the catalytic particles and the catalytically inert particles can be introduced separately into the reactor system such that the catalyst system can be formed within the reactor system. In such embodiments, the catalytic particles and the catalytically inert particles can both be introduced into the same zone or into different zones or a first portion of the catalytic particles and/or the catalytically inert particles can be introduced into the reactor system at a first location and a second portion of the catalytic particles and/or the catalytically inert particles can be introduced into the reactor system at a second location.

[0088] During the process for upgrading the hydrocarbon, the weight ratio of the catalytic particles to the catalytically inert particles can be adjusted, which can be used to adjust or control a composition of the effluent recovered from the reactor system. In some embodiments, the amount of the catalytic particles, the amount of the catalytically inert particles, or both the amount of the catalytic particles and the amount of the catalytically inert particles can be adjusted during the contacting of the first hydrocarbon-containing feed with the catalyst system. In some embodiments, the weight ratio of the catalytic particles to the catalytically inert particles can be increased or decreased by adjusting the amount of the catalytic particles and/or the catalytically inert particles during the contacting of the first hydrocarbon-containing feed with the catalyst system.

[0089] Systems suitable for carrying out the processes disclosed herein can include systems that are well-known in the art such as the fixed bed reactors disclosed in WO Publication No. WO2017078894; the fluidized riser reactors and/or downer reactors disclosed in U.S. Patent Nos. 3,888,762; 7,102,050; 7,195,741; 7,122,160; and 8,653,317; and U.S. Patent Application Publication Nos. 2004/0082824; 2008/0194891; and the reverse flow reactors disclosed in U.S. Patent No. 8,754,276; U.S. Patent Application Publication No. 2015/0065767; and WO Publication No. WO2013169461.

First hydrocarbon-containing Feed

[0090] The first hydrocarbon-containing feed can be or can include, but is not limited to, one or more alkane hydrocarbons, e.g., C₂-C₁₆ linear or branched alkanes and/or C₄-C₁₆ cyclic alkanes, and/or one or more alkyl aromatic hydrocarbons, e.g., C₈-C₁₆ alkyl

aromatics. In some embodiments, the first hydrocarbon-containing feed can optionally include 0.1 vol% to 50 vol% of steam, based on a total volume of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics in the first hydrocarbon-containing feed. In other embodiments, the first hydrocarbon-containing feed can include < 0.1 vol% of steam or
5 can be free of steam, based on the total volume of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics in the first hydrocarbon-containing feed.

[0091] The C₂-C₁₆ alkanes can be or can include, but are not limited to, ethane, propane, n-butane, isobutane, n-pentane, isopentane, n-hexane, 2-methylpentane, 3-methylpentane, 2,2-dimethylbutane, n-heptane, 2-methylhexane, 2,2,3-trimethylbutane, cyclopentane,
10 cyclohexane, methylcyclopentane, ethylcyclopentane, n-propylcyclopentane, 1,3-dimethylcyclohexane, or a mixture thereof. For example, the first hydrocarbon-containing feed can include propane, which can be dehydrogenated to produce propylene, and/or isobutane, which can be dehydrogenated to produce isobutylene. In another example, the first hydrocarbon-containing feed can include liquid petroleum gas (LP gas), which can
15 be in the gaseous phase when contacted with the catalyst system. In some embodiments, the hydrocarbon in the first hydrocarbon-containing feed can be composed of substantially a single alkane such as propane. In some embodiments, the first hydrocarbon-containing feed can include ≥ 50 mol%, ≥ 75 mol%, ≥ 95 mol%, ≥ 98 mol%, or ≥ 99 mol% of a single C₂-C₁₆ alkane, e.g., propane, based on total moles of all hydrocarbons in the first
20 hydrocarbon-containing feed. In some embodiments, the first hydrocarbon-containing feed can include at least 50 vol%, at least 55 vol%, at least 60 vol%, at least 65 vol%, at least 70 vol%, at least 75 vol%, at least 80 vol%, at least 85 vol%, at least 90 vol%, at least 95 vol%, at least 97 vol%, or at least 99 vol% of a single C₂-C₁₆ alkane, e.g., propane, based on a total volume of the first hydrocarbon-containing feed.

[0092] The C₈-C₁₆ alkyl aromatics can be or can include, but are not limited to, ethylbenzene, propylbenzene, butylbenzene, one or more ethyl toluenes, or a mixture thereof. In some embodiments, the first hydrocarbon-containing feed can include ≥ 50 mol%, ≥ 75 mol%, ≥ 95 mol%, ≥ 98 mol%, or ≥ 99 mol% of a single C₈-C₁₆ alkyl aromatic, e.g., ethylbenzene, based on a total weight of all hydrocarbons in the first hydrocarbon-
30 containing feed. In some embodiments, the ethylbenzene can be dehydrogenated to produce styrene. As such, in some embodiments, the first process for upgrading a hydrocarbon disclosed herein can include propane dehydrogenation, butane dehydrogenation, isobutane dehydrogenation, pentane dehydrogenation, pentane

dehydrocyclization to cyclopentadiene, naphtha reforming, ethylbenzene dehydrogenation, ethyltoluene dehydrogenation, and the like.

