

**PROCESSES FOR REGENERATING AND REDUCING CATALYSTS AND FOR
UPGRADING ALKANES AND/OR ALKYL AROMATIC HYDROCARBONS**

CROSS-REFERENCE TO RELATED APPLICATION

5 [0001] This application claims priority to and the benefit of U.S. Provisional Application No. 63/512,684 having a filing date of July 10, 2023, the disclosure of which is incorporated herein by reference in its entirety.

FIELD

10 [0002] This disclosure relates to processes for regenerating and reducing a catalyst and for upgrading alkanes and/or alkyl aromatic hydrocarbons.

BACKGROUND

[0003] Catalytic dehydrogenation, dehydroaromatization, and dehydrocyclization of alkane and/or alkyl aromatic hydrocarbons are industrially important chemical conversion processes that are endothermic and equilibrium limited. The dehydrogenation of alkanes, *e.g.*, C₂-C₁₂ 15 alkanes, and/or alkyl aromatics, *e.g.*, ethylbenzene, can be done through a variety of different supported catalyst systems such as the Pt-based, Cr-based, Ga-based, V-based, Zr-based, In-based, W-based, Mo-based, Zn-based, and Fe-based systems. Among the existing propane dehydrogenation processes, certain process uses an alumina supported chromia catalyst that provides one of the highest propylene yields of approximately 50% (55% propane conversion 20 at 90% propylene selectivity), which is obtained at a temperature of approximately 560°C to 650°C and at a low pressure of 20 kPa-absolute to 50 kPa-absolute. It is desirable to increase the propylene yield without having to operate at such low pressure to increase the efficiency of the dehydrogenation process.

[0004] Increasing the temperature of the dehydrogenation process is one way to increase the 25 conversion of the process according to the thermodynamics of the process. For example, at 670°C, 100 kPa-absolute, in the absence of any inert/diluent, the equilibrium propylene yield has been estimated via simulation to be approximately 74%. At such high temperature, however, the catalyst deactivates very rapidly and/or the propylene selectivity becomes uneconomically low. The rapid catalyst deactivation is believed to be caused by coke 30 depositing onto the catalyst and/or agglomeration of the active phase. Coke can be removed by combustion using an oxygen-containing gas, however, agglomeration of the active phase is believed to be exacerbated during the combustion process, which rapidly reduces the activity and stability of the catalyst.

[0005] There is a need, therefore, for improved processes for regenerating and reducing at least partially deactivated catalysts and processes for dehydrogenating, dehydroaromatizing, and/or dehydrocyclizing alkane and/or alkyl aromatic hydrocarbons. This disclosure satisfies this and other needs.

5 **SUMMARY**

[0006] Processes for regenerating and reducing an at least partially deactivated catalyst and processes for upgrading a hydrocarbon are provided. In some embodiments, the process can be used to regenerate and reduce an at least partially deactivated catalyst that can include a contaminant and a Group 10 element disposed on an inorganic support. The Group 10 element
10 can be present in an amount of from 0.001 wt% to 6 wt%, based on the weight of the inorganic support. The process can include (I) heating the at least partially deactivated catalyst by contacting the at least partially deactivated catalyst with a combustion product to produce a precursor catalyst. The combustion product can be produced by combusting a combustion mixture comprising a fuel and an oxidant. The combustion product, prior to, during, or after
15 contact with the at least partially deactivated catalyst, can include H₂O at a concentration of greater than 2 mol% and, optionally, O₂ at a concentration of less than 2 mol%, based on the total moles in the combustion product. The amount of O₂ in the combustion product, prior to, during, or after contact with the at least partially deactivated catalyst, can be maintained at the concentration of less than 2 mol% by controlling a molar ratio of the oxidant to the fuel in the
20 combustion mixture. The process can also include (II) providing an oxidative gas comprising no greater than 2 mol% of H₂O, based on the total moles in the oxidative gas. The process can also include (III) contacting the precursor catalyst with the oxidative gas at an oxidizing temperature in a range of from 620°C to 1,000°C for a duration of at least 30 seconds to produce a regenerated catalyst. The process can also include (IV) contacting the regenerated catalyst
25 with a H₂-containing gas at a reducing temperature in a range of from 620°C to 1,000°C for a duration of at least 0.1 seconds to produce a regenerated and reduced catalyst.

[0007] In other embodiments, a process for upgrading a hydrocarbon can include (I) contacting a hydrocarbon-containing feed with a catalyst that can include a Group 10 element disposed on an inorganic support to effect one or more of dehydrogenation,
30 dehydroaromatization, and dehydrocyclization of at least a portion of the hydrocarbon-containing feed to produce an at least partially deactivated catalyst that can include a contaminant and the Group 10 element disposed on the inorganic support 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, one or more C₈-C₁₆ alkyl aromatics, or a mixture thereof. The Group 10 element can have a concentration in the range of from 0.001 wt% to 6 wt%, based on the weight of the inorganic support. The hydrocarbon-containing feed and the catalyst can be contacted at a temperature in a range of from 300°C to 900°C. The one or more upgraded hydrocarbons can include at least one of a dehydrogenated hydrocarbon, a dehydroaromatized hydrocarbon, and a dehydrocyclized hydrocarbon. The process can also include (II) heating the at least partially deactivated catalyst by contacting the at least partially deactivated catalyst with a combustion product that can include H₂O at a concentration of greater than 2 mol% and, optionally, O₂ at a concentration of less than 2 mol%, based on the total moles in the combustion product to produce a precursor catalyst. The combustion product can be produced by combusting a combustion mixture that can include a fuel and an oxidant. The amount of O₂ in the combustion product can be maintained at the concentration of less than 2 mol% by controlling a molar ratio of the oxidant to the fuel in the combustion mixture. The process can also include (III) providing an oxidative gas that can include no greater than 2 mol% of H₂O, based on the total moles in the oxidative gas. The process can also include (IV) contacting the precursor catalyst at an oxidizing temperature in a range of from 620°C to 1,000°C with the oxidative gas for a duration of at least 30 seconds to produce a regenerated catalyst. The process can also include (V) contacting the regenerated catalyst with a H₂-containing gas at a reducing temperature in a range of from 620°C to 1,000°C for a duration of at least 0.1 seconds to produce a regenerated and reduced catalyst. The process can also include (VI) contacting an additional quantity of the hydrocarbon-containing feed with at least a portion of the regenerated and reduced catalyst to produce additional at least partially deactivated catalyst and additional effluent.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The Figure shows an illustrative system for regenerating an at least partially deactivated catalyst, according to one or more embodiments described.

DETAILED DESCRIPTION

[0009] 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.

[0010] 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.

[0011] 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.

[0012] 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.

[0013] 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 or 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.

[0014] 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 $m+2$,
5 ..., 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.
10 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
15 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).

[0015] 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
20 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
25 otherwise by the context.

[0016] 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.

[0017] The term “aromatic” is to be understood in accordance with its art-recognized scope,
30 which includes alkyl substituted and unsubstituted mono- and polynuclear compounds.

[0018] 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 lower than in the feed material fed to the same device from which the stream is derived.

[0019] 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 an Mg/Al hydrotalcite that has the general chemical formula $[Mg_{(1-x)}Al_x(OH)_2](A_x^{n-}) \cdot mH_2O$, where A is a counter anion of a negative charge n, x is in a range of from > 0 to < 1 , and m is ≥ 0 . 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.

[0020] 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.

[0021] 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, 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%. Yield (carbon mole basis) is conversion times selectivity.

[0022] 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).

Hydrocarbon Upgrading and Catalyst Regeneration Process

[0023] The 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
5 embodiments, the 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 hydrocarbon-containing feed. In other embodiments, the hydrocarbon-containing feed can include < 0.1 vol% of steam or can be free of steam, based on the total volume of any C₂-C₁₆
10 alkanes and any C₈-C₁₆ alkyl aromatics in the hydrocarbon-containing feed. The hydrocarbon-containing feed can be contacted with a catalyst that includes a Group 10 element, *e.g.*, Pt, disposed on an inorganic support, to effect one or more of dehydrogenation, dehydroaromatization, and dehydrocyclization of at least a portion of the hydrocarbon-containing feed to produce an at least partially deactivated catalyst that includes a contaminant, *e.g.*, coke, and the Group 10 element disposed on the inorganic support and an effluent that can
15 include one or more upgraded hydrocarbons and molecular hydrogen.

[0024] The one or more upgraded hydrocarbons can be or can include, but are not limited to, one or more dehydrogenated hydrocarbons, one or more dehydroaromatized hydrocarbons, one or more dehydrocyclized hydrocarbons, or a mixture thereof. The hydrocarbon-containing feed and catalyst can be contacted at a temperature in a range from 300°C to 900°C. In some
20 embodiments, the hydrocarbon-containing feed and catalyst can be contacted for a time period of ≤ 5 hours, ≤ 4 hours, or ≤ 3 hours, ≤ 1 hour, ≤ 0.5 hours, ≤ 0.1 hours, ≤ 3 minutes, ≤ 1 minute, ≤ 30 seconds, or ≤ 0.1 second. In some embodiments, the hydrocarbon-containing feed and catalyst 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
25 any C₈-C₁₆ alkyl aromatics in the hydrocarbon-containing feed. In some embodiments, the hydrocarbon-containing feed and catalyst can be contacted under a total pressure of at least atmospheric pressure. In some embodiments, the hydrocarbon-containing feed and catalyst can be contacted under a total pressure in a range of from 101 kPa-absolute, 110 kPa-absolute, or 120 kPa-absolute to 130 kPa-absolute, 140 kPa-absolute, 150 kPa-absolute, 160 kPa-
30 absolute, 170 kPa-absolute, 180 kPa-absolute, 190 kPa-absolute, 200 kPa-absolute, 225 kPa-absolute, 250 kPa-absolute, 275 kPa-absolute, or 300 kPa-absolute. The catalyst can include from 0.001 wt% to 6 wt% of the Group 10 element, *e.g.*, Pt, based on the weight of the inorganic support. The at least partially deactivated catalyst can be subjected to a regeneration and reducing process to produce a regenerated and reduced catalyst that can be further contacted

with an additional quantity of the hydrocarbon-containing feed to produce additional at least partially deactivated catalyst and additional effluent.

[0025] A precursor catalyst can be obtained from the at least partially deactivated catalyst. In some embodiments, the at least partially deactivated catalyst can be heated by contacting the at least partially deactivated catalyst with a combustion product to produce the precursor catalyst. The combustion product can be produced by combusting a combustion mixture that can include a fuel and an oxidant. The fuel can be or can include, but is not limited to, at least one of H₂, CO, a hydrocarbon, and the contaminant disposed on the inorganic support of the at least partially deactivated catalyst. In some embodiments, suitable hydrocarbons that can be used as the fuel can be or can include, but are not limited to methane, ethane, propane, butane, pentane, hexane, heptane, octane, nonane, decane, natural gas, fuel oil, heavy fuel oil, gasoline, diesel, kerosene, distillate(s), naphthalene, any other suitable hydrocarbon, and any mixture thereof. The oxidant can be or can include, but is not limited to, O₂, O₃, CO, or any mixture thereof.

