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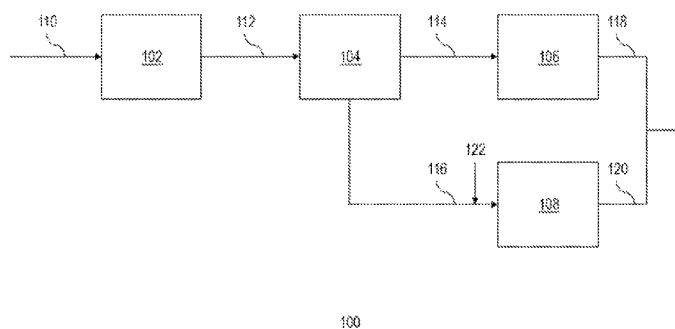
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(54) Title: A PROCESS AND SYSTEM INTEGRATING HYDROCRACKING WITH HYDROCARBON DEHYDROGENATION

FIGURE 1



(57) Abstract: A pyrolysis oil is contacted with a hydrocracking catalyst disposed within a hydrocracking unit to convert at least a portion of the pyrolysis oil into a lower alkane to produce a hydrocracking product stream. The hydrocracking product stream is separated into an ethane feed stream comprising ethane and a C3+ feed stream comprising at least one of a C3 alkane, a C4 alkane, or a higher alkane. The C3+ feed stream is diluted with steam to form a steam cracking feed stream. The steam cracking feed stream is heated in a steam cracker to convert at least a portion of the C3+ feed stream to ethylene. The ethane feed stream is diluted with an oxidant to form an oxidative dehydrogenation (ODH) feed stream. The ODH feed stream is contacted with an ODH catalyst disposed within an ODH reactor to convert at least a portion of the ethane to ethylene.

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A PROCESS AND SYSTEM INTEGRATING HYDROCRACKING WITH HYDROCARBON DEHYDROGENATION

TECHNICAL FIELD

The present specification is directed to an integration of hydrocarbon cracking and
5 hydrocarbon dehydrogenation. More specifically, processes and systems integrating a
hydrocracking process for producing lower alkanes with an oxidative dehydrogenation
process to convert ethane to ethylene are described.

BACKGROUND ART

Olefins like ethylene, propylene, and butylene are basic building blocks for a variety
10 of commercially valuable polymers. Since naturally occurring sources of olefins do not
exist in commercial quantities, polymer producers rely on methods for converting the more
abundant lower alkanes into olefins. To produce ethylene commercial scale producers
typically use steam cracking, an energy intensive process that requires extensive
downstream separation and is subjected to periodic shutdowns for cleaning and maintenance
15 related to the buildup of coke by-products within the cracking infrastructure. Steam
cracking involves the cracking of alkanes into alkenes, which produces hydrogen gas.
Another method is oxidative dehydrogenation (“ODH”), where the lower alkane, such as
ethane, is mixed with oxygen in the presence of a catalyst to produce the corresponding
olefin, such as ethylene. The ODH reaction couples endothermic removal of hydrogen from
20 the lower alkane with exothermic oxidation of hydrogen to produce water.

However, oxidative dehydrogenation requires oxygen, which is typically provided
by energy-intensive air separation. Additionally, certain processes for preparing an
oxidative dehydrogenation feedstock, such as hydrocracking, require hydrogen, which is
typically provided by steam methane reforming, which produces carbon dioxide, a
25 greenhouse gas. Thus, the product effluents of such processes may include trace
contaminants. For example, trace oxygen may exist in the product effluent of the oxidative
dehydrogenation process. As another example, trace hydrogen may exist in the product
effluent of the hydrocracking process. Typically, the trace contaminants are separated from
the product effluents. Reducing the operational and capital costs of the production of
30 ethylene (including separation of trace contaminants) can be beneficial.

SUMMARY OF INVENTION

Certain aspects of the subject matter described can be implemented as a process. A
hydrocracking feed stream comprising pyrolysis oil is contacted with a hydrocracking
catalyst disposed within a hydrocracking unit to convert, in the presence of hydrogen, at

least a portion of the pyrolysis oil into a lower alkane to produce a hydrocracking product stream. The hydrocracking product stream is separated into an ethane feed stream and a C3+ feed stream. The ethane feed stream comprises ethane. The C3+ feed stream comprises at least one of a C3 alkane, a C4 alkane, or a higher alkane. The C3+ feed stream is diluted with steam to form a steam cracking feed stream. The steam cracking feed stream is heated in a steam cracker to convert at least a portion of the C3+ feed stream to ethylene. The ethane feed stream is diluted with an oxidant to form an oxidative dehydrogenation (ODH) feed stream. The ODH feed stream is contacted with an ODH catalyst disposed within an ODH reactor to convert at least a portion of the ethane to ethylene.

This, and other aspects, can include one or more of the following features. The pyrolysis oil can be derived from pyrolysis of waste plastic. Contacting the hydrocracking feed stream with the hydrocracking catalyst can produce a yield of C2-C4 alkanes in a range of from about 40 wt.% to about 100 wt.%. The hydrocracking product stream can comprise at least about 90 wt.% of C2-C4 alkanes. The hydrocracking product stream can comprise at least about 95 wt.% of C2-C4 alkanes. The pyrolysis oil can comprise from about 20 wt.% to about 40 wt.% of one or more linear alkanes (e.g., paraffins), from 0 wt.% to about 40 wt.% of one or more cyclic alkanes (e.g., naphthenes), from 0 wt.% to about 50 wt.% of one or more alkenes (e.g., olefins), from 0 wt.% to about 40 wt.% of one or more aromatic compounds, and from 0 wt.% to about 50 wt.% of one or more C15+ hydrocarbons. The hydrocracking catalyst can comprise natural zeolites, synthetic zeolites, bauxite, alkali oxides, alkaline metal earth oxides, aluminum phosphates, transition metal oxides, or any combination of these. The hydrocracking catalyst can comprise palladium dispersed on a zeolite support. In some implementations, the hydrocracking catalyst comprises 0.2 wt.% of palladium. The ODH reactor can operate at a temperature from about 300°C to about 500°C. The ODH reactor can operate at a temperature from about 315°C to about 400°C. The ODH reactor can operate at an outlet pressure from about 0.5 psig to about 100 psig. The ODH reactor can operate at an outlet pressure from about 15 psig to about 504 psig. A selectivity to ethylene of the ODH catalyst disposed within the ODH reactor can be in a range of from about 75 molar percent (mol. %) to about 99 mol. %. The hydrocracking unit can operate at a pressure from about 300 psig to about 1002 psig. The hydrocracking unit can operate at a temperature from about 350°C to about 500°C. The hydrocracking feed stream can have a liquid hourly space velocity (LHSV) from about 0.2 per hour (hr^{-1}) to about 5 hr^{-1} in the hydrocracking unit. A volumetric ratio of hydrogen in a gas phase at standard temperature and pressure (STP, which is pressure of 1 atmosphere (atm) and

temperature of 0°C) within the hydrocracking unit to the pyrolysis oil in a liquid phase within the hydrocracking unit can be from about 500:1 to about 2000:1. The C3+ feed stream can be separated into a C3 feed stream and a C4 feed stream. The C3+ feed stream can be diluted with ethane, propane, butane, or any combinations thereof. A C4+ portion of the hydrocracking product stream can be recycled to the hydrocracking unit. The C4+ portion can include at least one of a C5 alkane or a higher alkane.