[0093] In some embodiments, the first hydrocarbon-containing feed can be diluted, e.g., with one or more diluents such as one or more inert gases. Suitable inert gases can be or can include, but are not limited to, Ar, Ne, He, N₂, CO₂, CH₄, or a mixture thereof. If the hydrocarbon containing-feed includes a diluent, the first hydrocarbon-containing feed can include 0.1 vol%, 0.5 vol%, 1 vol%, or 2 vol% to 3 vol%, 8 vol%, 16 vol%, or 32 vol% of the diluent, based on a total volume of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics in the first hydrocarbon-containing feed.

10 [0094] In some embodiments, the first hydrocarbon-containing feed can also include H₂. In some embodiments, when the first hydrocarbon-containing feed includes H₂, a molar ratio of the H₂ to a combined amount of any C₂-C₁₆ alkane and any C₈-C₁₆ alkyl aromatic can be in a range from 0.1, 0.3, 0.5, 0.7, or 1 to 2, 3, 4, 5, 6, 7, 8, 9, or 10. In other embodiments, H₂ can be introduced into the reactor system as a feed separate and apart
15 from the first hydrocarbon-containing feed.

[0095] In some embodiments, first hydrocarbon-containing feed and the environment within the reactor system can be substantially free of any steam, e.g., < 0.1 vol% of steam, based on a total volume of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics in the first hydrocarbon-containing feed. In other embodiments, the first hydrocarbon-containing
20 feed can include steam and/or steam can be introduced into the reactor system as a feed separate and apart from the first hydrocarbon-containing feed. For example, the first hydrocarbon-containing feed or, if introduced separate from the first hydrocarbon-containing feed, the environment within the reactor system can include 0.1 vol%, 0.3 vol%, 0.5 vol%, 0.7 vol%, 1 vol%, 3 vol%, or 5 vol% to 10 vol%, 15 vol%, 20 vol%, 25 vol%,
25 30 vol%, 35 vol%, 40 vol%, 45 vol%, or 50 vol% of steam, based on a total volume of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics in the first hydrocarbon-containing feed. In other embodiments, the first hydrocarbon-containing feed or, if introduced separate from the first hydrocarbon-containing feed, the environment within the reactor system can include ≤ 50 vol%, ≤ 45 vol%, ≤ 40 vol%, ≤ 35 vol%, ≤ 30 vol%, ≤ 25 vol%,
30 ≤ 20 vol%, or ≤ 15 vol% of steam, based on a total volume of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics in the first hydrocarbon-containing feed. In other embodiments, the first hydrocarbon-containing feed or, if introduced separate from the first hydrocarbon-containing feed, the environment within the reactor system can include at least 1 vol%, at least 3 vol%, at least 5 vol%, at least 10 vol%, at least 15 vol%, at least

20 vol%, at least 25 vol%, or at least 30 vol% of steam, based on a total volume of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics in the first hydrocarbon-containing feed.

[0096] In some embodiments, the first hydrocarbon-containing feed can include sulfur or sulfur can be introduced as a feed separate and apart from the first hydrocarbon-containing feed. For example, the first hydrocarbon-containing feed can include sulfur in a range from 0.5 ppm, 1 ppm, 5 ppm, 10 ppm, 20 ppm 30 ppm, 40 ppm, 50 ppm, 60 ppm, 70 ppm, or 80 ppm to 100 ppm, 150 ppm, 200 ppm, 300 ppm, 400 ppm, or 500 ppm. In other embodiments, the first hydrocarbon-containing feed can include sulfur in a range from 1 ppm to 10 ppm, 10 ppm to 20 ppm, 20 ppm to 50 ppm, 50 ppm to 100 ppm, or 100 ppm to 500 ppm. The sulfur, if present in the first hydrocarbon-containing feed, can be or can include, but is not limited to, H₂S, dimethyl disulfide, as one or more mercaptans, or any mixture thereof.

[0097] In some embodiments, the first hydrocarbon-containing feed and the environment within the reaction or conversion zone can be substantially free or free of molecular oxygen. In some embodiments, the first hydrocarbon-containing feed can include ≤ 5 mol%, ≤ 3 mol%, or ≤ 1 mol% of molecular oxygen (O₂). It is believed that providing a first hydrocarbon-containing feed substantially-free of molecular oxygen substantially prevents oxidative reactions that would otherwise consume at least a portion of the alkane and/or the alkyl aromatic in first hydrocarbon-containing feed.

20 Recovery and Use of the First Upgraded Hydrocarbon

[0098] In some embodiments, the first upgraded hydrocarbon in the effluent can include at least one upgraded hydrocarbon, e.g., an olefin, water, unreacted hydrocarbons, molecular hydrogen, etc. The upgraded hydrocarbon can be recovered or otherwise obtained via any convenient process, e.g., by one or more conventional processes. One such process can include cooling and/or compressing the effluent to condense at least a portion of any water and any heavy hydrocarbon that may be present, leaving the olefin and at least a portion of any unreacted alkane or alkyl aromatic primarily in the vapor phase. Olefin and unreacted alkane or alkyl aromatic hydrocarbons can then be removed from the reaction product in one or more separator drums. For example, one or more splitters or distillation columns can be used to separate the dehydrogenated product from the unreacted first hydrocarbon-containing feed.