[0026] It has been surprisingly and unexpectedly discovered that when contacting the at least partially deactivated catalyst with the combustion product to produce the precursor catalyst, the presence of a high amount (> 2 mol%, based on the total moles in the combustion product) of both H₂O and O₂ in the combustion product can significantly reduce the activity and/or selectivity of the regenerated and reduced catalyst. For example, if the amount of H₂O in the combustion product is > 2 mol%, then it is desirable for the amount of O₂ in the combustion product to be < 2 mol%, based on the total moles in the combustion product. In another example, if the amount of O₂ in the combustion product is > 2 mol%, then it is desirable for the amount of H₂O in the combustion product to be < 2 mol%, based on the total moles in the combustion product. Since most fuel contains hydrogen and it is generally undesirable to use an excessive amount of oxidant, it is more likely that the amount of H₂O in the combustion product will be > 2 mol%. Therefore, it is important to control the amount of oxidant so that the amount of O₂ in the combustion product can be < 2 mol%, based on the total moles in the combustion product. This can be achieved by using a stoichiometric rich or slightly lean combustion mixture. Without wishing to be bound by theory, it is believed that a combination of high levels of H₂O/O₂ can significantly reduce the effectiveness of the subsequent regeneration of the catalyst. In other embodiments, the at least partially deactivated catalyst can be contacted with a gas that includes O₂ and is free of or includes < 2 mol% of H₂O, based on the total moles in the gas, instead of the combustion product to produce the precursor catalyst. In such embodiments, i.e., when the at least partially deactivated catalyst is contacted

with a gas that includes O₂ and < 2 mol% of H₂O, such contact step can be sufficient to produce the regenerated catalyst that can then be contacted with a H₂-containing gas to produce the regenerated and reduced catalyst.

5 [0027] In some embodiments, the combustion product, prior to, during, or after contact with the at least partially deactivated catalyst, can include H₂O at a concentration of greater than 2 mol% and, optionally, O₂ at a concentration of less than 2 mol%, based on the total moles in the combustion product. The amount of O₂ in the combustion product, prior to, during, or after contact with the at least partially deactivated catalyst, can be maintained at the concentration of less than 2 mol% by controlling a molar ratio of the oxidant to the fuel in the combustion
10 mixture.

[0028] In some embodiments, the combustion product can be produced by combusting the combustion mixture in the presence of the at least partially deactivated catalyst. In other embodiments, the combustion product can be produced by combusting the combustion mixture prior to contacting the at least partially deactivated catalyst with the combustion product such
15 that the combustion product prior to contacting the at least partially deactivated catalyst can include greater than 2 mol% of H₂O and, optionally, less than 2 mol% of O₂. In still other embodiments, the combustion product can be produced by combusting a first portion of the combustion mixture prior to contacting the at least partially deactivated catalyst and combusting a second portion of the combustion mixture in the presence of the at least partially
20 deactivated catalyst to produce the combustion product and the precursor catalyst. In some embodiments, the combustion product or the dry, hot air can contact the partially deactivated catalyst for a duration of < 30 min, < 25 min, < 20 min, < 15 min, < 12 min, < 10 min, < 7 min, < 5 min, < 4 min, < 3 min, < 2.5 min, < 2 min, < 1.5 min, < 1 min, < 30 s, < 10 s, < 5 s, < 1 s, < 0.5 s, or < 0.1 s.

25 [0029] In some embodiments, the combustion product can include H₂O at a concentration in a range of from greater than 2 mol%, 2.5 mol%, 3 mol%, 3.5 mol%, 4 mol%, 4.5 mol%, 5 mol%, 5.5 mol%, 6 mol%, 6.5 mol%, 7 mol%, 8 mol%, 9 mol%, or 10 mol% to 11 mol%, 12 mol%, 15 mol%, 20 mol%, 25 mol%, 30 mol%, 35 mol%, 40 mol%, 45 mol%, 50 mol%, 55 mol%, or 60 mol%, based on the total moles in the combustion product. In some embodiments,
30 the combustion product can include H₂O at a concentration of greater than 2 mol% and O₂ at a concentration in a range of from 0.0001 mol%, 0.001 mol%, 0.01 mol%, 0.1 mol%, 0.2 mol%, 0.3 mol%, or 0.5 mol% to 0.7 mol%, 1 mol%, 1.3 mol%, 1.5 mol%, 1.7 mol%, or 1.9 mol%, based on the total moles in the combustion product to produce the precursor catalyst. In some embodiments, the combustion product can include H₂O at a concentration of greater than 2

mol% and can be free of any O₂, based on the total moles in the combustion product. In still other embodiments, the combustion product can include H₂O at a concentration of greater than 2 mol%, can be free of any O₂, and can include residual fuel, based on the total moles in the combustion product.

5 [0030] It should be understood that the composition of the combustion product during contact with the at least partially deactivated catalyst can be dynamic. For example, when the combustion mixture is combusted in the presence of the at least partially deactivated catalyst, the combustion mixture, prior to any combustion, can contain greater than 2 mol% of O₂ and can contain less than 2 mol% or greater than 2 mol% of H₂O. As the combustion mixture
10 combusts to produce the combustion product that heats the at least partially deactivated catalyst, the amount of O₂ can decrease to less than 2 mol% and the amount of H₂O can increase such that the combustion product just after contacting with the at least partially deactivated catalyst can contain greater than 2 mol% of H₂O and less than 2 mol% of O₂. For example, in a fixed-bed reactor, the combustion product that includes greater than 2 mol% of H₂O and, optionally,
15 less than 2 mol% of O₂ would be the combustion product right before exiting the reactor. In another example, in a fluidized reactor system that includes a regeneration system that includes an upward flowing riser, the combustion product that includes greater than 2 mol% of H₂O and, optionally, less than 2 mol% of O₂ would be the combustion product upon exiting from a riser termination separator located at the top of the upward flowing riser and into a primary
20 separation device. An illustrative regeneration system that includes an upward flowing riser is shown and described in more detail below with reference to the FIG.

[0031] An oxidative gas that includes no greater than 2 mol% of H₂O can be provided and contacted with the precursor catalyst to produce a regenerated catalyst. In some embodiments, the oxidative gas can include no greater than 2 mol% of H₂O, no greater than 1.9 mol% of H₂O,
25 no greater than 1.7 mol% of H₂O, no greater than 1.5 mol% of H₂O, no greater than 1.3 mol% of H₂O, no greater than 1 mol% of H₂O, no greater than 0.7 mol% of H₂O, no greater than 0.5 mol% of H₂O, no greater than 0.3 mol% of H₂O, or no greater than 0.1 mol% of H₂O, based on the total moles in the oxidative gas.

[0032] It has been surprisingly and unexpectedly discovered that contacting the precursor
30 catalyst with the oxidative gas that includes no greater than 2 mol% of H₂O can significantly improve the activity and/or selectivity of the regenerated catalyst. Without wishing to be bound by theory, it is believed that the Group 10 element, e.g., Pt, is re-dispersed during regeneration and a combination of high amounts of O₂, e.g., greater than 2 mol%, and greater than 2 mol% of H₂O present in the oxidative gas can significantly reduce the effectiveness of the re-

dispersion of the group 10 element and hence the effectiveness of the regenerated catalyst. Re-dispersing at least a portion of the Group 10 element can increase the activity and improve the stability of the catalyst over many cycles.

[0033] The precursor catalyst can be contacted with the oxidative gas at an oxidizing temperature in a range of from 620°C, 650°C, 675°C, 700°C, or 750°C to 775°C, 800°C, 850°C, 900°C, 950°C, or 1,000°C to produce a regenerated catalyst. In some embodiments, the oxidative gas can be or can include, but is not limited to, O₂, O₃, CO, or a mixture thereof. The precursor catalyst can be contacted with the oxidative gas for a duration of at least 30 seconds, at least 1 minute, at least 5 minutes, at least 7 minutes, at least 10 minutes, at least 15 minutes, at least 20 minutes, at least 25 minutes, or at least 30 minutes to produce the regenerated catalyst. In some embodiments, the precursor catalyst can be contacted with the oxidative gas for a duration in a range of from 30 seconds, 1 minute, 5 minutes, or 10 minutes to 30 minutes, 60 minutes, or 120 minutes to produce the regenerated catalyst. In some embodiments, the precursor catalyst and the oxidative gas can be contacted with one another for a duration of ≤ 2 hours, ≤ 1 hour, ≤ 30 minutes, ≤ 10 minutes, ≤ 5 minutes, ≤ 1 min, ≤ 30 seconds, ≤ 10 seconds, ≤ 5 seconds, or ≤ 1 second to produce the regenerated catalyst. For example, the precursor catalyst and the oxidative gas can be contacted with one another for a duration in a range from 2 seconds to 2 hours to produce the regenerated catalyst. In some embodiments, the precursor catalyst and oxidative gas can be contacted for a duration sufficient to remove ≥ 50 wt%, ≥ 75 wt%, ≥ 90 wt% or > 99 wt% of the contaminant, e.g., coke disposed on the precursor catalyst.

[0034] The precursor catalyst and the oxidative gas can be contacted with one another under an oxidative gas partial pressure in a range from 5 kPa-absolute, 10 kPa-absolute, 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 to produce the regenerated catalyst. In some embodiments, the oxidative gas partial pressure during contact with the precursor catalyst can be in a range from 5 kPa-absolute, 10 kPa-absolute, 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.

[0035] In some embodiments, the oxidative gas can be provided at a temperature below the oxidizing temperature and the oxidative gas can be pre-heated to a temperature higher than the temperature of the precursor catalyst before contacting the precursor catalyst with the oxidative gas at the oxidizing temperature. In some embodiments, the oxidative gas can be pre-heated

by using a radiant/conductive heat source, a heat exchanger, or a combination thereof. In other embodiments, the oxidative gas, the precursor catalyst, or both the oxidative gas and the precursor catalyst can be heated by using a radiant/conductive heat source, a heat exchanger, or a combination thereof. In other words, the precursor catalyst and/or the oxidative gas can be heated separately and then contacted with one another at the oxidizing temperature or heated in the presence of one another to the oxidizing temperature. In some embodiments, the radiant/conductive heat source can be or can include one or more electric heating elements.

[0036] In some embodiments, the regenerated catalyst can be provided directly as the regenerated catalyst. In some embodiments, the regenerated catalyst can optionally be contacted with a first stripping gas that can be free of O₂ to produce a stripped regenerated catalyst. The first stripping gas can be or can include, but is not limited to, CO, CO₂, N₂, a C₁-C₄ hydrocarbon, H₂O, He, Ne, Ar, or any mixture thereof.

[0037] In some embodiments, at least a portion of the Group 10 element, e.g., Pt, in the regenerated catalyst or the stripped regenerated catalyst can be at a higher oxidized state as compared to the Group 10 element in the catalyst contacted with the hydrocarbon-containing feed and as compared to the Group 10 element in the at least partially deactivated catalyst. In some embodiments, the regenerated catalyst or the stripped regenerated catalyst can be contacted with a H₂-containing gas to produce a reduced catalyst. In other embodiments, the regenerated catalyst or the stripped regenerated catalyst can be contacted with an atmosphere containing H₂, CO, CH₄, C₂H₆, C₃H₈, C₂H₄, C₃H₆, steam, or a mixture thereof to produce the reduced catalyst. In some embodiments, the atmosphere contacted with the regenerated catalyst or the stripped regenerated catalyst can also include 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 10 element in the reduced catalyst can be reduced to a lower oxidation state, e.g., the elemental state, as compared to the Group 10 element in the regenerated catalyst or the stripped regenerated catalyst.