Certain aspects of the subject matter described can be implemented as a system. The system comprises a hydrocracking feed stream, a hydrocracking unit, a separation unit, a steam cracker, and an ODH reactor. The hydrocracking feed stream comprises pyrolysis oil. The hydrocracking unit comprises a hydrocracking catalyst that is configured to convert, in the presence of hydrogen, at least a portion of the pyrolysis oil into a lower alkane in response to contacting the hydrocracking feed stream to produce a hydrocracking product stream. The separation unit is configured to receive the hydrocracking product stream and separate the hydrocracking product stream into an ethane feed stream and a C3+ feed stream. The ethane feed stream comprises ethane. The C3+ feed stream comprises at least one of a C3 alkane, a C4 alkane, or a higher alkane. The steam cracker is configured to receive and heat at least a portion of the C3+ feed stream diluted with steam to convert the portion of the C3+ feed stream to ethylene. The ODH reactor is configured to receive at least a portion of the ethane feed stream and an oxidant, the ODH reactor comprising an ODH catalyst configured to, under ODH conditions and in the presence of the oxidant, convert at least a portion of the ethane from the ethane feed stream to ethylene.

This, and other aspects, can include one or more of the following features. The pyrolysis oil can be derived from pyrolysis of waste plastic. The hydrocracking catalyst can be configured to produce a yield of C2-C4 alkanes in a range of from about 40 wt.% to about 100 wt.%. The hydrocracking product stream can comprise at least about 90 wt.% of C2-C4 alkanes. the hydrocracking product stream comprises at least 95 about wt.% of C2-C4 alkanes. The pyrolysis oil can comprise from about 20 wt.% to about 40 wt.% of one or more linear alkanes, from 0 wt.% to about 40 wt.% of one or more cyclic alkanes, from 0 wt.% to about 50 wt.% of one or more alkenes, from 0 wt.% to about 40 wt.% of one or more aromatic compounds, and from 0 wt.% to about 50 wt.% of one or more C15+ hydrocarbons. The hydrocracking catalyst can comprise natural zeolites, synthetic zeolites, bauxite, alkali oxides, alkaline metal earth oxides, aluminum phosphates, transition metal oxides, or any combination of these. The hydrocracking catalyst can comprise palladium dispersed on a zeolite support. In some implementations, the hydrocracking catalyst

comprises 0.2 wt.% of palladium. The ODH reactor can be configured to operate at a temperature from about 300°C to about 500°C. The ODH reactor can be configured to operate at a temperature from about 315°C to about 400°C. The ODH reactor can be configured to operate at an outlet pressure from about 0.5 psig to about 100 psig. The ODH reactor can be configured to operate at an outlet pressure from about 15 psig to about 504 psig. The ODH catalyst can be configured to exhibit a selectivity to ethylene in a range of from about 75 mol. % to about 99 mol. %. The hydrogen can be at least partially sourced from the steam cracker. The ODH reactor can be configured to receive additional ethane from the steam cracker, pyrolysis oil, or both along with the ethane feed stream. The hydrocracking unit can be configured to operate at a pressure from about 300 psig to about 1002 psig. The hydrocracking unit can be configured to operate at a temperature from about 350°C to about 500°C. The hydrocracking feed stream can have a liquid hourly space velocity (LHSV) from about 0.2 per hour (hr^{-1}) to about 5 hr^{-1} in the hydrocracking unit. A volumetric ratio of hydrogen in a gas phase at STP within the hydrocracking unit to the pyrolysis oil in a liquid phase within the hydrocracking unit can be from about 500:1 to about 2000:1. The separation can be configured to separate the C3+ feed stream can be separated into a C3 feed stream and a C4 feed stream. The C3+ feed stream can be diluted with ethane, propane, butane, or any combinations thereof. A C4+ portion of the hydrocracking product stream can be recycled to the hydrocracking unit. The C4+ portion can include at least one of a C5 alkane or a higher alkane.

The details of one or more implementations of the invention are set forth in the accompanying drawings and the following description. Other features, objects, and advantages of the invention will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1 is a block diagram of an example system that integrates an ethane oxidative dehydrogenation (ODH) process with a hydrocracking process in series.

Figure 2A is a block diagram of an example system that integrates an ethane ODH process with a hydrocracking process in parallel.

Figure 2B is a block diagram of an example system that integrates an ethane ODH process with a hydrocracking process in parallel that also incorporates an acetic acid hydrogenation process.

Figure 2C is a block diagram of an example system that integrates an ethane ODH process with a hydrocracking process in parallel that also incorporates an acetic acid hydrogenation process and a hydrogen oxidation process.

Figure 3 is a block diagram of an example system that integrates a steam cracking process with a hydrocracking process.

Figure 4 is a flow chart of an example process for integrating ethane ODH with hydrocracking in series.

Figure 5 is a flow chart of an example process for integrating ethane ODH with hydrocracking in parallel.

DESCRIPTION OF EMBODIMENTS

Provided herein are processes and systems for producing ethylene from pyrolysis oil (also referred to as pyoil) by integrating oxidative dehydrogenation (ODH) of ethane into ethylene with hydrocracking and steam cracking. The pyrolysis oil undergoes a hydrocracking process in the presence of hydrogen for conversion into C2-C4 alkanes. The processes described includes oxidatively dehydrogenating the ethane into ethylene in an ODH reactor in the presence of oxygen and an ODH catalyst and under ODH conditions to form an output stream that includes ethylene.

While conventional hydrocracking processes utilize crude oil (as well as ethane, propane, and butanes) as feedstock, the systems and processes described utilize pyrolysis oil that has been derived from waste plastic. The systems and processes described may also process components such as ethane, propane, butanes, and hydrogen (for example, recycled within the systems and processes), but the primary feedstock to the systems and processes described can be the pyrolysis oil derived from waste plastic. The pyrolysis oil derived from waste plastic can be converted into ethylene at greater yields (for example, greater than 70% conversion by weight into ethylene) in comparison to conventional processes, such as direct steam cracking of pyrolysis oil. The systems and processes described integrate hydrocracking, steam cracking, and oxidative dehydrogenation to increase ethylene yields. The hydrocracking processes described herein implement hydrocracking catalyst(s) that can convert pyrolysis oil derived from waste plastic into light C1-C4 hydrocarbons. The hydrocracking processes described herein implement operating conditions that improve the performance of the hydrocracking catalyst(s) for improving the yield of light C1-C4 hydrocarbons from pyrolysis oil that has been derived from waste plastic. The hydrocracking processes described herein can convert heavier portions of the pyrolysis oil in comparison to conventional hydrocracking process. For example,

conventional hydrocracking processes can typically convert lighter portions of the pyrolysis oil, up to about 171 degrees Celsius (°C) boiling point cut, whereas the hydrocracking processes described herein can convert heavier portions of the pyrolysis oil, from about 15°C up to about 600°C boiling point cut. Thus, a larger portion (and in some cases, close to 100%) of the pyrolysis oil can be converted by the systems and processes described herein. The processes and systems provide an integration opportunity which allows use of trace contaminants from the respective product effluents from the ODH process and the hydrocracking process, such that downstream separation of such trace contaminants can be eliminated, resulting in more efficient production of ethylene.