[0099] In some embodiments, a recovered olefin, e.g., propylene, can be used for producing polymer, e.g., recovered propylene can be polymerized to produce polymer having segments or units derived from the recovered propylene such as polypropylene,

ethylene-propylene copolymer, etc. Recovered isobutene can be used, e.g., for producing one or more of: an oxygenate such as methyl tert-butyl ether, fuel additives such as diisobutene, synthetic elastomeric polymer such as butyl rubber, etc.

A Second Process for Upgrading a Hydrocarbon

5 [0100] The second process for upgrading a hydrocarbon can include contacting a second hydrocarbon-containing feed with the catalyst system that can include a mixture of the catalytic particles and the catalytically inert particles to effect reforming of at least a portion of the second hydrocarbon-containing feed to produce a coked catalyst system and an effluent that can include carbon monoxide and molecular hydrogen. The catalyst system and the second
10 hydrocarbon-containing feed can be contacted with one another within any suitable environment such as one or more reaction or conversion zones disposed within one or more reactors to produce the effluent and the coked catalyst system. The reaction or conversion zone can be disposed or otherwise located within one or more fixed bed reactors, one or more fluidized or moving bed reactors, one or more reverse flow reactors, or any combination thereof.
15 For clarity and ease of description, the reforming reaction will be discussed in the context of a fluidized bed reactor, but it should be understood that fixed bed reactors, reverse flow or moving bed reactors, or any other reactor can be used to carry out the reforming of the second hydrocarbon-containing feed.

[0101] The reforming reaction can be used to produce reformed hydrocarbons via a
20 continuous reaction process or a discontinuous reaction process. In some embodiments, the reaction process can include a reforming step, e.g., an endothermic reaction, and a regeneration step, e.g., an exothermic reaction, that operate continuously while the fluidized catalyst is transported in-between the reforming zone and regeneration zone of the reactor. The endothermic reaction can include hydrocarbon reforming in the presence of the catalyst system.
25 Fresh hydrocarbon and regenerated fluidized catalytic particles and catalytically inert particles can enter the reforming zone. After spending some time in the reforming zone, the hydrocarbon can be at least partially converted to a reforming product that can exit the reforming zone together with the spent catalyst system. The reforming product and unreacted feed can be separated from the spent catalyst system by one or more separating devices. While the
30 reforming product and unreacted feed from the separating devices go downstream for further purification, the spent catalyst system can be sent to the regeneration zone for regeneration. The exothermic regeneration reaction can be the reaction of an oxidant and, optionally a fuel, under combustion conditions to produce a regenerated catalyst system and a flue gas. After regeneration, the regenerated catalyst system can be separated from the flue gas by one or more

separating devices and can be transported back to the reforming zone, joining more hydrocarbon feed to enter the reforming zone to initiate more reforming reaction. The reforming step can convert CO₂ and/or H₂O and hydrocarbons, e.g., CH₄, to a synthesis gas that includes H₂ and CO. The regeneration step can combust reactants, e.g., coke disposed on the spent catalyst system and/or the optional fuel and an oxidant, to generate heat that heats up the regenerated catalyst system that can provide heat that can be used to drive the reforming reaction. In some embodiments, the catalyst system can be heated to an average temperature in a range of from 600°C, 700°C, or 800°C to 1,000°C, 1,300°C, or 1,600°C during the regeneration step.

[0102] Illustrative fuels can be or can include, but are not limited to, hydrocarbons, e.g., methane, ethane, propane, butane, pentane, or hydrocarbon containing streams, e.g., natural gas, molecular hydrogen, fuel oil, heavy fuel oil, gasoline, diesel, kerosene, distillate, and/or other combustible compounds. The oxidant can be or can include O₂. In some embodiments, the oxidant can be or can include air, O₂ enriched air, O₂ depleted air, or any other suitable O₂ containing stream.

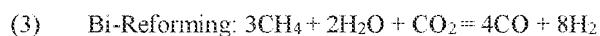
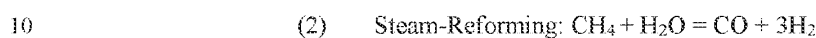
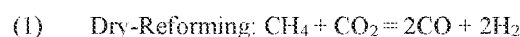
[0103] The regeneration of the catalyst system can correspond to removal of coke from the particles in the catalyst system. In some embodiments, during reforming, a portion of the feed introduced into the reforming zone can form coke. This coke can potentially block access to the catalytic sites (such as metal sites) of the catalytic particles in the catalyst system. During regeneration at least a portion of the coke generated during reforming can be removed as CO or CO₂. The regeneration of the catalyst system can also correspond to re-dispersion of any agglomerated active phase of the catalyst such as the Group 8-10 element.