[0038] In some embodiments, the regenerated catalyst or the stripped regenerated catalyst can be contacted with the H₂-containing gas or the atmosphere containing H₂, CO, CH₄, C₂H₆, C₃H₈, C₂H₄, C₃H₆, steam, or a mixture thereof 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 to produce a regenerated and reduced catalyst. The regenerated catalyst or the stripped regenerated catalyst and the H₂-containing gas or the atmosphere containing H₂, CO, CH₄, C₂H₆, C₃H₈, C₂H₄, C₃H₆, steam, or a mixture thereof can be contacted for a duration in a range from 0.01 seconds, 0.1 seconds, 1 second, 5 seconds, 10 seconds, 20 seconds, 30 seconds, or 1 minute to

10 minutes, 30 minutes, or 60 minutes. The regenerated catalyst or the stripped regenerated catalyst and the H₂-containing gas or the atmosphere containing H₂, CO, CH₄, C₂H₆, C₃H₈, C₂H₄, C₃H₆, steam, or a mixture thereof can be contacted at a reducing agent partial pressure of 0.1 kPa-absolute, 1 kPa-absolute, 5 kPa-absolute, 10 kPa-absolute, 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, where the reducing agent includes any H₂, CO, CH₄, C₂H₆, C₃H₈, C₂H₄, C₃H₆, and steam. In other embodiments, the reducing agent partial pressure can be in a range from 0.1 kPa-absolute, 1 kPa-absolute, 5 kPa-absolute, 10 kPa-absolute, 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 and reduced catalyst, where the reducing agent includes any H₂, CO, CH₄, C₂H₆, C₃H₈, C₂H₄, C₃H₆, and steam.

15 [0039] In some embodiments, the regenerated catalyst or the stripped regenerated precursor catalyst can be contacted with the H₂-containing gas at a temperature higher than a use temperature of the regenerated catalyst or the stripped regenerated catalyst. In such embodiment, the regenerated and reduced catalyst can be cooled to the use temperature. In some embodiments, the regenerated and reduced catalyst can be cooled to the use temperature

20 in a duration no greater than 20 minutes, no greater than 15 minutes, no greater than 10 minutes, no greater than 7 minutes, no greater than 5 minutes, no greater than 2 minutes, no greater than 1 minute, no greater than 30 seconds, no greater than 10 seconds, no greater than 5 seconds, no greater than 2 seconds, no greater than 1 second, no greater than 0.1 seconds, no greater than 0.01 seconds, or no greater than 0.001 seconds. The use temperature of the regenerated and

25 reduced catalyst is the temperature at which the hydrocarbon-containing feed or the additional quantity of the hydrocarbon-containing feed is contacted with the catalyst or the regenerated and reduced catalyst to effect one or more of dehydrogenation, dehydroaromatization, and dehydrocyclization of at least a portion of the hydrocarbon-containing feed to produce the at least partially deactivated catalyst and the effluent that can include the one or more upgraded

30 hydrocarbons and molecular hydrogen. In some embodiments, the H₂ can be free or substantially free of contaminants, excluding inerts such as N₂, Ar, and/or He. For example, the H₂ can include < 1,000 ppm, < 750 ppm, < 500 ppm, < 250 ppm, < 100 ppm, < 75 ppm, < 50 ppm, < 25 ppm, < 10 ppm, or < 1 ppm of hydrocarbon(s). In another example, the H₂ can

include < 20 mol%, < 15 mol%, < 10 mol%, < 5 mol%, < 3 mol%, < 2 mol%, < 1.6 mol%, < 0.8 mol%, < 0.4 mol%, < 0.2 mol%, < 0.1 mol%, or < 0.05 mol% of steam.

[0040] In some embodiments, the regenerated and reduced catalyst can be provided directly as the regenerated and reduced catalyst. In other embodiments, the regenerated and reduced catalyst can be contacted with a second stripping gas to produce a stripped regenerated and reduced catalyst. The second stripping gas can be or can include, but is not limited to, CO, CO₂, N₂, a C₁-C₄ hydrocarbon, H₂O, He, Ne, Ar, or any mixture thereof.

[0041] At least a portion of the regenerated and reduced catalyst, the stripped regenerated and reduced catalyst, new or fresh catalyst, or a mixture thereof can be contacted with the additional quantity of the hydrocarbon-containing feed within the reaction or conversion zone to produce additional effluent and additional at least partially deactivated catalyst. The cycle time from contacting the hydrocarbon-containing feed with fresh or new catalyst, the regenerated and reduced catalyst, the stripped regenerated and reduced catalyst or a mixture thereof to the contacting of the additional quantity of the hydrocarbon-containing feed with at least a portion of the regenerated and reduced catalyst, the stripped regenerated and reduced catalyst, and optionally with new or fresh catalyst can be ≤ 5 hours, ≤ 4.5 hours, ≤ 4 hours, ≤ 3.5 hours, ≤ 3 hours, ≤ 2.5 hours, ≤ 2 hours, ≤ 1 hour, ≤ 45 minutes, ≤ 30 minutes, ≤ 25 minutes, ≤ 20 minutes, ≤ 15 minutes, ≤ 10 minutes, ≤ 6 minutes, ≤ 3 minutes, ≤ 2 minutes, ≤ 1 minute, or ≤ 0.6 seconds.

[0042] The first cycle begins upon contact of the new or fresh catalyst and/or the regenerated and reduced catalyst and/or the stripped regenerated and reduced catalyst with the hydrocarbon-containing feed, followed by contact with the combustion product, followed by contact with the oxidative gas, followed by contact with the H₂-containing gas and the first cycle ends upon contact of the regenerated and reduced catalyst with the additional quantity of the hydrocarbon-containing feed. If the first stripping gas and/or the second stripping gas or any other stripping gas(es) are utilized between flows of the hydrocarbon-containing feed and the combustion product, between combustion product and the oxidative gas, between the oxidative gas and the reducing gas, and/or between the reducing gas and the additional quantity of the 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 hydrocarbon-containing feed with the catalyst to the contacting the additional quantity of the hydrocarbon-containing feed with the regenerated and reduced catalyst or the stripped regenerated and reduced catalyst can be ≤ 5 hours.

[0043] The catalyst that includes a Group 10 element, e.g., Pt, and the inorganic support 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 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, 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 hydrocarbon-containing feed includes propane, at an upgraded hydrocarbon selectivity, e.g., propylene, of $\geq 75\%$, $\geq 80\%$, $\geq 85\%$, $\geq 90\%$, or $> 95\%$ when initially contacted with the 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%, 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 $\geq 75\%$, $\geq 80\%$, $\geq 85\%$, $\geq 90\%$, or $\geq 95\%$.

[0044] In some embodiments, when the hydrocarbon-containing feed includes propane and the upgraded hydrocarbon includes propylene, contacting the hydrocarbon-containing feed with the catalyst can produce a propylene yield of $> 45\%$, $\geq 46\%$, $\geq 47\%$, $\geq 48\%$, $\geq 49\%$, $\geq 50\%$, $\geq 51\%$, $\geq 52\%$, $\geq 53\%$, $\geq 54\%$, $\geq 55\%$, $\geq 56\%$, $\geq 57\%$, $\geq 58\%$, $\geq 59\%$, $\geq 60\%$, $\geq 61\%$, $\geq 62\%$, $\geq 63\%$, $\geq 64\%$, $\geq 65\%$, or $\geq 66\%$ at a propylene selectivity of $\geq 75\%$, $\geq 80\%$, $\geq 85\%$, $\geq 90\%$, $\geq 93\%$, or $\geq 95\%$. In some embodiments, when the hydrocarbon-containing feed includes propane and the upgraded hydrocarbon includes propylene, contacting the hydrocarbon-containing feed with the catalyst can produce a propylene yield of at least 45%, at least 46%, at least 47%, at least 48%, at least 49%, at least 50%, at least 51%, at least 52%, at least 53%, at least 55%, at least 57%, at least 60%, at least 62%, at least 63%, at least 64%, at least 65%, at or at least 66% at a propylene selectivity of at least 75%, at least 80%, at least 85%, at least 90%, or at least 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 embodiments, when the hydrocarbon-containing feed includes at least 70 vol%, at least 75 vol%, at least 80 vol%, at least 85 vol%, at least 90 vol%, or at least 95 vol% of propane, based on a total volume of the hydrocarbon-containing feed, is contacted

under a propane partial pressure of at least 20 kPa-absolute, a propylene yield of at least 45%, at least 46%, at least 47%, at least 48%, at least 49%, at least 50%, at least 51%, at least 52%, at least 53%, at least 55%, at least 57%, at least 60%, at least 62%, at least 63%, at least 64%, at least 65%, or at least 66% at a propylene selectivity of at least 75%, at least 80%, at least 85%, at least 90%, or at least 95% can be obtained 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. It is believed that the propylene yield can be further increased to at least 67%, at least 68%, at least 70%, at least 72%, at least 75%, at least 77%, at least 80%, or at least 82% at a propylene selectivity of at least 75%, at least 80%, at least 85%, at least 90%, or at least 95% for at least 15 cycles, 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 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 is contacted with the hydrocarbon-containing feed at a temperature of at least 620°C, at least 630°C, at least 640°C, at least 650°C, at least 655°C, at least 660°C, at least 670°C, at least 680°C, at least 690°C, at least 700°C, or at least 750°C 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.

[0045] 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.

Catalyst

[0046] The catalyst 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%, 0.075 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 the Group 10 element disposed on the inorganic support, based on the weight of the inorganic support. In some embodiments, the catalyst composition can include ≤ 5.5 wt%, ≤ 4.5 wt%, ≤ 3.5 wt%, ≤ 2.5 wt%, ≤ 1.5 wt%, ≤ 1 wt%, ≤ 0.9 wt%, ≤ 0.8

wt%, ≤ 0.7 wt%, ≤ 0.6 wt%, ≤ 0.5 wt%, ≤ 0.4 wt%, ≤ 0.3 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%, ≤ 0.009 wt%, ≤ 0.008 wt%, ≤ 0.007 wt%, ≤ 0.006 wt%, ≤ 0.005 wt%, ≤ 0.004 wt%, ≤ 0.003 wt%, or ≤ 0.002 wt% of the Group 10 element disposed on the inorganic support, based on the weight of the inorganic support. In some embodiments, the catalyst can include > 0.001 , > 0.003 wt%, > 0.005 wt%, > 0.007 , > 0.009 wt%, > 0.01 wt%, > 0.02 wt%, > 0.04 wt%, > 0.06 wt%, > 0.08 wt%, > 0.1 wt%, > 0.13 wt%, > 0.15 wt%, > 0.17 wt%, > 0.2 wt%, > 0.23 , > 0.25 wt%, > 0.27 wt%, or > 0.3 wt% and < 0.5 wt%, < 1 wt%, < 2 wt%, < 3 wt%, < 4 wt%, < 5 wt%, or < 6 wt% of the Group 10 element disposed on the inorganic support, based on the weight of the inorganic support. In some embodiments, the Group 10 element can be or can include Ni, Pd, Pt, a combination thereof, or a mixture thereof. In at least one embodiment, the Group 10 element can be or can include Pt. If two or more Group 10 elements are disposed on the inorganic support, the catalyst 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%, 0.075 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 10 elements disposed on the inorganic support, based on the weight of the inorganic support. In some embodiments, an active component of the regenerated catalyst that can be capable of effecting one or more of dehydrogenation, dehydroaromatization, and dehydrocyclization of the hydrocarbon-containing feed that includes one or more of C₂-C₁₆ linear or branched alkanes, or one or more of C₄-C₁₆ cyclic alkanes, one or more C₈-C₁₆ alkyl aromatics, or a mixture thereof can include the group 10 element.

[0047] In some embodiments, the inorganic support can be or can include, but is not limited to, one or more Group 2 elements, a combination thereof, or a mixture thereof. In some embodiments, the Group 2 element can be present in its elemental form. In other embodiments, the Group 2 element can be present in the form of a compound. For example, the Group 2 element can be present as an oxide, 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, or a silicide. In some embodiments, a mixture of any two or more compounds that include the Group 2 element can be present in different forms. For example, a first compound can be an oxide and a second

compound can be an aluminate where the first compound and the second compound include the same or different Group 2 element, with respect to one another.