Figure 1 is a block diagram of an example system 100 for producing ethylene from pyroil that integrates an ethane ODH process with a hydrocracking process in series. The system 100 includes a hydrocracking unit 102, a separation unit 104, an ODH reaction unit 106, and a steam cracker 108. The system 100 includes a hydrocracking feed stream 110, a hydrocracking product stream 112, an ethane feed stream 114, a C3+ feed stream 116, an ODH product stream 118, and a steam cracking product stream 120. The hydrocracking feed stream 110 includes pyrolysis oil that is derived from pyrolysis of synthetic rubber and/or waste plastic, including but not limited to polyesters (for example, polyethylene terephthalate (PET) or polycaprolactone), polyolefins (for example, low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), medium-density polyethylene (MDPE), high-density polyethylene (HDPE), or polypropylene (PP)), polyvinyl chloride (PVC), polystyrene (PS), polycarbonates, polylactides, polyethers, polyacrylates, acrylonitrile rubbers (for example, acrylonitrile butadiene styrene (ABS), styrene-acrylonitrile resin (SAN), acrylonitrile styrene acrylate (ASA), acrylonitrile butadiene rubber (NBR)), nylons, polyurethanes, or any combination or copolymers of these. Pyrolysis is the process of thermal decomposition of a material (such as waste plastic) at elevated temperatures in an inert atmosphere (for example, absence of oxygen). In some implementations, the pyrolysis oil includes from 0 weight percent (wt.%) to about 20 wt.% of one or more aromatic compounds (such as benzene, xylene, or toluene). For example, the pyrolysis oil includes less than about 15 wt.%, less than about 10 wt.%, less than about 5 wt.%, or less than about 1 wt.% of one or more aromatic compounds. For example, the pyrolysis oil includes from about 1 wt.% to 20 wt.%, from about 1 wt.% to about 15 wt.%, from about 1 wt.% to about 10 wt.%, or from about 1 wt.% to about 5 wt.% of one or more aromatic compounds.

The hydrocracking unit 102 is configured to receive the hydrocracking feed stream 110. The hydrocracking unit 102 is configured to convert the hydrocracking feed stream 110 into the hydrocracking product stream 112. The hydrocracking unit 102 is configured to discharge the hydrocracking product stream 112. The hydrocracking unit 102 includes a hydrocracking catalyst, for example, disposed within a hydrocracking reactor. In some implementations, the hydrocracking reactor includes an adiabatic multiple-bed reactor (e.g., a fixed-bed or trickle-bed reactor) with interstage cooling or a heat exchanger-type reactor. The hydrocracking catalyst is configured to convert, in response to contacting the hydrocracking feed stream 110, at least a portion of the pyrolysis oil of the hydrocracking feed stream 110 in the presence of hydrogen into a lower alkane. A lower alkane can include at least one of a C1 alkane, a C2 alkane, a C3 alkane, or a C4 alkane. C1-C4 alkanes can include alkanes having a number of carbon atoms from 1 to 4. Examples of C1-C4 alkanes include methane (C1), ethane (C2), propane (C3), and butane (C4). C4+ alkanes are alkanes that have a number of carbon atoms greater than 4 (that is, at least 5 carbon atoms). C4+ alkanes can be referred to as higher alkanes. C4+ hydrocarbons are hydrocarbons that have a number of carbon atoms greater than 4 (that is, at least 5 carbon atoms). In some implementations, the hydrocracking unit 102 is configured to convert at least about 80 wt.% of the pyrolysis oil of the feed stream 107 into one or more C1-C4 alkanes. For example, the hydrocracking unit 102 can be configured to convert from about 80 wt.% to 100 wt.%, from about 90 wt.% to 100 wt.%, or from about 95 wt.% to 100 wt.% of the pyrolysis oil of the hydrocracking feed stream 110 into one or more C1-C4 alkanes. Hydrogen gas can be provided to the hydrocracking reactor along with the hydrocracking feed stream 110. In some implementations, a volume ratio at STP of hydrogen gas to the hydrocracking feed stream 110 (pyrolysis oil) entering the hydrocracking reactor is equal to or less than 2,000:1. The hydrocracking unit 102 can convert a wide range of compositions of the hydrocracking feed stream 110 into C1-C4 alkanes. For example, the hydrocracking unit 102 can convert the hydrocracking feed stream 110 free of (that is, 0%) C15+ hydrocarbon content (considered as a light pyoil) into C1-C4 alkanes. As another example, the hydrocracking unit 102 can convert the hydrocracking feed stream 110 having a C15+ hydrocarbon content of up to about 50% (with 50% considered as a heavy/waxy pyoil) into C1-C4 alkanes. In some implementations, the hydrocracking unit 102 is configured to convert the hydrocracking feed stream 110 to produce a yield in a range of from about 40 wt.% to about 100 wt.%, from about 60 wt.% to about 98 wt.%, or from about 70 wt.% to about 95 wt.% of one or more C2-C4 alkanes.

In some implementations, the hydrocracking catalyst includes a metallic component and a support. For example, the metallic component of the hydrocracking catalyst can include palladium (Pd), rhodium (Rh), ruthenium (Ru), iridium (Ir), osmium (Os), copper (Cu), cobalt (Co), nickel (Ni), platinum (Pt), iron (Fe), zinc (Zn), gallium (Ga), indium (In),
5 molybdenum (Mo), tungsten (W), vanadium (V), or any combination of these. For example, the support of the hydrocracking catalyst can include a naturally occurring zeolite that is mined or synthetically manufactured (such as mordenite, cancrinite, gmelinite, faujasite, or clinoptilolite) or a man-made zeolite (such as a synthetic zeolite), or any of their acidic forms.

10 In some implementations, a reaction temperature maintained in the hydrocracking reactor is in a range of from about 250°C to about 500°C, from about 300°C to about 450°C, from about 350°C to about 410°C, from about 350°C to about 450°C, or from about 350°C to about 500°C. In some implementations, a reactor inlet pressure in the hydrocracking reactor is in a range of from about 2,755 kilopascals gauge (kPag) to about
15 10,340 kPag, from about 3,450 kPag to about 8,615 kPag, or from about 4,825 kPag to about 6,895 kPag. In some implementations, the liquid hourly space velocity (LHSV) of the hydrocracking feed stream 110 in the hydrocracking reactor is in a range of from about 0.2 per hour to about 5 per hour, from about 0.5 per hour to about 3 per hour, from about 0.5 per hour to about 1.25 per hour, or from about 0.75 per hour to about 2 per hour. The
20 hydrocracking product stream 112 is discharged by the hydrocracking unit 102.