Second Hydrocarbon-Containing Feed

[0104] The second hydrocarbon-containing feed can be or can include, but is not limited to, one or more reformable C₁-C₁₆ hydrocarbons such as alkanes, alkenes, cycloalkanes, alkylaromatics, or any mixture thereof. In some embodiments, the second hydrocarbon-containing feed can be or can include methane, ethane, propane, butane, pentane, or a mixture thereof. In some embodiments, the second hydrocarbon-containing feed can be exposed to the catalyst system under a pressure of less than 35 kPag. For example, the second hydrocarbon-containing feed can be exposed to the catalyst system under a pressure in a range of from 0.7 kPag, 2 kPag, 3.5 kPag, 5 kPag, or 10 kPag to 15 kPag, 20 kPag, 25 kPag, or 30 kPag. In other embodiments, the second hydrocarbon-containing feed can be exposed to the catalyst system under a pressure in a range of from 35 kPag to 15 MPag. In still other embodiments, the second hydrocarbon-containing feed can be exposed to the catalyst system under a pressure in a range

of from 0.7 kPag, 2 kPag, 5 kPag, 20 kPag, 35 kPag, 50 kPag, or 100 kPag to 200 kPag, 1 MPag, 3 MPag, 5 MPag, 10 MPag, or 15 MPag. In still other embodiments, the second hydrocarbon-containing feed can be exposed to the catalyst system under a pressure of less than 2.8 MPag, less than 2.5 MPag, less than 2.2 MPag, or less than 2 MPag.

- 5 [0105] The reforming reaction of the second hydrocarbon-containing feed, e.g., CH₄, can occur in the presence of H₂O (steam-reforming), in the presence of CO₂ (dry-reforming), or in the presence of both H₂O and CO₂ (bi-reforming). Examples of stoichiometry for steam, dry, and bi-reforming of CH₄ are shown in equations (1) – (3).



- [0106] As shown in equations (1) – (3), dry reforming can produce lower ratios of H₂ to CO than steam reforming. Reforming reactions performed with only steam can generally produce a synthesis gas having a H₂:CO molar ratio of around 3, such as 2.5 to 3.5. In contrast, 15 reforming reactions performed with only CO₂ can generally produce a synthesis gas having a H₂:CO molar ratio of roughly 1 or even lower. By using a combination of CO₂ and H₂O during reforming, the reforming reaction can be controlled to generate a wide variety of H₂ to CO ratios in a resulting synthesis gas.

- [0107] It should be noted that the ratio of H₂ to CO in a synthesis gas can also be dependent 20 on the water gas shift equilibrium. Although the stoichiometry in Equations (1) – (3) shows ratios of roughly 1 or roughly 3 for dry reforming and steam reforming, respectively, the equilibrium amounts of H₂ and CO in a synthesis gas can be different from the reaction stoichiometry. The equilibrium amounts can be determined based on the water gas shift equilibrium, which relates the concentrations of H₂, CO, CO₂ and H₂O based on the reaction 25 shown in equation (4).



- [0108] In some embodiments, the catalyst system can also serve as water gas shift catalysts. Thus, if a reaction environment for producing H₂ and CO also includes H₂O and/or CO₂, the initial stoichiometry from the reforming reaction may be altered based on the water gas shift 30 equilibrium. However, this equilibrium is also temperature dependent, with higher temperatures favoring production of CO and H₂O. As a result, the ratio of H₂ to CO that is generated when forming synthesis gas is constrained by the water gas shift equilibrium at the temperature in the reaction zone when the synthesis gas is produced.

[0109] The ability to adjust the H₂:CO molar ratio of the synthesis gas provides a flexible process that can be combined with a wide variety of synthesis gas upgrading processes. Illustrative synthesis gas upgrading processes can include, but are not limited to, Fischer-Tropsch processes, methanol and/or other alcohol synthesis, *e.g.*, one or more C₁-C₄ alcohols, fermentation processes, separation processes that can separate hydrogen to produce a H₂-rich product, dimethyl ether, and combinations thereof. These synthesis gas upgrading processes are well-known to persons having ordinary skill in the art. In some embodiments, the upgraded product can include, but is not limited to, methanol, syncrude, diesel, lubricants, waxes, olefins, dimethyl ether, other chemicals, or any combination thereof.

[0110] Systems suitable for carrying out the reforming of the second hydrocarbon-containing feed can include systems that are well-known in the art such as the fixed bed reactors disclosed in WO Publication No. WO2017078894; the fluidized riser reactors and/or downer reactors disclosed in U.S. Patent Nos. 3,888,762; 7,102,050; 7,195,741; 7,122,160; and 8,653,317; and U.S. Patent Application Publication Nos. 2004/0082824; 2008/0194891; and the reverse flow reactors disclosed in U.S. Patent Nos.: 7,740,829; 8,551,444; 8,754,276; 9,687,803; and 10,160,708; and U.S. Patent Application Publication Nos.: 2015/0065767 and 2017/0137285; and WO Publication No. WO2013169461.