[0048] In some embodiments, the inorganic support can include ≥ 0.5 wt%, ≥ 1 wt%, ≥ 2 wt%, ≥ 3 wt%, ≥ 4 wt%, ≥ 5 wt%, ≥ 6 wt%, ≥ 7 wt%, ≥ 8 wt%, ≥ 9 wt%, ≥ 10 wt%, ≥ 11 wt%,
 5 ≥ 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 inorganic support. In some embodiments, the inorganic support can
 10 include the Group 2 element in a range of from 0.5 wt%, 1 wt%, 2 wt%, 2.5 wt%, 3 wt%, 5 wt%, 7 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 inorganic support. In some
 15 embodiments, a molar ratio of the Group 2 element to the Group 10 element 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, 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.

20 [0049] In some embodiments, the inorganic support can include the Group 2 element and Al and can be in the form of a mixed Group 2 element/Al metal oxide that has O, Mg, and Al atoms mixed on an atomic scale. In some embodiments the inorganic support can be or can include the Group 2 element and Al in the form of an oxide or one or more oxides of the Group
 25 2 element and Al_2O_3 that can be mixed on a nm scale. In some embodiments, the inorganic support can be or can include an oxide of the Group 2 element, e.g., MgO , and Al_2O_3 mixed on a nm scale.

[0050] In some embodiments, the inorganic support can be or can include a first quantity of the Group 2 element and 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
 30 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.

[0051] In other embodiments, the inorganic support can be or can include a first quantity of the Group 2 element and a first quantity of 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 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 Group 2 element/Al metal oxide can be mixed on the atomic scale.

[0052] In some embodiments, when the inorganic support includes the Group 2 element and Al, a weight ratio of the Group 2 element to the Al in the inorganic 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 inorganic support includes Al, the inorganic 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 inorganic support.

[0053] In some embodiments, the inorganic support can be or can include, but is not limited to, one or more of the following compounds: $\text{Mg}_w\text{Al}_2\text{O}_{3+w}$, where w is a positive number; $\text{Ca}_x\text{Al}_2\text{O}_{3+x}$, where x is a positive number; $\text{Sr}_y\text{Al}_2\text{O}_{3+y}$, where y is a positive number; $\text{Ba}_z\text{Al}_2\text{O}_{3+z}$, where z is a positive number. BeO ; MgO ; CaO ; BaO ; SrO ; BeCO_3 ; MgCO_3 ; CaCO_3 ; SrCO_3 ; BaCO_3 ; CaZrO_3 ; $\text{Ca}_7\text{ZrAl}_6\text{O}_{18}$; CaTiO_3 ; $\text{Ca}_7\text{Al}_6\text{O}_{18}$; $\text{Ca}_7\text{HfAl}_6\text{O}_{18}$; BaCeO_3 ; one or more magnesium chromates, one or more magnesium tungstates, one or more magnesium molybdates, combinations thereof, and mixtures thereof. 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 oxide that includes MgO . In some embodiments, the inorganic support can be or can include, but is not limited to, a $\text{MgO-Al}_2\text{O}_3$ mixed metal oxide. In some embodiments, when the inorganic support is a $\text{MgO-Al}_2\text{O}_3$ mixed metal oxide, the inorganic support can have a molar ratio of Mg to Al equal to 20, 10, 5, 2, 1 to 0.5, 0.1, or 0.01.

[0054] The $\text{Mg}_w\text{Al}_2\text{O}_{3+w}$, where w is a positive number, if present as the inorganic support or as a component of the inorganic 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 $\text{Mg}_w\text{Al}_2\text{O}_{3+w}$ can include MgAl_2O_4 , $\text{Mg}_2\text{Al}_2\text{O}_5$, or a mixture thereof. The $\text{Ca}_x\text{Al}_2\text{O}_{3+x}$, where x is a positive number, if present as the inorganic support or as a component of the inorganic 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 $\text{Ca}_x\text{Al}_2\text{O}_{3+x}$ 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 $\text{Sr}_y\text{Al}_2\text{O}_{3+y}$, where y is a positive number, if present as the inorganic support or as a component of the inorganic 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 $\text{Ba}_z\text{Al}_2\text{O}_{3+z}$, where z is a positive number, if present as the inorganic support or as a component of the inorganic support can have a molar ratio of Ba to Al 0.05, 0.3, or 0.6 to 0.9, 1.5, or 3.

[0055] In some embodiments, the inorganic support can also include one or more promoters disposed thereon. The promoter can be or can include, but is not limited to, Sn, Ag, Cu, a combination thereof, or a mixture thereof. In some embodiments, the promoter can be associated with the Group 10 element, e.g., Pt. For example, the promoter and the Group 10 element disposed on the inorganic support can form Group 10 element-promoter clusters that can be dispersed on the inorganic support. The promoter, if present, can improve the selectivity/activity/longevity of the catalyst for a given upgraded hydrocarbon. In some embodiments, the addition of the promoter can improve the propylene selectivity of the catalyst when the hydrocarbon-containing feed includes propane. The catalyst can include the promoter in an amount of 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 3 wt%, 5 wt%, 7 wt%, or 10 wt%, based on the weight of the inorganic support.

[0056] In some embodiments, the inorganic support can also include one or more alkali metal elements disposed thereon. The alkali metal element, if present, can be or can include, but is not limited to, Li, Na, K, Rb, Cs, 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. The alkali metal element, if present, can improve the selectivity of the catalyst for a given upgraded hydrocarbon. The catalyst can include the alkali metal element in an amount 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%, based on the weight of the inorganic support. In some embodiments, suitable catalyst can include those described in U.S. Patent Nos.: 5,073,662 and 6,313,063; U.S. Patent Application Publication Nos: 2011/0301392 and 2005/0003960; and European Patent Application Publication Nos.: EP0486993A1 and EP1073516A1.

[0057] In some embodiments, the inorganic support can also include, but is not limited to, at least one metal element and/or at least one metalloid element selected from Groups other than Group 2 and Group 10 and/or at least one compound thereof, where the at least one metal element and/or at least one metalloid element is not Li, Na, K, Rb, Cs, Sn, Ag, Cu. If the support also includes a compound that includes the metal element and/or metalloid element selected from Groups other than Group 2 and Group 10, where the at least one metal element

and/or at least one metalloid element is not Li, Na, K, Rb, Cs, Sn, Ag, or Cu, the compound can be present in the support as an oxide, 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, or a silicide. In some embodiments, suitable compounds that include the metal element and/or metalloid element selected from Groups other than Group 2 and Group 10, where the at least one metal element and/or at least one metalloid element is not Li, Na, K, Rb, Cs, Sn, Ag, or Cu, can be or can include, but are not limited to, one or more of the following: B_2O_3 , $AlBO_3$, Al_2O_3 , SiO_2 , SiC , Si_3N_4 , an aluminosilicate, 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.

[0058] The preparation of the inorganic support can be accomplished via any known process. For simplicity and ease of description, the preparation of a suitable inorganic support that includes a mixed oxide of magnesium and aluminum ($Mg(Al)O$ or MgO/Al_2O_3) inorganic support will be described in more detail. Catalyst synthesis techniques are well-known, and the following description is for illustrative purposes and not to be considered as limiting the synthesis of the inorganic support or the catalyst. In some embodiments, to make the MgO/Al_2O_3 mixed oxide inorganic support, Mg and Al precursors can be mixed together, e.g., ball-milled, followed by calcination. In some embodiments, the Mg precursor can be or can include, but is not limited to, magnesium nitrate, a hydrated magnesium nitrate having a formula of $Mg(NO_3)_2(H_2O)_x$, where $x = 6$ or 2 ; a magnesium oxide; a magnesium hydroxide; hydromagnesite (a hydrated magnesium carbonate mineral, $Mg_5(CO_3)_4(OH)_2 \cdot 4H_2O$); a magnesium salt; a magnesium-containing clay; or a mixture thereof. In some embodiments, the Al precursor can be or can include, but is not limited to, aluminum nitrate, a hydrated aluminum nitrate having a formula of $Al(NO_3)_3(H_2O)_9$; aluminum oxide; $(NaAlCO_3(OH)_2 \cdot (Al_5(CO_3)(OH)_{13} \cdot 5(H_2O)))$; $(Al_{14}(CO_3)_3(OH)_{36} \cdot nH_2O)$; $AlCl_3$; a mixture thereof.

[0059] In another embodiment, the two precursors can be dissolved in H_2O , stirred until dry (with heat optionally applied), followed by calcination to produce the inorganic support. In another embodiment, the two precursors can be dissolved in H_2O , followed by the addition of a base and a carbonate, e.g., $NaOH/Na_2CO_3$, to produce hydrotalcite, followed by calcination to produce the inorganic support. In another embodiment, a commercial ready MgO and Al_2O_3 may be mixed and ball-milled to produce the inorganic support. In another embodiment, the $Mg(NO_3)_2$ precursor can be dissolved in H_2O and the solution can be impregnated onto an

existing inorganic support, e.g., an Al_2O_3 inorganic support, that can be dried and calcined to produce the inorganic support. In another embodiment, Mg from $\text{Mg}(\text{NO}_3)_2$ can be loaded onto an existing Al_2O_3 inorganic support through ion adsorption, followed by liquid-solid separation, drying and calcination to produce the inorganic support. Without wishing to be bound by theory, it is believed that the inorganic support produced via any one of the above methods and/or other methods can include (i) the Mg and Al mixed together on the nm scale, (ii) the Mg and Al in the form of a mixed Mg/Al metal oxide, or (iii) a combination of (i) and (ii).

[0060] Group 10 metals and any promoter and/or any alkali metal element may be loaded onto the mixed oxide inorganic support by any known technique. For example, one or more Group 10 element precursors, e.g., chloroplatinic acid, tetramineplatinum nitrate, and/or tetramineplatinum hydroxide, one or more promoter precursors (if used), e.g., a salt such as SnCl_4 and/or AgNO_3 , and one or more alkali metal element precursors (if used), e.g., KNO_3 , KCl , and/or NaCl , can be dissolved in water. The solution can be impregnated onto the inorganic support, followed by drying and calcination. In some embodiments, the Group 10 element precursor and optionally the promoter precursor and/or the alkali metal element precursor can be loaded onto the inorganic support at the same time, or separately in a sequence separated by drying and/or calcination steps. In other embodiments, the Group 10 element and, optionally the promoter and/or alkali metal element, can be loaded onto the inorganic support by chemical vapor deposition, where the precursors are volatilized and deposited onto the inorganic support, followed by calcination. In other embodiments, the Group 10 element precursor and, optionally, the promoter precursor and/or alkali metal precursor, can be loaded onto the inorganic support through ion adsorption, followed by liquid-solid separation, drying and calcination. Optionally, the catalyst can also be synthesized using a one-pot synthesis method where the precursors of the inorganic support, the Group 10 metal active phase and the promoters are all mixed together, dry or wet, with or without any other additives to aid the synthesis, followed by drying and calcination.

[0061] Suitable processes that can be used to prepare the catalysts disclosed herein can include the processes described in U.S. Patent Nos. 4,788,371; 4,962,265; 5,922,925; 8,653,317; EP Patent No. EP0098622; Journal of Catalysis 94 (1985), pp. 547-557; and/or Applied Catalysis 54 (1989), pp. 79-90.