The hydrocracking product stream 112 can include from 0 wt.% to about 15 wt.% of hydrogen (H₂). The hydrocracking product stream 112 can include from 0 wt.% to about 10 wt.% of methane. The hydrocracking product stream 112 can include from 0 wt.% to about 20 wt.% of a combined content of hydrogen and methane. The hydrocracking product
25 stream 112 can include from 0 wt.% to about 15 wt.% of ethane. The hydrocracking product stream 112 can include from 0 wt.% to about 45 wt.% of propane. The hydrocracking product stream 112 can include from about 10 wt.% to about 40 wt.% of butane. The hydrocracking product stream 112 can include from about 15 wt.% to about 95 wt.% of LPGs (a combined content of ethane, propane, and butane (and any isomers
30 thereof)). The hydrocracking product stream 112 can include from 0 wt.% to about 70 wt.% of C₄+ hydrocarbons. The hydrocracking product stream 112 can be processed to separate components from the hydrocracking product stream 112 prior to being discharged by the hydrocracking unit 102. For example, hydrogen, methane, and C₄+ hydrocarbons (that is, hydrocarbons having a number of carbon atoms greater than 4) can be separated from the

hydrocracking product stream 112, such that a majority of the hydrocracking product stream 112 is C2-C4 alkanes prior to undergoing separation in the separation unit 104. The hydrocracking product stream 112 can flow from the hydrocracking unit 102 to the separation unit 104.

5 The gas analysis was performed using a Varian CP-3800 gas chromatograph. The apparatus was directly connected at the back end of the hydrocracking unit 102 with about 10 psig of head pressure. The gas chromatograph was equipped with a sampling valve with two 250 microliter (μL) loops. Each loop was directed to a different column: A Molsieve 5A 45/60 1.5 m x 1/8" (for permanent gases) and a HayeSep D 80/100 1.8 m x 1/8" (for
10 hydrocarbons). Each column was equipped with its own Thermal Conductivity Detector (TCD) detector. Both injectors were operated at 100°C. The columns in the oven were initially at 50°C. This initial temperature (50°C) was maintained for 4 minutes and then increased to 268°C at a temperature increase rate of 8.4°C per minute. The final temperature (268°C) was maintained for 5 minutes. Pressure for the Molsieve column was
15 initially set at 14 psig and maintained for 4 minutes. The pressure was then increased to 27 psig at a pressure increase rate of 0.5 psi per minute (psi/min) during the temperature increase. The final pressure (27 psig) was maintained for 5 minutes. Pressure for the HayeSep column was initially set at 21 psig and maintained for 4 minutes. The pressure was then increased to 39.2 psig at 0.7 psi/min during the temperature increase. The carrier
20 gas included argon for both columns. Both TCDs were maintained at a temperature of 170°C. Identification and quantification of the gas chromatography peaks were completed by an external standard using a calibration gas mixture. The Hayesep column was used for the main quantification procedure of the light hydrocarbon product gases. Table 1 provides a gas product composition of the example hydrocracking product (hydrocracking product
25 stream 108). The example hydrocracking product (hydrocracking product stream 108) had an average molecular weight of 9.98 grams per mole. As shown in Table 1, over 90% of the carbon-based components (hydrocarbons, excluding hydrogen gas) were C2-C4 alkanes.

Table 1: Gas Composition of Hydrocracking Product

Component	Concentration (wt.%)	Yield (wt.%)
Hydrogen (H ₂)	15.8	N/A
Methane (CH ₄)	6.8	8.1
Ethylene (C ₂ H ₄)	0.1	Negligible
Ethane (C ₂ H ₆)	6.9	6.9
Propane (C ₃ H ₈)	42	45.1
Isobutane (i-C ₄)	12.9	38.7*
Normal Butane (n-C ₄)	14.3	
Isopentane (i-C ₅)	0.9	1.4*
Normal Pentane (n-C ₅)	0.3	

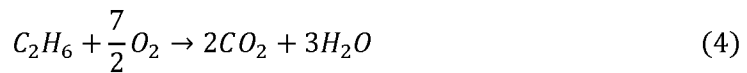
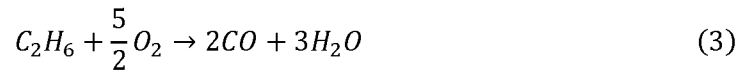
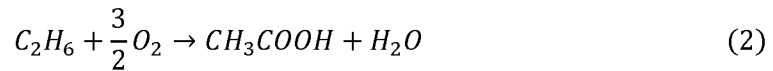
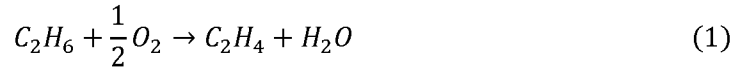
*C4 and C5 isomer contents are combined for yield values.

The separation unit 104 is configured to receive the hydrocracking product stream 112. The separation unit 104 is configured to separate the hydrocracking product stream 112 into the ethane feed stream 114 and the C3+ feed stream 116. The separation unit 104 is configured to discharge the ethane feed stream 114. The separation unit 104 is configured to discharge the C3+ feed stream 116. In some implementations, the separation unit 104 includes a de-methanizer column. The de-methanizer column can be configured to receive and fractionate the hydrocracking product stream 112 from the hydrocracking unit 102. The de-methanizer column can be configured to separate hydrogen and methane from a remaining portion of the hydrocracking product stream 112 (such as ethane, propane, and butane). In some implementations, the hydrogen separated by the de-methanizer column is recycled to the hydrocracking unit 102. The remaining portion of the hydrocracking product stream 112 (for example, C2-C4 alkanes) is substantially free of hydrogen and methane. For example, the remaining portion of the hydrocracking product stream 112 after the hydrogen and methane has been separated can have less than about 1 wt.%, less than about 0.5 wt.%, less than about 0.1 wt.%, or less than about 0.01 wt.% of hydrogen. For example, the remaining portion of the hydrocracking product stream 112 after the hydrogen and methane has been separated can have less than about 1 wt.%, less than about 0.5 wt.%, less than about 0.1 wt.%, or less than about 0.01 wt.% of methane. The separated hydrogen, the separated methane, or both can be recycled to the hydrocracking unit 102. In some implementations, the separation unit 104 includes a de-ethanizer column. The de-ethanizer column can be configured to receive and fractionate the hydrocracking product stream 112 or the remaining portion of the hydrocracking product stream 112 from the de-methanizer column. The de-ethanizer column can be configured to separate ethane from heavier hydrocarbons, such as propane and butane. The ethane separated from the de-ethanizer

column can be discharged from the separation unit 104 as the ethane feed stream 114. The ethane feed stream 114 can flow to the ODH reaction unit 106. The heavier hydrocarbons, such as propane and butane, separated from the de-ethanizer column can be discharged from the separation unit 104 as the C3+ feed stream 116. The C3+ feed stream 116 can flow to the steam cracker 108.