[0111] During the first and/or second processes for upgrading the hydrocarbon, especially in the context of one or more fluidized or moving bed reactors, at least a portion of the Group 8-10 element can potentially be transferred from the catalytic particles to the catalytically inert particles via contact with one another. Similarly, if the catalytic particles and the catalytically inert particles are mixed prior to introduction into the reactor system, at least a portion of the Group 8-10 element may also be transferred from the catalytic particles to the catalytically inert particles. Such transfer of the Group 8-10 element can convert at least a portion of the catalytically inert particles to catalytic particles. As such, in some embodiments, the weight ratio of the catalytic particles to the catalytically inert particles can also be adjusted during the hydrocarbon conversion process via transfer of a portion of the Group 8-10 element from the catalytic particles to the catalytically inert particles.

Feeds and Energy

[0112] The first and second hydrocarbon-containing feeds described herein can be derived either from fossil fuel or non-fossil fuel resources. For example, propane can be a product or by-product of a process using biomass as the feed. The fuels described in this work can also be derived either from fossil fuel or non-fossil fuel resources. For example, methane or H₂ can be a product or by-product of a process using biomass as the feed. The fuels described in this

work can also be made from renewable energy such as renewable electricity. For example, renewable electricity can be used to produce H_2 through water electrolysis. The energy used in the processes described herein can also be provided by renewable electricity, instead of a fuel.

5 Examples:

[0113] The foregoing discussion can be further described with reference to the following non-limiting examples.

[0114] The catalyst and selected inert particles used in Examples 1-6 were prepared according to the following procedure. Support particles of a mixed Mg/Al metal oxide
10 (PURALOX® MG80/150, Sasol) were dried in air at 550°C for 3 hours. The dried support was impregnated with an appropriate amount of chloroplatinic acid solution, or an appropriate amount of an aqueous solution of $SnCl_4$, or both. The impregnated material stayed at room temperature for 24 hours, before it was dried in air at 110°C for 6 hours, and calcined at 800°C in air for 12 hours to produce the final particles that included Pt, Sn, or both Pt and Sn.

15 [0115] In Examples 1-6, fixed bed experiments that used the catalysts were conducted at approximately 100 kPa-absolute. A gas chromatograph (GC) was used to measure the composition of the reactor effluents. The concentrations of each component in the reactor effluents were then used to calculate the C_3H_6 yield and selectivity. The C_3H_6 yield and selectivity, as reported in these examples, were calculated on the carbon mole basis.

20 [0116] In each example, an appropriate amount of catalyst was mixed with an appropriate amount of quartz diluent and loaded into a quartz reactor. The amount of diluent was determined so that the catalyst bed (catalyst + diluent) overlapped with the isothermal zone of the quartz reactor and the catalyst bed was largely isothermal during operation. The dead volume of the reactor was filled with quartz chips/rods.

25 [0117] The process steps in examples 1 – 6 were as follows: 1. The system was flushed with an inert gas. 2. Dry air at a flow rate of 83.9 sccm was passed through a by-pass of the reaction zone, while an inert gas was passed through the reaction zone. The reaction zone was heated to a regeneration temperature of 800°C. 3. Dry air at a flow rate of 83.9 sccm was then passed through the reaction zone for 10 minutes to regenerate the catalyst. 4. The system was
30 flushed with an inert gas. 5. A H_2 containing gas with 10 vol% H_2 and 90 vol % Ar at a flow rate of 46.6 sccm was passed through the by-pass of the reaction zone for a certain period of time, while an inert gas was passed through the reaction zone. This was then followed by flowing the H_2 containing gas through the reaction zone at 800°C for 3 seconds. 6. The system was flushed with an inert gas. During this process, the temperature of the reaction zone was

changed from 800°C to a reaction temperature of 670°C. 7. A hydrocarbon-containing (HC gas) feed that included 81 vol% of C₃H₈, 9 vol% of inert gas (Ar or Kr) and 10 vol% of steam at a flow rate of 17.6 sccm was passed through the by-pass of the reaction zone for a certain period of time, while an inert gas was passed through the reaction zone. The hydrocarbon-containing feed was then passed through the reaction zone at 670°C for 10 minutes. GC sampling of the reaction effluent was started as soon as the feed was switched from the by-pass of the reaction zone to the reaction zone. The above process steps were repeated in cycles.

[0118] While the Examples utilized a fixed bed reactor, fluid bed reactors or processes could equally be utilized and, without wishing to be bound by theory, the interaction of the active catalyst portion of the catalyst system in a fluidized bed reactor would be expected to interact more effectively with the catalytically inert particles whether that be the mixed Mg/Al metal oxide, the Sn-doped mixed Mg/Al metal oxide, or other catalytically inert particles.