[0062] The as-synthesized catalyst, when examined under scanning electron microscope or transmission electron microscope, can appear as either primary particles, as agglomerates of primary particles, as aggregated primary particles, or a combination thereof. The primary particles in the as-synthesized catalyst, when examined under scanning electron microscope or

transmission electron microscope, can have an average particle size, *e.g.*, a diameter when spherical, in a range from 0.2 nm, 0.5 nm, 1 nm, 5 nm, 10 nm, 25 nm, 30 nm, 40 nm, 50 nm, 60 nm, 70 nm, 80 nm, 90 nm, 100 nm, 150 nm, 200 nm, 250 nm, 300 nm, 350 nm, 400 nm, 450 nm, or 500 nm to 1 μ m, 10 μ m, 25 μ m, 50 μ m, 100 μ m, 150 μ m, 200 μ m, 250 μ m, 300 μ m, 400 μ m, or 500 μ m. In some embodiments, the catalyst particles can have an average cross-sectional length of 0.2 nm to 500 μ m, 0.5 nm to 300 μ m, 1 nm to 200 μ m, 2 nm to 100 μ m, or 2 nm to 500 nm as measured by a transmission electron microscope.

[0063] The catalyst 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 catalyst 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.

[0064] In some embodiments, the inorganic support can be extruded or otherwise formed into any desired monolithic structure and the Group 10 element and any optional promoter and/or alkali metal element can be disposed thereon. Suitable monolithic structures can be or can include, but are not limited to, structures having a plurality of substantially parallel internal passages such as those in the form of a ceramic honeycomb. In some embodiments, the support can be in the form of beads, spheres, rings, toroidal shapes, irregular shapes, rods, cylinders, flakes, films, cubes, polygonal geometric shapes, sheets, fibers, coils, helices, meshes, sintered porous masses, granules, pellets, tablets, powders, particulates, extrudates, cloth or web form materials, honeycomb matrix monolith, including in comminuted or crushed forms, and the Group 10 element and any optional promoter and/or alkali metal element can be disposed thereon.

[0065] The as-synthesized catalyst can be formulated into one or more appropriate forms for different short cycle (≤ 5 hours) hydrocarbon upgrading processes. Alternatively, the support can be formulated into appropriate forms for different short cycle hydrocarbon upgrading processes, before the addition of the Group 10 element and, any optional promoter and/or alkali metal element. During formulation, one or more binders and/or additives can be added to the catalyst and/or support to improve the chemical/physical properties of the catalyst. For example, spray-dried catalyst particles having an average cross-sectional diameter in a range from 40 μ m to 100 μ m are typically used in an FCC type fluid-bed reactor. To make spray-

dried catalyst, the support/catalyst needs to be made into a slurry with binder/additive in the slurry before spray-drying and calcination.

Hydrocarbon Upgrading Process

[0066] Returning to the hydrocarbon upgrading process, the hydrocarbon-containing feed and the catalyst and/or at least a portion of the regenerated and reduced catalyst 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 at least partially deactivated catalyst. In some embodiments, 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.

[0067] The hydrocarbon-containing feed and catalyst and/or at least a portion of the regenerated and reduced catalyst can be contacted at a temperature in a range from 300°C, 350°C, 400°C, 450°C, 500°C, 550°C, 600°C, 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 hydrocarbon-containing feed and catalyst and/or at least a portion of the regenerated and reduced catalyst 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 hydrocarbon-containing feed can be introduced into the reaction or conversion zone and contacted with the catalyst and/or at least a portion of the regenerated and reduced catalyst 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, ≤ 1 second, or ≤ 0.5 seconds. In some embodiments, the hydrocarbon-containing feed can be contacted with the catalyst and/or at least a portion of the regenerated and reduced catalyst 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.

[0068] The hydrocarbon-containing feed and the catalyst and/or at least a portion of the regenerated and reduced catalyst 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 hydrocarbon-containing feed. In some embodiments, the hydrocarbon partial pressure during contact of the hydrocarbon-containing feed and the catalyst and/or at least a portion of the regenerated and reduced catalyst 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 hydrocarbon-containing feed. In other embodiments, the hydrocarbon partial pressure during contact of the hydrocarbon-containing feed and the catalyst and/or at least a portion of the regenerated and reduced catalyst 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 hydrocarbon-containing feed.

[0069] In some embodiments, the 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 hydrocarbon-containing feed. The hydrocarbon-containing feed and catalyst and/or at least a portion of the regenerated and reduced catalyst 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.

[0070] The hydrocarbon-containing feed can be contacted with the catalyst and/or at least a portion of the regenerated and reduced catalyst 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 and/or moving regenerated catalyst, a ratio of the catalyst 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.

[0071] When the activity of the at least partially deactivated catalyst decreases below a desired minimum amount, the at least partially deactivated catalyst or at least a portion thereof can be subjected to the regeneration and reduction process described above to produce the regenerated and reduced catalyst. Regeneration and reduction of the at least partially deactivated catalyst can occur within the reaction or conversion zone or within one or more

additional zones that can be separate and apart from the reaction or conversion zone, depending on the particular reactor configuration, to produce the regenerated and reduced catalyst. For example, regeneration and reduction of the at least partially deactivated catalyst can occur within the reaction or conversion zone when a fixed bed or reverse flow reactor is used, or within a separate zones 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. Accordingly, the hydrocarbon containing feed can be contacted with the catalyst 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 and a first effluent that includes the one or more upgraded hydrocarbons and molecular hydrogen in a cyclic type process such as those commonly employed in fixed bed and reverse flow reactors and/or a continuous type process commonly employed in fluidized bed reactors. The separation of the effluent that includes the upgraded hydrocarbon and molecular hydrogen from the coked catalyst, if needed, can be accomplished via one or more separators such as a cyclone separator.

Hydrocarbon-Containing Feed

[0072] 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, cyclohexane, methylcyclopentane, ethylcyclopentane, n-propylcyclopentane, 1,3-dimethylcyclohexane, or a mixture thereof. For example, the 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 hydrocarbon-containing feed can include liquid petroleum gas (LP gas), which can be in the gaseous phase when contacted with the catalyst. In some embodiments, the hydrocarbon in the hydrocarbon-containing feed can be composed of substantially a single alkane such as propane. In some embodiments, the 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 a total weight of all hydrocarbons in the hydrocarbon-containing feed. In some embodiments, the 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 hydrocarbon-containing feed.

[0073] The C₈-C₁₆ alkyl aromatics can be or can include, but are not limited to, ethylbenzene, propylbenzenes, butylbenzenes, one or more ethyl toluenes, or a mixture thereof. In some

embodiments, the 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 hydrocarbon-containing feed. In some embodiments, the ethylbenzene can be dehydrogenated to produce styrene. As such, in some embodiments, the processes disclosed herein can include propane dehydrogenation, butane dehydrogenation, isobutane dehydrogenation, pentane dehydrogenation, pentane dehydrocyclization to cyclopentadiene, naphtha reforming, ethylbenzene dehydrogenation, ethyltoluenes dehydrogenation, and the like.

[0074] In some embodiments, the 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 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 hydrocarbon-containing feed.

[0075] In some embodiments, the hydrocarbon-containing feed can also include H₂. In some embodiments, when the 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 0.01, 0.05, 0.1, 0.3, 0.5, 0.7, or 1 to 2, 3, 4, 5, 6, 7, 8, 9, or 10.

[0076] In some embodiments, the hydrocarbon-containing feed 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 hydrocarbon-containing feed. In other embodiments, the hydrocarbon-containing feed can include steam. For example, the hydrocarbon-containing feed 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%, 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 hydrocarbon-containing feed. In other embodiments, the hydrocarbon-containing feed can include ≤ 50 vol%, ≤ 45 vol%, ≤ 40 vol%, ≤ 35 vol%, ≤ 30 vol%, ≤ 25 vol%, ≤ 20 vol%, or ≤ 15 vol%, ≤ 10 vol%, ≤ 5 vol%, ≤ 3 vol%, or ≤ 1 vol% of steam, based on a total volume of any C₂-C₁₆ alkanes and any C₈-C₁₆ alkyl aromatics in the hydrocarbon-containing feed. In other embodiments, the hydrocarbon-containing feed 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 hydrocarbon-containing feed.

[0077] In some embodiments, the hydrocarbon-containing feed can include sulfur. For example, the 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 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 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.

[0078] The hydrocarbon-containing feed can be substantially free or free of molecular oxygen. In some embodiments, the hydrocarbon-containing feed can include ≤ 5 mol%, ≤ 3 mol%, or ≤ 1 mol% of molecular oxygen (O₂). It is believed that providing a hydrocarbon-containing feed substantially-free of molecular oxygen substantially prevents oxidative reactions that would otherwise consume at least a portion of the alkane(s) and/or the alkyl aromatic(s) in the hydrocarbon-containing feed.

Recovery and Use of the Upgraded Hydrocarbons

[0079] The upgraded hydrocarbon 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 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 hydrocarbon-containing feed.

[0080] 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.

[0081] The FIG. shows an illustrative catalyst regeneration system 1000 for regenerating an at least partially deactivated catalyst, according to one or more embodiments. The catalyst regeneration system 1000 can include a combustor 1003, a riser 1005, a catalyst separation

section 1007, and an oxygen soaking zone 1009. The combustor 1003 can include one or more lower combustor inlet ports 1011 and can be in fluid communication with the riser 1005. The combustor 1003 can be in fluid communication with a standpipe 1013 that can supply the at least partially deactivated catalyst particles to the combustor 1003 for catalyst regeneration (e.g., contaminant removal, coke removal, heating, Group 10 element re-dispersion, etc.). The oxygen soaking zone 1009 can be in fluid communication with a standpipe 1015, which can supply the regenerated catalyst particles from the oxygen soaking zone 1009 to a catalyst reduction system for catalyst reduction. An oxidant inlet 1017 can connect to the combustor 1003 through the lower combustor inlet port 1011. The oxidant inlet 1017 can supply an oxidant, e.g., air or other oxidizing gas(es), to the combustor 1003 to aid in the combustion of the fuel. The combustor 1003 can also include a fuel inlet 1019. The fuel inlet 1019 can supply a fuel 1021 to the combustor 1003. The combustion mixture can be produced when the fuel injected through fuel inlet 1019 meets with the oxidant injected through the oxidant inlet 1017. The oxygen soaking zone 1009 can include an inlet 1023, which can supply an oxidative gas to the oxygen soaking zone 1009 for oxygen soaking of the catalyst particles.

[0082] An FCC-like system, which includes a reactor system (not shown), a catalyst reduction system (not shown), and a catalyst regeneration system 1000 can be used for propane dehydrogenation. A detailed explanation on the FCC-like system can be found in U.S. Patent Application Publication No. 2022/0274901. The at least partially deactivated catalyst particles, after leaving the reactor system (not shown), can be separated from the product gas and enter via standpipe 1013 into the combustor 1003 where it meets with the combustion mixture. A substantial amount of combustion is expected to occur in the combustor 1003 when the at least partially deactivated catalyst particles contacts the combustion mixture. In the combustor 1003, the at least partially deactivated catalyst particles can catalyze the combustion of the combustion mixture to form the combustion product. Upon contacting the combustion product and/or during conversion of the combustion mixture to the combustion product, the at least partially deactivated catalyst particles can start to convert to the precursor catalyst particles. The combustion product can also include additional gases that can be emitted by the combustion of the contaminant(s) disposed on the at least partially deactivated catalyst particles. For example, if the contaminant is coke, the additional gases emitted can include CO, CO₂, and H₂O, since coke is mainly composed of elemental carbon and a small amount of elemental hydrogen. If the contaminant is a sulfur-containing material, the additional gases emitted can include SO₂ and SO₃. However, since the amount of the contaminant(s) is expected to be small, the generation of the additional gases are not expected to change the H₂O and O₂ concentrations

in the combustion product significantly. The combustion product can also include residual fuel and/or oxidant. Compared with the at least partially deactivated catalyst particles, the precursor catalyst particles can contain less coke, less contaminant(s), and can be heated to a greater temperature than the at least partially deactivated catalyst particles during contact with the combustion product.