In some implementations, the separation unit 104 includes a separator. The separator can, for example, be configured to receive and fractionate the hydrocracking product stream 112, the remaining portion of the hydrocracking product stream 112 from the de-methanizer column, or the heavier hydrocarbons from the de-ethanizer column. The separator can be configured to separate C4+ hydrocarbons from lighter hydrocarbons, such as C3-C4 alkanes. The C3-C4 alkanes can be the C3+ feed stream 116 that flows from the separation unit 104 to the steam cracker 108. The separated C4+ hydrocarbons can be recycled to the hydrocracking unit 102.

The ODH reaction unit 106 is configured to receive the ethane feed stream 114. The ODH reaction unit 106 is configured to convert the ethane feed stream 114 into the ODH product stream 118. The ODH reaction unit 106 converts the ethane feed 114 into the ODH product stream 118 by dehydrogenating the ethane in the ethane feed 114 into ethylene. The ODH reaction unit 106 includes an oxidative dehydrogenation catalyst. Contacting the ethane feed 114 with the ODH catalyst within the ODH reaction unit 106 under ODH conditions converts the ethane in the ethane feed stream 114 into ethylene. In some implementations, the ethane feed stream 114 is diluted with an oxidant (for example, oxygen) to form an ODH feed stream, and the ODH feed stream is contacted with the ODH catalyst within the ODH reaction unit 106 under ODH conditions to convert the ethane in the ODH feed stream (from the ethane feed stream 114) into ethylene. The ODH reaction unit 106 is configured to discharge the ODH product stream 118. The ODH product stream 118 includes the ethylene produced in the ODH reaction unit 106. In some implementations, the ODH product stream 118 has an ethylene content of at least 99 wt.% (for example, at least 99.5 wt.%, at least 99.9 wt.%, at least 99.99 wt.%, or at least 99.999 wt.%). In some implementations, the ODH product stream 118 has an ethylene content of at least 95 volume percent (vol.%) (for example, at least 96 vol.%, at least 97 vol.%, at least 98 vol.%, at least 99 vol.%, at least 99.5 vol.%, at least 99.9 vol.%, at least 99.99 vol.%, or at least 99.999 vol.%). Equations 1, 2, 3, and 4 show four example chemical reactions that can occur in the ODH reaction unit 106. Fewer or additional chemical reactions may occur in the ODH reaction unit 106.



5 In some implementations, the ODH catalyst includes molybdenum, vanadium, oxygen, and iron. The molar ratio of molybdenum to vanadium in the ODH catalyst can be from 1:0.1 to 1:0.5. The molar ratio of molybdenum to iron in the ODH catalyst can be from 1:0.25 to 1:5.5. Further, oxygen can be present in the ODH catalyst at least in amount to satisfy the valency of any present metal oxides. In some implementations, the ODH catalyst includes molybdenum, vanadium, oxygen, and aluminum. The molar ratio of molybdenum to vanadium can be from 1:0.1 to 1:0.5. The molar ratio of molybdenum to aluminum can be from 1:1.5 to 1:6.5. Further, oxygen can be present at least in an amount to satisfy the valency of any present metal oxides. In some implementations, the ODH catalyst includes molybdenum, vanadium, beryllium, and oxygen. The molar ratio of molybdenum to vanadium can be from 1:0.25 to 1:0.65. The molar ratio of molybdenum to beryllium can be from 1:0.25 to 1:85. Further, oxygen is present at least in an amount to satisfy the valency of any present metal oxides.

The steam cracker 108 is configured to receive the C3+ feed stream 116. The steam cracker 108 is configured to crack the C3+ feed stream 116 in the presence of steam to produce the steam cracking product stream 120. The steam cracker 108 is configured to discharge the steam cracking product stream 120. The C3+ feed stream 116 from the separation unit 104 is diluted with steam 122 prior to cracking by the steam cracker 108. In some implementations, a mass ratio of steam 122 to the C3+ feed stream 116 that is provided to the steam cracker 108 is in a range of from about 1:5 to about 2:5. In some implementations, a mass ratio of steam 122 to ethane in the C3+ feed stream 116 that is provided to the steam cracker 108 is in a range of from about 1:5 to about 2:5. The steam cracker 108 is configured to receive and heat at least a portion of the C3+ feed stream 116 diluted with steam 122 to convert at least a portion of the one or more C3+ alkanes (for example, propane and butane) to ethylene. In some implementations, the C3+ feed stream 116 is also diluted with hydrogen, methane, or any combination of these. Dilution of the C3+ feed stream 116 with hydrogen and/or methane can reduce production of carbon

dioxide. In some implementations, the C3+ feed stream 116 diluted with steam 122 is heated to a temperature in a range of from about 700°C to about 1,000°C, from about 800°C to about 900°C, or from about 800°C to about 850°C. In some implementations, the operating pressure in the steam cracker 108 is in a range of from about 150 kPag to about 200 kPag. In some implementations, the residence time of the C3+ feed stream 116 diluted with steam 122 through the steam cracker 108 is less than about 1.5 seconds or less than about 1 second. For example, the residence time of the C3+ feed stream 116 diluted with steam 122 through the steam cracker 108 can be a few milliseconds. The ethylene from the steam cracker 108 is separated (for example, by distillation or membrane separation) to form the steam cracking product stream 120. In some implementations, the steam cracker 108 includes a separation unit that purifies the steam cracking product stream 120 to be predominantly ethylene. In some implementations, the steam cracking product stream 120 has an ethylene content of at least 99 wt.% (for example, at least 99.5 wt.%, at least 99.9 wt.%, at least 99.99 wt.%, or at least 99.999 wt.%). In some implementations, the steam cracking product stream 120 has an ethylene content of at least 95 volume percent (vol.%) (for example, at least 96 vol.%, at least 97 vol.%, at least 98 vol.%, at least 99 vol.%, at least 99.5 vol.%, at least 99.9 vol.%, at least 99.99 vol.%, or at least 99.999 vol.%). In some implementations, a mass ratio of the steam cracking product stream 120 to the hydrocracking feed stream 110 (pyrolysis oil) is in a range of from about 3:10 to about 10:10, from about 5:10 to about 10:10, from about 6:10 to about 9:10 or from about 7:10 to about 8:10. In some implementations, unreacted ethane from the steam cracker 108 is separated and recycled back to the steam cracker 108 for improving overall conversion to ethylene.

In some implementations, a mass ratio of the ethylene of the combined ODH product stream 118 and the steam cracking product stream 120 to the hydrocracking feed stream 102 (pyrolysis oil) is in a range of from about 6:10 to about 9:10 or from about 7:10 to about 8:10. In other words, the system 100 can convert from about 60 wt.% to about 90 wt.%, from about 70 wt.% to about 80 wt.%, or about 75 wt.% of pyrolysis oil (entering the hydrocracking unit 102) into ethylene (exiting the ODH reaction unit 106 and the steam cracker 108).