Table		Ex. 1	Ex. 2	Ex. 3	Ex. 4	Ex. 5	Ex. 6
Catalyst Particles (g)		0.03	0.03	0.03	0.03	0.06	0.3
Pt on Catalyst Particles (wt%)		0.3	0.3	0.3	0.3	0.3	0.05
Sn on Catalyst Particles (wt%)		1	1	1	1	1	1
Catalytically Inert Particles							
Inert Quartz (g)		0.5	0	0.2	0	0.2	0.2
PURALOX® MG80/150 (g)		0	0.47	0.27	0.27	0.27	0
Sn (wt%) on PURALOX® MG80/150		0	0	1	1	1	0
Catalyst in Charge (wt%)		6	6	6	10	11	60
Total Pt in Charge (mg)		9	9	9	9	18	15
Performance	Y _{ini}	25.8	27.6	39	38.6	53.3	66.3
	Y _{end}	8.3	13.1	28.9	24	41.7	64
	S _{ini}	90.8	91.3	95.1	94.6	95.1	93.5
	S _{end}	80.7	87.4	94.1	92.9	95	95.4

[0119] Example 2 vs. Example 1 shows there is a benefit to using the mixed Mg/Al metal oxide particles as the catalytically inert particles vs. quartz.

15 [0120] Examples 3 and 4 that utilized catalytically inert Sn-doped mixed Mg/Al metal oxide particles vs. Examples 1 and 2 that utilized quartz or undoped mixed Mg/Al metal oxide particles as the inert exhibited a greater yield and selectivity. As such, based on Examples 3 and 4, it appears the catalytically inert Sn-doped mixed Mg/Al metal oxide particles enhanced the activity of the catalytically active particles and/or became catalytically active via transfer

of some of the Pt from the catalytic particles to the catalytically inert particles making the catalytically inert particles catalytically active particles.

[0121] Example 5 vs. Example 3 shows the impact of increasing the amount of the catalytic particles from 10 wt% to 20 wt% with respect to the amount of the catalytically inert particles.

5 By increasing the amount of the catalytic particles, the yield significantly increased.

[0122] Example 6 shows that by including an order of magnitude more of the catalyst particles (0.3 g of the catalyst particles vs. 0.03 g of the catalyst particles used in Examples 1-4), but at a lower concentration of Pt (0.05 wt% vs. 0.3 wt% of Examples 1-4) lead to a significant improvement in the yield.

10 Listing of Embodiments

[0123] This disclosure may further include the following non-limiting embodiments.

[0124] A1. A process for upgrading a hydrocarbon, comprising: (I) contacting a hydrocarbon-containing feed with a catalyst system comprising a mixture of catalytic particles and catalytically inert particles to effect reforming of at least a portion of the hydrocarbon-containing feed to produce a coked catalyst system and a synthesis gas comprising H₂ and CO, wherein: the hydrocarbon-containing feed comprises one or more C₁-C₁₆ hydrocarbons and H₂O, CO₂, or a mixture of H₂O and CO₂, the hydrocarbon-containing feed and catalyst system are contacted at a temperature of 400°C or more, the catalytic particles comprise a Group 8-10 element and a first promoter comprising Sn, Cu, Au, Ag, Ga, a combination thereof, or a mixture thereof disposed on a support, the catalytic particles comprise 0.001 wt% to 6 wt% of the Group 8-10 element, up to 10 wt% of the first promoter, and the support comprises Al and at least 0.5 wt% of a Group 2 element, based on the weight of the support, the catalytically inert particles are free of a Group 8-10 element, and a composition of the catalytically inert particles and a composition of the support is the same or different.

25 [0125] A2. The process of A1, further comprising (II) contacting at least a portion of the coked catalyst system with an oxidant to effect combustion of at least a portion of the coke to produce a regenerated catalyst system lean in coke and a combustion gas.

[0126] A3. The process of A2, further comprising (III) contacting a fuel with the oxidant and the coked catalyst system to effect combustion of at least a portion of the fuel.

30 [0127] A4. The process of A2 or A3, further comprising (IV) contacting an additional quantity of the hydrocarbon-containing feed with at least a portion of the regenerated catalyst system to produce a re-coked catalyst system and additional effluent.

[0128] A5. The process of any of A1 to A4, wherein the hydrocarbon-containing feed is contacted with the catalyst system in a fluidized bed reactor.