[0083] The conversion of the combustion mixture to the combustion product and the conversion of the at least partially deactivated catalyst particles to the precursor catalyst particles is expected to substantially complete in the combustor 1003. The combustion product and the precursor catalyst particles can be passed out of the combustor 1003 and through the riser 1005 to a riser termination separator 1023, where the combustion product and precursor catalyst particles from the riser 1005 can exit the riser 1005. The combustion product and the precursor catalyst particles can be transported via the riser termination separator 1023 to a primary separation device 1025 in the catalyst regeneration system 1000 where a majority, if not all, of the catalyst particles can be separated from the combustion product and introduced via conduit 1027 into the oxygen soaking zone 1009. An overhead via conduit 1029 that includes the combustion product and any entrained catalyst particles can be transported to a secondary separation device 1031 in the catalyst regeneration system 1000. At least a portion of any entrained catalyst particles in the overhead in conduit 1029 can be separated from the combustion product and introduced via conduit 1033 into the oxygen soaking zone 1009. The combustion product and/or any residual fuel and/or any other gases introduced in the above described processes can be transported via conduit 1035 and removed from the catalyst generation system 1000 via a combustion gas outlet 1037. In some embodiments, the primary and secondary separation devices 1025, 1031 can independently include one or a plurality of cyclone separation units that can be arranged in series or in multiple cyclone pairs.

[0084] In some embodiments, the precursor catalyst particles can be regenerated by conditioning the precursor catalyst particles through an oxygen soaking treatment in the oxygen soaking zone 1009. The oxygen soaking treatment can include treating the precursor catalyst particles with an oxidative gas for a period of at least 30 seconds, which can regenerate the precursor catalyst particles to produce regenerated catalyst particles. In some embodiments, the oxidative gas can include no greater than 2 mol% of H₂O, based on the total moles in the oxidative gas. The regenerated catalyst particles, after reduction, can have a catalytic activity that is greater than the at least partially deactivated catalyst particles. In some embodiments, the oxygen soaking zone 1009 can be downstream of the catalyst separation section 1007 of the catalyst regeneration system 1000, such that the precursor catalyst particles can be separated

from the combustion product before being exposed to the oxidative gas during the oxygen soaking treatment. In some embodiments, the oxygen soaking zone 1009 can include a fluid/solids contacting device 1039. The fluid/solids contacting device 1039 can be or can include one or more baffles or grid structures to facilitate contact of the precursor catalyst particles with the oxidative gas. In some embodiments, the fluid/solid contacting device(s) can include those described in U.S. Patent Nos.: 9,827,543 and 9,815,040.

[0085] The regenerated catalyst particles can be passed via standpipe 1015 from the oxygen soaking zone 1009 to a catalyst reducer or reduction zone (not shown) to produce the regenerated and reduced catalyst particles, which can be more active than the at least partially deactivated catalyst particles. In some embodiments, processing the at least partially deactivated catalyst particles in the catalyst regeneration system 1000 can further include stripping entrained oxidative gas from the regenerated catalyst particles that can be trapped within or between catalyst particles and physisorbed oxygen that can be desorbable at a temperature of at least 620°C. Such stripping step can occur prior to introducing the regenerated catalyst particles into the catalyst reducer. In some embodiments, the stripping step can include maintaining the regenerated catalyst particles at a temperature of at least 620°C and exposing the regenerated catalyst particles to a stripping gas that is substantially free of molecular oxygen and combustible fuels for a period of time sufficient to remove the entrained oxidative gas between catalyst particles and physisorbed oxygen that is desorbable at the temperature of at least 620°C.

[0086] Although it is expected that most of the conversion of the combustion mixture to the combustion product and the conversion of the at least partially deactivated catalyst particles to the precursor catalyst particles occur in the combustor 1003, in some embodiments, the conversion of the combustion mixture to the combustion product and the conversion of the at least partially deactivated catalyst particles to the precursor catalyst particles can be incomplete in the combustor 1003. In some embodiments, the conversions can continue through the riser 1005, the riser termination separator 1023, and the primary and secondary separation devices 1025, 1031. In other words, the gas composition in the combustor 1003, the riser 1005, the riser termination separator 1023, and the primary and secondary separation devices 1025, 1031 can be changing. The proportion of precursor catalyst particles among all catalysts may also be evolving. As such, the composition of the combustion product is defined as the composition of the gas mixture at the location where the combustion gas and the precursor catalyst exit the riser termination separator 1023 into the primary separation device 1025 since most of the combustion is expected to occur upstream of this location. For the same reasoning, the

composition of the precursor catalyst can be defined as the composition of the catalyst mixture at the location where the combustion gas and the catalyst mixture exit the riser termination separator 1023 into the primary separation device 1025. Downstream of this location, the solids and the gases are separated and very little further conversion is expected to occur.

5 [0087] In a fuel-lean situation, the extent of combustion can be defined as the amount of fuel combusted divided by the amount of fuel fed. In cases when the fuel is a multi-component species, the amount of fuel may be defined as the higher heating value (HHV) of the fuel. In a fuel-rich situation, the extent of combustion can be defined as the amount of O₂ combusted divided by the amount of O₂ fed. The extent of combustion in the combustor 1003 can be >
10 80%, > 90%, > 95%, > 97%, > 99%, > 99.5%, > 99.9%, > 99.99%, or > 99.9999%. The extent of combustion at the location when the combustion gas and the precursor catalyst particles exit the riser termination separator 1023 can be > 85%, > 95%, > 97%, > 99%, > 99.5%, > 99.9%, > 99.99%, or > 99.9999%.

[0088] In the catalyst regeneration system 1000, the combustor 1003, the riser 1005, the riser
15 termination separator 1023, the primary and secondary separation devices 1025 and 1031 can be considered as a first stage regenerator. The combustion of the combustion mixture (fuel and oxidant) generates a combustion product that includes any combination of steam, heat, residual fuel, residual O₂, N₂, CO, CO₂, or any mixture thereof. The composition of the combustion product can vary depending, at least in part, on the extent of combustion. As noted above, the
20 composition of the combustion product can be taken at the location where the combustion product and precursor catalyst particles exit the riser termination separator 1023 and into the primary separation device 1025. The composition of the precursor catalyst can be defined as the composition of the catalyst mixture at the location where the combustion gas and the catalyst mixture exit the riser termination separator 1023 into the primary separation device
25 1025. The Group 10 element, e.g., Pt, disposed on the catalyst particles may catalyze combustion. The heat generated by combustion heats up the catalyst particles. The coke on the catalyst particles can be at least partially combusted in this first stage regenerator. If the fuel is hydrogen rich so that the amount of steam in the combustion product is > 2 vol%, then the relative amount of fuel and air can be adjusted so that the residual O₂ in the combustion
30 product can be < 2 vol%. The catalyst particles can then be separated from the combustion product to provide the precursor catalyst particles. The precursor catalyst particles can then enter a second stage regenerator, i.e., oxygen soaking zone 1009, where the catalyst particles can be soaked in the oxidative gas that can include < 2% H₂O to produce the regenerated catalyst particles. In the catalyst regeneration system 100, the oxygen soaking zone 1009 can

be considered as the second stage regenerator. At least a portion of any residual coke on the precursor catalyst particles can also be combusted in the second stage regenerator. The regenerated catalyst particles can then be separated from oxidative gas and enter a reduction system where it can be reduced by contacting the regenerated catalyst particles with the reducing gas to produce the regenerated and reduced catalyst particles. The regenerated and reduced catalyst particles can be combined with additional hydrocarbon-containing feed and, optionally, steam in a reactor system to produce additional effluent and additional at least partially deactivated catalyst particles. One example of the reactor system can be an FCC reactor system.

5 [0089] In an alternative embodiment, an FCC-like reactor can be used for upgrading a hydrocarbon, e.g., propane dehydrogenation. The at least partially deactivated catalyst, after leaving the riser in the reactor, can be separated from the product gas, and enter a first stage regenerator where it can be contacted with the combustion mixture/combustion product. The combustion of the combustion mixture (fuel and air) in a burner can generate the combustion product that can include any combination of steam, heat, residual fuel, residual O₂, N₂, CO, and/or CO₂. The burner and the first stage regenerator can be physically separate vessels. A catalyst can be present in the burner to catalyze the combustion of the combustion mixture. The combustion product can heat up the at least partially deactivated catalyst. The coke on the at least partially deactivated catalyst can be at least partially combusted in this first stage regenerator. If the fuel is hydrogen-rich so that the amount of steam in the combustion product is > 2 mol%, the relative amount of fuel and oxidant can be adjusted so that the residual O₂ in the combustion product can be < 2 mol%. The precursor catalyst can be separated from the combustion product. The precursor catalyst can enter a second stage regenerator where it can be soaked in an oxidative gas that includes no greater than 2 mol% H₂O to generate the regenerated catalyst. Any residual coke on the precursor catalyst can also be combusted in the second stage regenerator. The regenerated catalyst can then be separated from the oxidative gas and enter a reducer where it can be reduced by contacting it with a reducing gas to produce a regenerated and reduced catalyst. The regenerated and reduced catalyst can then be combined with additional hydrocarbon-containing feed and, optionally, steam in the riser of the reactor to generate additional product gas and additional at least partially deactivated catalyst. The first stage regenerator can be a riser, a dense fluid bed reactor, or a riser with a frustum bottom. The second stage regenerator can be a dense fluid bed reactor.

25 [0090] In another alternative embodiment, an FCC-like reactor can be used for upgrading a hydrocarbon, e.g., propane dehydrogenation. The at least partially deactivated catalyst, after

leaving the riser in the reactor, can be separated from the product gas, and enter a first stage regenerator where the at least partially deactivated catalyst can contact a hot, dry air that can be free of or include < 2 mol% H_2O to produce a regenerated catalyst. The hot, dry air can also heat up the at least partially deactivated catalyst. At least a portion of any coke on the at least partially deactivated catalyst can also be combusted in the first stage regenerator. The regenerated catalyst can then be separated from the hot, dry air and enter a reducer where it can be reduced by a reducing gas to form a regenerated and reduced catalyst. The regenerated and reduced catalyst can then be combined with additional hydrocarbon-containing feed and, optionally, steam in the riser of the reactor to generate additional product gas and additional at least partially deactivated catalyst. The first stage regenerator can be a riser, a dense fluid bed reactor, or a riser with a frustum bottom. The hot, dry air that can be free of or include < 2 mol% H_2O can be obtained by heating a dry air with a combustion product generated by combusting a combustion mixture using a heat exchanger.

[0091] In another alternative embodiment, an FCC-like reactor can be used for upgrading a hydrocarbon, e.g., propane dehydrogenation. The at least partially deactivated catalyst, after leaving the riser in the reactor, can be separated from the product gas and enter an electrically heated furnace with a dry air that can be free of or include < 2 mol% H_2O flowing therethrough to generate the regenerated catalyst. The electrically heated furnace can heat up the at least partially deactivated catalyst. At least a portion of any coke on the at least partially deactivated catalyst can also be combusted in the electrically heated furnace. The regenerated catalyst can then be separated from the hot, dry air and enter a reducer where it can be reduced by contacting it with a reducing gas to form a regenerated and reduced catalyst. The regenerated and reduced catalyst can then be combined with additional hydrocarbon-containing feed and, optionally, steam in the riser of the reactor to generate additional product gas and additional at least partially deactivated catalyst.