The ODH process in the ODH reaction unit 106 produces less greenhouse gases (such as carbon dioxide) in comparison to the steam cracking process in the steam cracker 108. By separating the ethane from the remaining, heavier hydrocarbons (such as propane and butane) in the separation unit 104, greenhouse gas production by the system 100 can be

reduced in comparison to conventional systems and processes where C₃+ (for example, the non-separated hydrocracking product stream 112) undergoes steam cracking. Further, the ODH process in the ODH reaction unit 106 can more efficiently convert ethane into ethylene in comparison to the steam cracking process in the steam cracker 108. By
5 integrating the ODH process in the ODH reaction unit 106 with the steam cracking process in the steam cracker 108, the system 100 can increase overall ethylene yields and can exhibit increased feed flexibility (that is, composition fluctuations in the feed) while also reducing energy consumption (tied to operational costs) and greenhouse gas production in comparison to conventional systems and processes that implement only the ODH process,
10 only the steam cracking process, or both processes separately (without integration with one another).

The hydrocracking feed stream 110 may include impurities, depending on the type and composition of the plastic waste used to generate the pyrolysis oil. Some examples of impurities that may exist in the hydrocracking feed stream 110 include compounds
15 including heteroatoms (such as sulfur (S), oxygen (O), nitrogen (N), chlorine (Cl), phosphorus (P)) and metal impurities. Some examples of heteroatom-containing compounds include nitrogen gas (N₂), oxygen gas (O₂), chlorine gas (Cl₂), ammonia (NH₃), and amides. Some examples of metal impurities include compounds including calcium (Ca), magnesium (Mg), iron (Fe), or sodium (Na), which can be bound to hydrocarbon
20 components or exist as parts of other compounds, such as salts (for example, calcium carbonate (CaCO₃), magnesium chloride (MgCl₂), and iron hydroxide (Fe(OH)₃)). As described previously, the types and amount of impurities that exist in the hydrocracking feed stream 110 depend on the type and composition of the feedstock used to generate the pyrolysis oil. Impurities in the hydrocracking feed stream 110 may negatively impact (for
25 example, deactivate) catalyst activity (for example, in the hydrocracking unit 102). Thus, in some cases (and especially in cases where impurities exist in the hydrocracking feed stream 110), it can be beneficial to purify the hydrocracking feed stream 110 (for example, to remove such impurities).

In some implementations, the system 100 includes a purification unit upstream of
30 the hydrocracking unit 102. The purification unit can be configured to remove impurities (such as heteroatom-containing compounds and/or metal impurities) from the hydrocracking feed stream 110. The purification unit can also saturate olefins in the hydrocracking feed stream 110 into naphthenes and/or paraffins. The purification unit can implement various processes (such as hydrotreatment, adsorption, and absorption) to purify the hydrocracking

feed stream 110. In some implementations, the purification unit includes a hydrotreater that includes a hydrotreatment catalyst. The hydrotreatment catalyst can include, for example, nickel-molybdenum (NiMo), nickel-tungsten (NiW), or cobalt-molybdenum (CoMo). In some implementations, the hydrotreatment catalyst is supported by an alumina carrier. As
5 an example, the purification unit can include two packed bed reactors in series, each loaded with hydrotreatment catalyst. The packed bed reactors can be operated at a hydrotreatment temperature in a range of from about 300°C to about 400°C or from about 350°C to about 380°C. For example, the first packed bed reactor can operate at a first hydrotreatment temperature of about 350°C, and the second packed bed reactor can operate at a second
10 hydrotreatment temperature of about 380°C. In some implementations, both packed bed reactors operate at an operating pressure of about 6,895 kPag. In some implementations, the LHSV of the feed stream 106 in each of the packed bed reactors is about 0.5 per hour. Hydrogen gas can be provided to the purification unit along with the hydrocracking feed stream 110. In some implementations, a volume ratio at standard temperature and pressure
15 (STP, which is pressure of 1 atmosphere (atm) and temperature of 0°C) of hydrogen gas to the hydrocracking feed stream 110 entering the purification unit is equal to or less than 2,000:1. For example, the volume ratio at STP of hydrogen gas to the hydrocracking feed stream 110 entering the purification unit is in a range of from about 500:1 to about 2,000:1. In some implementations, the purification unit is configured to remove enough impurities
20 from the hydrocracking feed stream 110, such that the hydrocracking feed stream 110 exiting the purification unit and entering the hydrocracking unit 102 has a sulfur content of less than about 100 parts per million (ppm), less than about 50 ppm, less than about 10 ppm, less than about 1 ppm, or less than about 0.1 ppm. In some implementations, the hydrocracking feed stream 110 exiting the purification unit and entering the hydrocracking
25 unit 102 has a nitrogen content of less than about 100 ppm, less than about 50 ppm, less than about 10 ppm, less than about 1 ppm, or less than about 0.1 ppm. In some implementations, the hydrocracking feed stream 110 exiting the purification unit and entering the hydrocracking unit 102 has an oxygen content of less than about 500 ppm, less than about 200 ppm, less than about 100 ppm, less than about 10 ppm, less than about 1
30 ppm, or less than about 0.1 ppm. In some implementations, the hydrocracking feed stream 110 exiting the purification unit and entering the hydrocracking unit 102 has a chlorine content of less than about 10 ppm, less than about 5 ppm, less than about 3 ppm, less than about 2 ppm, less than about 1 ppm, or less than about 0.1 ppm. In some implementations, the hydrocracking feed stream 110 exiting the purification unit and entering the

hydrocracking unit 102 has a phosphorus content of less than about 2 ppm, less than about 1 ppm, or less than about 0.1 ppm. In some implementations, the hydrocracking feed stream 110 exiting the purification unit and entering the hydrocracking unit 102 has a calcium content of less than about 20 ppm, less than about 10 ppm, less than about 1 ppm, or less than about 0.1 ppm. In some implementations, the hydrocracking feed stream 110 exiting the purification unit and entering the hydrocracking unit 102 has a sodium content of less than about 20 ppm, less than about 10 ppm, less than about 1 ppm, or less than about 0.1 ppm. In some implementations, the hydrocracking feed stream 110 exiting the purification unit and entering the hydrocracking unit 102 has a silicon content of less than about 20 ppm, less than about 10 ppm, less than about 1 ppm, or less than about 0.1 ppm. In some implementations, the hydrocracking feed stream 110 exiting the purification unit and entering the hydrocracking unit 102 has an iron content of less than about 10 ppm, less than about 5 ppm, less than about 3 ppm, less than about 2 ppm, less than about 1 ppm, less than about 0.1 ppm, less than about 0.01 ppm, or less than about 0.001 ppm.