- [0129] A6. The process of any of A1 to A4, wherein the hydrocarbon-containing feed is contacted with the catalyst system in a fixed bed reactor.
- [0130] A7. The process of any of A1 to A4, wherein the hydrocarbon-containing feed is contacted with the catalyst system in a reverse flow reactor.
- 5 [0131] A8. The process of any of A1 to A7, wherein the catalytic particles in the catalyst system comprises 0.001 wt%, 0.001 wt%, 0.01 wt%, 0.1 wt%, 0.15 wt%, or 0.2 wt% to 0.4 wt%, 0.6 wt%, 0.8 wt%, 1 wt%, 2 wt%, 3 wt%, 4 wt%, 5 wt%, or 6 wt% of the Group 8-10 element based on the weight of the support.
- [0132] A9. The process of any of A1 to A8, wherein the Group 8-10 element comprises Pt.
- 10 [0133] A10. The process of any of A1 to A9, wherein the catalyst system further comprises an alkali metal element comprising Li, Na, K, Rb, Cs, a combination thereof, or a mixture thereof disposed on the support in an amount of up to 5 wt% based on the weight of the support.
- [0134] A11. The process of any of A1 to A10, wherein the catalyst system is in the form of particles having a size and particle density that is consistent with a Geldart A or Geldart B
- 15 definition of a fluidizable solid.
- [0135] A12. The process of any of A1 to A11, wherein a weight ratio of the Group 2 element to the Al in the support is in a range from 0.001, 0.01, 0.1, or 1 to 6, 12.5, 100, or 1,000.
- [0136] A13. The process of any of A1 to A12, wherein: the Group 2 element comprises Mg, and at least a portion of the Mg is in the form of MgO or a mixed metal oxide comprising Mg.
- 20 [0137] A14. The process of any of A1 to A13, wherein: the Group 2 element comprises Mg, and at least a portion of the Mg and at least a portion of the Al is in the form of a mixed Mg/Al metal oxide.
- [0138] A15. The process of any of A1 to A14, wherein: the Group 2 element comprises Mg, at least a portion of the Mg and at least a portion of the Al is in the form of a mixed Mg/Al
- 25 metal oxide, and a weight ratio of the Mg to the Al in the mixed Mg/Al metal oxide is in a range from 0.001, 0.01, 0.1, or 1 to 6, 12.5, 100, or 1,000.
- [0139] A16. The process of any of A1 to A15, wherein: at least a portion of the Group 2 element is in the form of an oxide of the Group 2 element, at least a portion of the Al is in the form Al_2O_3 , and the oxide of the Group 2 element and the Al_2O_3 are mixed on a nm scale.
- 30 [0140] A17. The process of any of A1 to A16, wherein: the Group 2 element comprises Mg, at least a portion of the Mg is in the form of MgO, at least a portion of the Al is in the form Al_2O_3 , and the oxide of the MgO and the Al_2O_3 are mixed on a nm scale.
- [0141] A18. The process of any of A1 to A17, further comprising at least one of: reacting at least a portion of the synthesis gas under effective Fischer-Tropsch conditions in the presence

of a Fischer-Tropsch catalyst to produce an upgraded product, wherein the Fischer-Tropsch catalyst comprises a shifting Fischer-Tropsch catalyst or a non-shifting Fischer-Tropsch catalyst; subjecting at least a portion of the synthesis gas to a fermentation process to produce an alcohol, an organic acid, or a mixture thereof; contacting at least a portion of the synthesis gas with a catalyst to produce at least one C₁-C₄ alcohol; and separating H₂ from the synthesis gas to produce a H₂-rich product.

[0142] Various terms have been defined above. To the extent a term used in a claim is not defined above, it should be given the broadest definition persons in the pertinent art have given that term as reflected in at least one printed publication or issued patent. Furthermore, all patents, test procedures, and other documents cited in this application are fully incorporated by reference to the extent such disclosure is not inconsistent with this application and for all jurisdictions in which such incorporation is permitted.

[0143] While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

CLAIMS:

What is claimed is:

1. A catalyst system comprising a plurality of catalytic particles and a plurality of catalytically inert particles configured to be mixed with one another or mixed with one another, wherein:

the catalytic particles comprise a Group 8-10 element and a first promoter comprising Sn, Cu, Au, Ag, Ga, a combination thereof, or a mixture thereof disposed on a support,

the catalytic particles comprise 0.001 wt% to 6 wt% of the Group 8-10 element, up to 10 wt% of the first promoter, and the support comprises Al and at least 0.5 wt% of a Group 2 element, based on the weight of the support,

the catalytically inert particles are free of a Group 8-10 element, and

a composition of the catalytically inert particles and a composition of the support is the same or different.

2. The catalyst system of claim 1, wherein the support comprises a first mixed Mg/Al metal oxide.

3. The catalyst system of claim 2, wherein a weight ratio of the Mg to the Al in the first mixed Mg/Al metal oxide is in a range from 0.001 to 1,000.

4. The catalyst system of any one of claims 1 to 3, wherein the catalytically inert particles comprise aluminum oxide, magnesium oxide, a second mixed Mg/Al metal oxide, or a mixture thereof.

5. The catalyst system of any one of claims 1 to 4, wherein the catalytic particles comprise < 0.2 wt% of Si based on the weight of the support, and wherein the catalytically inert particles comprise < 0.2 wt% of Si based on the weight of the catalytically inert particles.

6. The catalyst system of any one of claims 1 to 5, wherein the catalytically inert particles comprise a second promoter comprising Sn, Cu, Au, Ag, Ga, a combination thereof, or a mixture thereof disposed thereon, and wherein the catalytically inert

particles comprise up to 10 wt% of the second promoter, based on the weight of the catalytically inert particles prior to the addition of the second promoter thereto.

7. The catalyst system of claim 6, wherein the first promoter and the second promoter each comprise Sn.

8. The catalyst system of any one of claims 1 to 7, wherein the Group 8-10 element comprises Pt.

9. The catalyst system of claim 1, wherein:
the Group 8-10 element comprises Pt,
wherein the first promoter comprises Sn,
the support comprises a first mixed Mg/Al metal oxide,
the catalytically inert particles comprise a second mixed Mg/Al metal oxide,
a weight ratio of the Mg to the Al in the first mixed Mg/Al metal oxide and a weight ratio of the Mg to the Al in the second mixed Mg/Al metal oxide are independently in a range from 0.001 to 1,000,
the catalytically inert particles comprise a second promoter comprising Sn, Cu, Au, Ag, Ga, a combination thereof, or a mixture thereof disposed thereon, and
the catalytically inert particles comprise up to 10 wt% of the second promoter, based on the weight of the catalytically inert particles prior to the addition of the second promoter thereto.