Examples:

[0092] The foregoing discussion can be further described with reference to the following non-limiting examples. Catalysts 1 and 2 were prepared according to the following procedures.

[0093] Catalyst 1 was prepared according to the following procedure. Calcined hydrotalcite support particles (23 g, $\text{MgO}:\text{Al}_2\text{O}_3 = 71/29$ w/w) that had physical properties consistent with those of Geldart A fluidizable particles were mixed with 40 ml of deionized (DI) water to form a slurry. An aqueous mixture that contained 0.38 g of an 8% chloroplatinic acid solution, 2.97 g of a 23.65% tin(IV) chloride pentahydrate solution, and 20 ml of DI water was prepared. The aqueous mixture was added slowly to the slurry while the slurry/solution mixture was stirred.

- After finishing addition of the aqueous mixture to the slurry, the mixture was stirred for an additional 10 minutes before the solid fraction was recovered by filtration. The solids were then dried in air at 110°C for 6 hours. After drying, the solids still contained a significant amount of volatile compounds and/or compounds that can form volatile compounds if subjected to thermal treatments at temperatures greater than 110°C. The non-volatile weight percentage of the catalyst (71.5 wt%) was quantified by thermogravimetric analysis (TGA) in an oxidative environment (air) by heating the synthesized catalyst to a temperature of 600°C. Synthesized Catalyst 1 had a Pt and Sn loading of approximately 0.05 wt% and 1 wt%, respectively, based on the non-volatile weight of the catalyst.
- 10 [0094] Catalyst 2 was prepared according to the following procedure. Calcined hydrotalcite support particles (2.3 g, MgO:Al₂O₃ = 80/20 w/w) that had physical properties consistent with those of Geldart A fluidizable particles were mixed with 4 ml of deionized (DI) water to make a slurry. An aqueous mixture that contained 0.0163 g of an 8% chloroplatinic acid solution, 0.295 g of a 23.65% tin(IV) chloride pentahydrate solution, and 2 ml of DI water was prepared.
- 15 The aqueous mixture was added slowly to the slurry while the slurry/solution mixture was stirred. After finishing addition of the aqueous mixture to the slurry, the mixture was stirred for an additional 10 minutes before the solid fraction was recovered by filtration. The solid fraction was kept in a closed container for 24 h before the solid fraction was dried in air at 110°C for 6 hours and calcined in air at 800°C for 12 h. Synthesized Catalyst 2 had a Pt and
- 20 Sn loading of approximately 0.025 wt% and 1 wt%, respectively, based on the non-volatile weight of the catalyst.
- [0095] Comparative Examples 1 and 2 (CEx. 1 and 2) and Examples 1–18 below, illustrate how combustion products of various compositions can affect the performance of the catalyst when the combustion product contacts the at least partially deactivated catalyst to form the precursor catalyst. N₂ and He were considered as inert under all circumstances.
- 25 [0096] In Comparative Examples 1 and 2 and Examples 1-14, fixed bed experiments that used Catalyst 1 or 2 were conducted at approximately 100 kPa-absolute. A gas chromatograph (GC) was used to measure the composition of the reactor effluents. The concentration of each component in the reactor effluents were then used to calculate the C₃H₆ yield and selectivity.
- 30 The C₃H₆ yield and selectivity, as reported in these examples, were calculated on the carbon mole basis.

Comparative Examples 1 and 2 and Examples 1–16

[0097] Catalyst 1 (0.41 g) was mixed with an appropriate amount of SiC 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.

[0098] Prior to any reaction, Catalyst 1 was subjected to the following pre-treatment steps in the quartz reactor: 1. Under a flow of 46.6 sccm of air, the reaction zone temperature was increased from room temperature to 550°C at 30°C/min and the catalyst particles were calcined at 550°C for 0.25 hours. 2. The reaction zone temperature was then increased from 550°C to 600°C at 30°C/min under a flow of inert gas. 3. Under a flow of 46.6 sccm of 10% H₂ in argon, the catalyst particles were calcined at 600°C for 0.625 hours. 4. The system was then purged with an inert gas. 5. The reaction zone temperature was then decreased from 600°C to 550°C at 30°C/min under a flow of 46.6 sccm of air and the catalyst particles were calcined at 550°C for 0.25 hours. 6. The reaction zone temperature was increased from 550°C to 600°C at 30°C/min under a flow of inert gas. 7. Under a flow of 46.6 sccm of 10% H₂ in argon, the catalyst particles were calcined at 600°C for 0.625 hours to produce the calcined catalyst particles. After the pre-treatment, the weight of the Catalyst 1 in the quartz reactor was expected to decrease from 0.41 to 0.29 g, based on the TGA measurement of non-volatile weight percentage of 71.5 % for Catalyst 1.

[0099] Catalyst 1 in the quartz reactor was subjected to the following process steps in Examples 1–13. Gas A that had a composition as shown in Table 1 was used to mimic combustion products of various compositions. 1. The system was flushed with an inert gas. 2. Gas A at a flow rate of B 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 720°C. 3. Gas A at a flow rate of B sccm was then passed through the reaction zone for C min. 4. Dry air at a flow rate of 83.9 sccm was then passed through the reaction zone for 5 min to regenerate the catalyst. 5. The system was flushed with an inert gas. 6. A H₂ containing gas with 10 vol% H₂ 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 H₂ containing gas through the reaction zone at 720°C for 120 s. 7. The system was flushed with an inert gas. During this process, the temperature of the reaction zone was changed from 720°C to a reaction temperature of 640°C. 8. A hydrocarbon-containing (HCgas) feed that included 90 vol% of C₃H₈ and 10 vol% of steam at a flow rate of 35.2 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 640°C

for 10 min. 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 1-8 were repeated in cycles until the performance stabilized.

[0100] Catalyst 1 in the quartz reactor was subjected to the following process steps in the Comparative Example 1: 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 720°C. 3. Dry air at a flow rate of 83.9 sccm was then passed through the reaction zone for 5 min to regenerate the catalyst. 4. The system was flushed with an inert gas. 5. A H₂ containing gas with 10 vol% H₂ 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 H₂ containing gas through the reaction zone at 720°C for 120 s. 6. The system was flushed with an inert gas. During this process, the temperature of the reaction zone was changed from 720°C to a reaction temperature of 640°C. 7. A hydrocarbon-containing (HCgas) feed that included 90 vol% of C₃H₈ and 10 vol% of steam at a flow rate of 35.2 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 640°C for 10 min. 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 until the performance stabilized.

Table 1					
	Gas Composition (A)	Flow Rate (B, sccm)	Contact Time (C, min)	C ₃ H ₆ Yld (Cmole%)	C ₃ H ₆ Sel (Cmole%)
Comparative Example 1				58.3	97.8
Example 1	90% He, 10% steam	93.2	5	57.5	97.8
Example 2	3.15% O ₂ , 13.5% CO ₂ , 10% steam, balance N ₂	93.2	5	53.1	97.8
Example 3	3.15% O ₂ , 13.5% CO ₂ , 10% steam, balance N ₂	93.2	0.2	57.1	97.7
Example 4	0.45% O ₂ , 13.5% CO ₂ , 10% steam, balance N ₂	93.2	5	53.7	97.7
Example 5	0.45% O ₂ , 13.5% CO ₂ , 10% steam, balance N ₂	93.2	0.2	56.9	97.8
Example 6	0.5% O ₂ , 15% CO ₂ , balance N ₂	83.9	5	58.3	97.8
Example 7	0.045% O ₂ , 13.5% CO ₂ , 10% steam, balance N ₂	93.2	5	57.5	97.9
Example 8	0.09% CO, 13.5% CO ₂ , 10% steam, balance N ₂	93.2	5	56.7	98
Example 9	0.9% CH ₄ , 13.5% CO ₂ , 10% steam, balance N ₂	93.2	5	57.2	97.5
Example 10	13.5% CO ₂ , 10% steam, balance N ₂	93.2	5	56.6	97.7
Example 11	15% CO ₂ , balance N ₂	83.9	5	58.5	97.8
Example 12	Air	83.9	5	58.7	97.7
Example 13	90% air, 10% steam	93.2	5	53.6	98

[0101] Comparative Example 1 and Example 12 show that a longer duration treatment with O₂ (5 min vs 10 min, respectively) had minimal impact to the C₃H₆ yield.

[0102] Comparative Example 1 and Example 1 show that subjecting the deactivated catalyst to a stream that consisted of 10% steam and He for 5 min before a dry air treatment reduced the C₃H₆ yield from 58.3% to 57.5%. As such, steam has a small negative impact to the C₃H₆ yield, approximately 1% to 2%.

[0103] Comparative Example 1 and Example 11 show that subjecting the spent catalyst to a stream consisting of 15% CO₂ and N₂ for 5 min before a dry air treatment had almost no impact to the C₃H₆ yield. As such, CO₂ has no impact to the C₃H₆ yield.

5 [0104] Comparative Examples 1 and Example 10 show that subjecting the spent catalyst to a stream consisting of 13.5% CO₂, 10% steam, and N₂ for 5 min before a dry air treatment reduced the C₃H₆ yield from 58.3% to 56.6%. The effect of steam (Example 1) is similar to the effect of CO₂ + steam (Example 7), suggesting that there is not a synergistic effect between CO₂ and steam.

10 [0105] Example 6 shows that a combination of CO₂ and O₂ did not impact the C₃H₆ yield. As such, there is not a synergistic effect between CO₂ and O₂.

[0106] Examples 7, 4, and 2 show that in the presence of 10% steam and 13.5% CO₂, the C₃H₆ yield reduced from 57.5% to 53.7% to 53.1%, respectively, as the amount of O₂ increased from 0.045% to 0.45% to 3.15%, respectively.

15 [0107] Examples 12 and 13 show that the presence of 10% steam in air reduced the C₃H₆ yield from 58.7 % to 53.6 %. It is believed that steam and O₂ behave synergistically in reducing the C₃H₆ yield, since steam alone only impacts C₃H₆ minimally, CO₂ alone does not impact the C₃H₆ yield, O₂ alone does not impact the C₃H₆ yield, and there is no synergetic effects between CO₂/steam and CO₂/O₂.

20 [0108] Comparing Examples 2 and 3 and Examples 4 and 5 show that the impact of steam/O₂ to C₃H₆ yield reduced as the duration of exposure was reduced (5 min vs 0.2 min).

[0109] Examples 8 and 9 show that 0.09% CO or 0.9% CH₄ has minimal impact to the C₃H₆ yield.

25 [0110] Table 2 shows the performance of Catalyst 1 in Examples 14–16 and Comparative Example 2. The process steps of Catalyst 1 in Comparative Example 2 and Examples 14–16 were identical to the process steps of Catalyst 1 in Comparative Example 1 and Examples 1–13 except that the hydrocarbon-containing (HCgas) feed in Comparative Example 1 and Examples 1–13 was 90 vol% of C₃H₈ and 10 vol% of steam at a flow rate of 35.2 sccm while the hydrocarbon-containing (HCgas) feed in Comparative Example 2 and Examples 14–16 was 81 vol% of C₃H₈, 9 vol% of Ar, and 10 vol% of steam at a flow rate of 35.2 sccm.