Figure 2A is a block diagram of an example system 200A that integrates an ethane ODH process with a hydrocracking process in parallel. The system 200A includes a hydrocracking unit 202, an ODH reaction unit 204, a hydrogen oxidation unit 206, and a separation unit 208. The system 200A includes a hydrocracking feed stream 210, a hydrocracking product stream 212, an ethane feed stream 214, an ODH product stream 216, and a mixed product stream 218. The hydrocracking unit 202 can be substantially similar to the hydrocracking unit 102 of system 100 (Figure 1). The ODH reaction unit 204 can be substantially similar to the ODH reaction unit 106 of system 100 (Figure 1). The hydrocracking feed stream 210 can be substantially similar to the hydrocracking feed stream 110 of system 100 (Figure 1). The hydrocracking product stream 212 can be substantially similar to the hydrocracking product stream 112 of system 100 (Figure 1). The ethane feed stream 214 can be substantially similar to the ethane feed stream 114 of system 100 (Figure 1). The ODH product stream 216 can be substantially similar to the ODH product stream 118 of system 100 (Figure 1).

The hydrocracking unit 202 is configured to receive the hydrocracking feed stream 210. The hydrocracking unit 202 is configured to convert, in the presence of hydrogen, the hydrocracking feed stream 210 into the hydrocracking product stream 212. The hydrocracking unit 202 is configured to discharge the hydrocracking product stream 212. An example composition of the hydrocracking product stream 212 is provided in Table 1. The hydrocracking product stream 212 can be processed to separate components from the

hydrocracking product stream 212 prior to being discharged by the hydrocracking unit 202. For example, methane and C4+ hydrocarbons (that is, hydrocarbons having a number of carbon atoms greater than 4) can be separated from the hydrocracking product stream 212, such that a majority of the hydrocracking product stream 212 is C2-C4 alkanes prior to
5 undergoing hydrogen combustion in the hydrogen oxidation unit 206. In some implementations, C4+ hydrocarbons are recycled to the hydrocracking unit 202 to improve overall cracking efficiency of the hydrocracking unit 202. The hydrocracking product stream 212 may include residual hydrogen that was not reacted in the hydrocracking unit 202. In some implementations, the hydrocracking product stream 212 has a residual
10 hydrogen content in a range of from about 0.01 molar percent (mol. %) to about 80 mol. %, from about 0.01 mol. % to about 70 mol. %, from about 0.01 mol. % to about 60 mol. %, or from about 0.01 mol. % to about 50 mol. %. The hydrocracking product stream 212 can flow from the hydrocracking unit 202 to the hydrogen oxidation unit 206.

The ODH reaction unit 204 is configured to receive the ethane feed stream 214. The
15 ODH reaction unit 204 is configured to convert the ethane feed stream 214 into the ODH product stream 216. The ODH reaction unit 204 converts the ethane feed 214 into the ODH product stream 216 by dehydrogenating the ethane in the ethane feed 214 into ethylene. In some implementations, the ethane feed stream 214 is diluted with an oxidant (for example, oxygen) to form an ODH feed stream, and the ODH feed stream is contacted with the ODH
20 catalyst within the ODH reaction unit 204 under ODH conditions to convert the ethane in the ODH feed stream (from the ethane feed stream 214) into ethylene. The ODH reaction unit 204 is configured to discharge the ODH product stream 216. The ODH product stream 216 includes the ethylene produced in the ODH reaction unit 204. In some implementations, the ODH reaction unit 204 includes a separation unit that purifies the
25 ODH product stream 216 to be predominantly ethylene. In some implementations, the ODH product stream 216 has an ethylene content of at least 99 wt.% (for example, at least 99.5 wt.%, at least 99.9 wt.%, at least 99.99 wt.%, or at least 99.999 wt.%). In some implementations, the ODH product stream 216 has an ethylene content of at least 95 vol.% (for example, at least 96 vol.%, at least 97 vol.%, at least 98 vol.%, at least 99 vol.%, at
30 least 99.5 vol.%, at least 99.9 vol.%, at least 99.99 vol.%, or at least 99.999 vol.%). Equations 1, 2, 3, and 4 show four example chemical reactions that can occur in the ODH reaction unit 204. Fewer or additional chemical reactions may occur in the ODH reaction unit 204. The ODH product stream 216 may include residual oxygen that was not reacted in the ODH reaction unit 204. In some implementations, the ODH product stream 216 has a

residual oxygen content in a range of from about 0.0001 mol. % to about 1 mol. %, from about 0.001 mol. % to about 1 mol. %, or from about 0.01 mol. % to about 1 mol. %. The ODH product stream 216 can flow from the ODH reaction unit 204 to the hydrogen oxidation unit 206.

5 The hydrogen oxidation unit 206 is configured to receive the hydrocracking product stream 212 and the ODH product stream 216. The hydrogen oxidation unit 206 is configured to combine the hydrocracking product stream 212 with the ODH product stream 216. The hydrogen oxidation unit 206 is configured to oxidize the residual hydrogen that may be present in the hydrocracking product stream 212 using the residual oxygen that may
10 be present in the ODH product stream 216. The combined hydrocracking product stream 212 and ODH product stream 216 make up the mixed product stream 218. The residual oxygen (from the ODH product stream 216) oxidizes at least a portion of the mixed product stream 212, such as the residual hydrogen from the hydrocracking product stream 212. In some implementations, the hydrogen oxidation unit 206 includes a combustion reactor that
15 combusts the residual hydrogen from the hydrocracking product stream 212 using the residual oxygen from the ODH product stream 216. The combustion reactor in the hydrogen oxidation unit 206 can be, for example, a controlled oxidation reactor. In some implementations, the hydrogen oxidation unit 206 includes an adiabatic reactor (for example, a shell-and-tube adiabatic reactor) that oxidizes the residual hydrogen from the
20 hydrocracking product stream 212 using the residual oxygen from the ODH product stream 216. The adiabatic reactor can be used instead of the combustion reactor (which can result in capital and operating cost savings), for example, in cases where the residual oxygen content of the ODH product stream 216 is equal to or less than about 0.1 mol. %. The residual hydrogen from the hydrocracking product stream 212 oxidizes into water in the
25 hydrogen oxidation unit 206. The mixed product stream 218 includes the water that is formed in the hydrogen oxidation unit 206. The mixed product stream 218 includes a remaining portion of the hydrocracking product stream 212 after the residual hydrogen has been oxidized. The mixed product stream 218 includes a remaining portion of the ODH product stream 216 after the residual oxygen has been used to oxidize the residual
30 hydrogen. The mixed product stream 218 includes ethylene, LPGs, and water. The hydrogen oxidation unit 206 is configured to discharge the mixed product stream 218. The mixed product stream 218 can flow from the hydrogen oxidation unit 206 to the separation unit 208. By utilizing the residual oxygen from the ODH product stream 216 to oxidize the residual hydrogen from the hydrocracking product stream 212, potential oxidation of other,

more useful compounds (such as carbon monoxide or hydrocarbons (including ethylene)) can be avoided. Thus, the system 200A reduces and/or eliminate potential product waste (by oxidation) and additional greenhouse gas production.