10. The catalyst system of any one of claims 1 to 9, wherein a weight ratio of the catalytic particles to the catalytically inert particles is in a range from 0.01:1 to 1:0.01.

11. A process for upgrading a hydrocarbon, comprising:
contacting a hydrocarbon-containing feed with a catalyst system comprising a mixture of catalytic particles and catalytically inert particles to effect one or more of dehydrogenation, dehydroaromatization, and dehydrocyclization of at least a portion of the hydrocarbon-containing feed to produce a coked catalyst system and an effluent comprising one or more upgraded hydrocarbons and molecular hydrogen, wherein:

the hydrocarbon-containing feed comprises one or more of C₂-C₁₆ linear or branched alkanes, or one or more of C₄-C₁₆ cyclic alkanes, or one or more C₈-C₁₆ alkyl aromatics, or a mixture thereof,

the one or more upgraded hydrocarbons comprise at least one of a dehydrogenated hydrocarbon, a dehydroaromatized hydrocarbon, and a dehydrocyclized hydrocarbon,

the catalytic particles comprise a Group 8-10 element and a first promoter comprising Sn, Cu, Au, Ag, Ga, a combination thereof, or a mixture thereof disposed on a support,

the catalytic particles comprise 0.001 wt% to 6 wt% of the Group 8-10 element, up to 10 wt% of the first promoter, and the support comprises Al and at least 0.5 wt% of a Group 2 element, based on the weight of the support,

the catalytically inert particles are free of a Group 8-10 element, and

a composition of the catalytically inert particles and a composition of the support is the same or different.

12. The process of claim 11, wherein the mixture of catalytic particles and catalytically inert particles is disposed within a fixed bed within a reactor.

13. The process of claim 11, wherein the mixture of catalytic particles and the catalytically inert particles is in the form of fluidized particles disposed within a reactor.

14. The process of claim 13, wherein the catalytic particles and the catalytically inert particles are introduced into the reactor separately such that the mixture of the catalytic particles and the catalytically inert particles is formed within the reactor.

15. The process of claim 14, further comprising adjusting an amount of the catalytic particles, the catalytically inert particles, or both the catalytic particles and the catalytically inert particles during the contacting of the hydrocarbon-containing feed with the catalyst system.

16. The process of claim 15, wherein a weight ratio of the catalytic particles to the catalytically inert particles is in a range from 0.01:1 to 1:0.01.

17. The process of any one of claims 11 to 16, wherein the support comprises a first mixed Mg/Al metal oxide.

18. The process of claim 17, wherein a weight ratio of the Mg to the Al in the first mixed Mg/Al metal oxide is in a range from 0.001 to 1,000.

19. The process of any one of claims 11 to 17, wherein the catalytically inert particles comprise aluminum oxide, magnesium oxide, a second mixed Mg/Al metal oxide, or a mixture thereof.

20. The process of any one of claims 11 to 19, wherein:
the Group 8-10 element comprises Pt,
the first promoter comprises Sn,
the catalytically inert particles comprise aluminum oxide, magnesium oxide, a mixed Mg/Al metal oxide, or a mixture thereof,
the catalytic particles comprise < 0.2 wt% of Si based on the weight of the support,
the catalytically inert particles comprise < 0.2 wt% of Si based on the weight of the catalytically inert particles, and
the catalytically inert particles comprise a second promoter comprising Sn, Cu, Au, Ag, Ga, a combination thereof, or a mixture thereof disposed thereon, and
the catalytically inert particles comprise up to 10 wt% of the second promoter, based on the weight of the catalytically inert particles prior to the addition of the second promoter thereto.

21. The process of any one of claims 11 to 20, wherein the hydrocarbon-containing feed and the catalyst system are contacted at a temperature in a range of from 300°C to 900°C under a hydrocarbon partial pressure of at least 20 kPa-absolute, wherein the hydrocarbon partial pressure is the total partial pressure of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics in the hydrocarbon-containing feed.

22. The process of any one of claims 11 to 21, further comprising:
contacting at least a portion of the coked catalyst system with an oxidant to effect combustion of at least a portion of the coke to produce a regenerated catalyst system lean in coke and a combustion gas; and
contacting an additional quantity of the hydrocarbon-containing feed with at least a portion of the regenerated catalyst system to produce a re-coked catalyst system and additional effluent.
23. The process of claim 22, further comprising contacting at least a portion of the regenerated catalyst system lean in coke with a reducing gas to produce a regenerated and reduced catalyst system, wherein the additional quantity of the hydrocarbon-containing feed is contacted with at least a portion of the regenerated and reduced catalyst system to produce the re-coked catalyst system and the additional effluent.