30

Table 2					
	Gas Composition (A)	Flow Rate (B, sccm)	Contact Time (C, min)	C ₃ H ₆ Yld (Cmole%)	C ₃ H ₆ Sel (Cmole%)
Comparative Example 2				58.5	97.7
Example 14	3.15% O ₂ , 13.5% CO ₂ , 10% steam, balance N ₂	93.2	5	53.8	98.1
Example 15	2.87% O ₂ , 12.3% CO ₂ , 18% steam, balance N ₂	93.2	5	52.5	97.8
Example 16	2.87% O ₂ , 12.3% CO ₂ , 18% steam, balance N ₂	93.2	1	54.7	97.7

[0111] Comparative Example 2 and Example 14 show that when the catalyst is subjected to a combined O₂/CO₂/steam/N₂ treatment, the C₃H₆ yield was reduced from 58.5% to 53.8%. The extent of reduction increased when the amount of steam was increased from 10% to 18% (Example 14 vs 15) and reduced when the duration of treatment was reduced from 5 to 1 min (Example 15 vs 16).

[0112] Based on the results in Comparative Examples 1 and 2 and Examples 1 to 16, it is believed that the co-existence of steam and O₂ synergistically reduces the C₃H₆ yield when steam and O₂ are in contact with the at least partially deactivated catalyst to produce the precursor catalyst and the combustion product. The extent of C₃H₆ yield reduction increased with steam or O₂ concentration and the duration of treatment.

Examples 17 and 18

[0113] Catalyst 2 (0.3045 g) was mixed with an appropriate amount of SiC 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.

[0114] Catalyst 2 in the quartz reactor was then subjected to the following process steps: 1. The system was flushed with an inert gas. 2. Gas A 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. Gas A at a flow rate of 83.9 sccm was then passed through the reaction zone for 10 min. 4. The system was flushed with an inert gas. 5. A H₂ containing gas with 10 vol% H₂ 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 H₂ containing gas through the reaction zone at 800°C for 3 s. 7. 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. 8. A hydrocarbon-containing (HCgas) feed that included 81 vol% of C₃H₈, 9 vol% of inert gas (Ar) 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 min. 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 initial C₃H₆ yield and selectivity were calculated and reported in the examples. The above process steps were repeated in cycles.

Table 3			
	A	C ₃ H ₆ Yld (Cmole%)	C ₃ H ₆ Sel (Cmole%)
Example 17	Air	65.3	93.8
Example 18	Air with 408 ppm H ₂ O	65.0	93.9

[0115] Examples 17 and 18 suggest that transforming the precursor catalyst to the regenerated catalyst in dry air vs. air with 408 ppm H₂O made little difference.

[0116] 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.

[0117] 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 process for regenerating and reducing an at least partially deactivated catalyst comprising a contaminant and a Group 10 element disposed on an inorganic support, wherein the Group 10 element is present in an amount of from 0.001 wt% to 6 wt%, based on the weight of the inorganic support, the process comprising:
 - (I) heating the at least partially deactivated catalyst by contacting the at least partially deactivated catalyst with a combustion product to produce a precursor catalyst, wherein:
 - the combustion product is produced by combusting a combustion mixture comprising a fuel and an oxidant,
 - the combustion product, prior to, during, or after contact with the at least partially deactivated catalyst, comprises H₂O at a concentration of greater than 2 mol% and, optionally, O₂ at a concentration of less than 2 mol%, based on the total moles in the combustion product, and
 - the amount of O₂ in the combustion product, prior to, during, or after contact with the at least partially deactivated catalyst, is maintained at the concentration of less than 2 mol% by controlling a molar ratio of the oxidant to the fuel in the combustion mixture;
 - (II) providing an oxidative gas comprising no greater than 2 mol% of H₂O, based on the total moles in the oxidative gas;
 - (III) contacting the precursor catalyst with the oxidative gas at an oxidizing temperature in a range of from 620°C to 1,000°C for a duration of at least 30 seconds to produce a regenerated catalyst; and
 - (IV) contacting the regenerated catalyst with a H₂-containing gas at a reducing temperature in a range of from 620°C to 1,000°C for a duration of at least 0.1 seconds to produce a regenerated and reduced catalyst.
 2. The process of claim 1, wherein the combustion product is produced by combusting the combustion mixture in the presence of the at least partially deactivated catalyst.
 3. The process of claim 1, wherein the combustion product is produced by combusting the combustion mixture prior to contacting the at least partially deactivated catalyst with the combustion product such that the combustion product prior to contacting the at least partially

deactivated catalyst comprises the H₂O at the concentration of greater than 2 mol% and, optionally, the O₂ at a concentration of less than 2 mol%, based on the total moles in the combustion product.

- 5 4. The process of any one of claims 1 to 3, wherein the combustion product comprises residual fuel and is free of any O₂.
5. The process of any one of claims 1 to 4, wherein the fuel comprises at least one of H₂, CO, a hydrocarbon, and the contaminant disposed on the inorganic support, and wherein the
10 oxidant comprises O₂.
6. The process of any one of claims 1 to 5, wherein the combustion product comprises the H₂O, the optional O₂, and one or more of residual fuel, N₂, CO, and CO₂.
- 15 7. The process of any one of claims 1 to 6, wherein step (II) comprises:
 (IIa) providing the oxidative gas at a temperature below the oxidizing temperature; and
 (IIb) pre-heating the oxidative gas to a temperature greater than the temperature of the precursor catalyst before the contacting in step (III).
- 20 8. The process of any one of claims 1 to 7, wherein step (III) further comprises, heating the oxidative gas, heating the precursor catalyst, or heating both the oxidative gas and the precursor catalyst during contact of the precursor catalyst with the oxidative gas by using a radiant/conductive heat source, a heat exchanger, or a combination thereof.
- 25 9. The process of any one of claims 1 to 8, wherein step (III) further comprises contacting the regenerated catalyst with a first stripping gas free of O₂ to produce a stripped regenerated catalyst, and wherein step (IV) comprises contacting the stripped regenerated catalyst with the H₂-containing gas to produce the regenerated and reduced catalyst.
- 30 10. The process of claim 9, further comprising contacting the regenerated and reduced catalyst with a second stripping gas to produce a stripped regenerated and reduced catalyst.

11. The process of any one of claims 1 to 10, wherein the Group 10 element comprises Pt, and wherein the inorganic support comprises at least 0.5 wt% of a Group 2 element, based on the weight of the inorganic support.
- 5 12. The process of claim 11, wherein:
the Group 2 element comprises Mg, and
at least a portion of the Group 2 element is in the form of MgO or a mixed metal oxide comprising MgO.
- 10 13. The process of any one of claims 1 to 12, wherein the at least partially deactivated catalyst further comprises up to 10 wt% of a promoter, based on the weight of the inorganic support, and wherein the promoter comprises one or more of the following elements: Sn, Ag, Cu, a combination thereof, or a mixture thereof.
- 15 14. The process of any one of claims 1 to 13, wherein the at least partially deactivated catalyst further comprises up to 5 wt% an alkali metal element disposed on the inorganic support, and wherein the alkali metal element comprises at least one of: Li, Na, K, Rb, and Cs.
- 20 15. A dehydrogenation process using the regenerated and reduced catalyst produced by a process of any one of claims 1 to 14, the dehydrogenation process comprising:
(V) contacting a hydrocarbon-containing feed with the regenerated and reduced catalyst to effect one or more of dehydrogenation, dehydroaromatization, and dehydrocyclization of at least a portion of the hydrocarbon-containing feed to produce additional at least partially deactivated catalyst and an effluent comprising one or more upgraded hydrocarbons and
25 molecular hydrogen, wherein the hydrocarbon-containing feed comprises one or more of C₂-C₁₆ linear or branched alkanes, one or more of C₄-C₁₆ cyclic alkanes, one or more of C₈-C₁₆ alkyl aromatic hydrocarbons, or a mixture thereof;
(VI) repeating steps (I) through (IV), wherein, in step (III) additional regenerated catalyst is produced, and wherein, in step (IV), additional regenerated and reduced catalyst is
30 produced from the additional regenerated catalyst; and
(VII) contacting an additional quantity of the hydrocarbon-containing feed with at least a portion of the additional regenerated and reduced catalyst to produce additional at least partially deactivated catalyst and additional effluent.

16. The dehydrogenation process of claim 15, wherein a cycle time from the contacting the hydrocarbon-containing feed with the regenerated and reduced catalyst in step (V) to the contacting the additional quantity of the hydrocarbon-containing feed with the additional regenerated and reduced catalyst in step (VII) is ≤ 5 hour.

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17. A process for upgrading a hydrocarbon, comprising:

(I) contacting a hydrocarbon-containing feed with a catalyst comprising a Group 10 element disposed on an inorganic support to effect one or more of dehydrogenation, dehydroaromatization, and dehydrocyclization of at least a portion of the hydrocarbon-
10 containing feed to produce an at least partially deactivated catalyst comprising a contaminant and the Group 10 element disposed on the inorganic support 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, one or more C₈-C₁₆ alkyl
15 aromatics, or a mixture thereof;

the Group 10 element has a concentration in the range of from 0.001 wt% to 6 wt%, based on the weight of the inorganic support;

the hydrocarbon-containing feed and the catalyst are contacted at a temperature in a range of from 300°C to 900°C; and

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

(II) heating the at least partially deactivated catalyst by contacting the at least partially deactivated catalyst with a combustion product comprising H₂O at a concentration of greater
25 than 2 mol% and, optionally, O₂ at a concentration of less than 2 mol%, based on the total moles in the combustion product to produce a precursor catalyst, wherein the combustion product is produced by combusting a combustion mixture comprising a fuel and an oxidant, and wherein the amount of O₂ in the combustion product is maintained at the concentration of less than 2 mol% by controlling a molar ratio of the oxidant to the fuel in the combustion
30 mixture;

(III) providing an oxidative gas comprising no greater than 2 mol% of H₂O, based on the total moles in the oxidative gas;

(IV) contacting the precursor catalyst at an oxidizing temperature in a range of from 620°C to 1,000°C with the oxidative gas for a duration of at least 30 seconds to produce a regenerated catalyst;

5 (V) contacting the regenerated catalyst with a H₂-containing gas at a reducing temperature in a range of from 620°C to 1,000°C for a duration of at least 0.1 seconds to produce a regenerated and reduced catalyst; and

(VI) contacting an additional quantity of the hydrocarbon-containing feed with at least a portion of the regenerated and reduced catalyst to produce additional at least partially deactivated catalyst and additional effluent.

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18. The process of claim 17, wherein the combustion product is produced in the presence of the at least partially deactivated catalyst.

15 19. The process of claim 17, wherein the combustion product is produced prior to contacting the at least partially deactivated catalyst with the combustion product.

20. The process of any one of claims 17 to 19, wherein the combustion product comprises residual fuel and is free of any O₂.

20 21. The process of any one of claims 17 to 20, wherein the fuel comprises at least one of H₂, CO, a hydrocarbon, and the contaminant disposed on the inorganic support, and wherein the oxidant comprises O₂.

25 22. The process of any one of claims 17 to 21, wherein the combustion product comprises the H₂O, the optional O₂, and one or more of residual fuel, N₂, CO, and CO₂.

23. The process of any one of claims 17 to 22, wherein the Group 10 element comprises Pt, and wherein the inorganic support comprises at least 0.5 wt% of a Group 2 element, based on the weight of the inorganic support.

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24. The process of claim 23, wherein:
the Group 2 element comprises Mg, and
at least a portion of the Group 2 element is in the form of MgO or a mixed metal oxide comprising MgO.

25. The process of any one of claims 17 to 24, wherein the at least partially deactivated catalyst further comprises up to 10 wt% of a promoter, based on the weight of the inorganic support, and wherein the promoter comprises one or more of the following elements: Sn, Ag,
- 5 Cu, a combination thereof, or a mixture thereof.