In some implementations, a reaction temperature maintained in the combustion reactor of the hydrogen oxidation unit 206 is in a range of from about 50°C to about 400°C, from about 80°C to about 120°C, from about 200°C to about 400°C, or from about 250°C to about 350°C. In some implementations, a reaction inlet pressure in the combustion reactor of the hydrogen oxidation unit 206 is in a range of from about 50 kPag to about 150 kPag or from about 75 kPag to about 125 kPag. In some implementations, the combustion reactor of the hydrogen oxidation unit 206 includes a hydrogen combustion catalyst that is configured to selectively combust hydrogen over different compounds (such as hydrocarbons). In some implementations, the hydrogen combustion catalyst includes a metallic component and a support. For example, the metallic component of the hydrogen combustion catalyst can include silver (Ag), cerium (Ce), zirconium (Zr), copper (Cu), cobalt (Co), any oxide thereof, or any combination of these. For example, the support of the hydrogen combustion catalyst can include a naturally occurring zeolite that is mined or synthetically manufactured (such as mordenite, cancrinite, gmelinite, faujasite, or clinoptilolite) or a man-made zeolite (such as a synthetic zeolite), or any of their acidic forms. As another example, the support of the hydrogen combustion catalyst can include silica.

The separation unit 208 is configured to receive the mixed product stream 218. The separation unit 208 is configured to separate the mixed product stream 218 into various, individual product streams. For example, the separation unit 208 can be configured to separate ethylene from the mixed product stream 218 to produce and discharge an ethylene stream 220. In some implementations, the ethylene stream 220 has an ethylene content of at least 99 wt.% (for example, at least 99.5 wt.%, at least 99.9 wt.%, at least 99.99 wt.%, or at least 99.999 wt.%). In some implementations, the ethylene stream 220 has an ethylene content of at least 95 volume percent (vol.%) (for example, at least 96 vol.%, at least 97 vol.%, at least 98 vol.%, at least 99 vol.%, at least 99.5 vol.%, at least 99.9 vol.%, at least 99.99 vol.%, or at least 99.999 vol.%). As another example, the separation unit 208 can be configured to separate LPGs from the mixed product stream 218 to produce and discharge an LPG stream 222. In some implementations, the LPG stream 222 has an LPGs content (that is, combined content of ethane, propane, and butane (and any isomers thereof)) of at least 99 wt.% (for example, at least 99.5 wt.%, at least 99.9 wt.%, at least 99.99 wt.%, or at

least 99.999 wt.%). In some implementations, the separation unit 208 is configured to separate ethane from heavier hydrocarbons, such as propane and butane. For example, the separation unit 208 can include a de-ethanizer column. The ethane separated from the de-ethanizer column can be discharged from the separation unit 208 and can, for example, be recycled to the hydrocracking unit 202, the ODH reaction unit 204, or both. In some implementations, the separation unit 208 is configured to separate water from the mixed product stream 218 to produce and discharge a water stream 224. The water stream 224 can, for example, be split into hydrogen and oxygen (for example, by electrochemical water splitting). The hydrogen produced by water splitting can be recycled and flowed to the hydrocracking unit 202. The oxygen produced by water splitting can be recycled and flowed to the ODH reaction unit 204.

Figure 2B is a block diagram of an example system 200B that integrates an ethane ODH process with a hydrocracking process in parallel that also incorporates an acetic acid hydrogenation process. The system 200B includes a hydrocracking unit 202, an ODH reaction unit 204, an acetic acid/water scrubber 209, an acetic acid hydrogenation unit 211, and a separation unit 213. The system 200A includes a hydrocracking feed stream 210, a hydrocracking product stream 212, an ethane feed stream 214, an ODH product stream 216, a liquid product stream 226, a gas product stream 228, and a mixed product stream 230. The hydrocracking unit 202 can be substantially similar to the hydrocracking unit 102 of system 100 (Figure 1). The ODH reaction unit 204 can be substantially similar to the ODH reaction unit 106 of system 100 (Figure 1). The hydrocracking feed stream 210 can be substantially similar to the hydrocracking feed stream 110 of system 100 (Figure 1). The hydrocracking product stream 212 can be substantially similar to the hydrocracking product stream 112 of system 100 (Figure 1). The ethane feed stream 214 can be substantially similar to the ethane feed stream 114 of system 100 (Figure 1). The ODH product stream 216 can be substantially similar to the ODH product stream 118 of system 100 (Figure 1).

The hydrocracking unit 202 is configured to receive the hydrocracking feed stream 210. The hydrocracking unit 202 is configured to convert, in the presence of hydrogen, the hydrocracking feed stream 210 into the hydrocracking product stream 212. The hydrocracking unit 202 is configured to discharge the hydrocracking product stream 212. An example composition of the hydrocracking product stream 212 is provided in Table 1. The hydrocracking product stream 212 can be processed to separate components from the hydrocracking product stream 212 prior to being discharged by the hydrocracking unit 202. For example, methane and C4+ hydrocarbons (that is, hydrocarbons having a number of

carbon atoms greater than 4) can be separated from the hydrocracking product stream 212, such that a majority of the hydrocracking product stream 212 is C2-C4 alkanes prior to undergoing hydrogen combustion in the hydrogen oxidation unit 206. In some implementations, C4+ hydrocarbons are recycled to the hydrocracking unit 202 to improve overall cracking efficiency of the hydrocracking unit 202. The hydrocracking product stream 212 may include residual hydrogen that was not reacted in the hydrocracking unit 202. In some implementations, the hydrocracking product stream 212 has a residual hydrogen content in a range of from about 0.01 molar percent (mol. %) to about 80 mol. %, from about 0.01 mol. % to about 70 mol. %, from about 0.01 mol. % to about 60 mol. %, or from about 0.01 mol. % to about 50 mol. %. The hydrocracking product stream 212 can flow from the hydrocracking unit 202 to the acetic acid hydrogenation unit 211.

The ODH reaction unit 204 is configured to receive the ethane feed stream 214. The ODH reaction unit 204 is configured to convert the ethane feed stream 214 into the ODH product stream 216. The ODH reaction unit 204 converts the ethane feed 214 into the ODH product stream 216 by dehydrogenating the ethane in the ethane feed 214 into ethylene. In some implementations, the ethane feed stream 214 is diluted with an oxidant (for example, oxygen) to form an ODH feed stream, and the ODH feed stream is contacted with the ODH catalyst within the ODH reaction unit 204 under ODH conditions to convert the ethane in the ODH feed stream (from the ethane feed stream 214) into ethylene. The ODH reaction unit 204 is configured to discharge the ODH product stream 216. The ODH product stream 216 includes the ethylene produced in the ODH reaction unit 204. In some implementations, the ODH product stream 216 has an ethylene content of at least 99 wt.% (for example, at least 99.5 wt.%, at least 99.9 wt.%, at least 99.99 wt.%, or at least 99.999 wt.%). In some implementations, the ODH product stream 216 has an ethylene content of at least 95 volume percent (vol.%) (for example, at least 96 vol.%, at least 97 vol.%, at least 98 vol.%, at least 99 vol.%, at least 99.5 vol.%, at least 99.9 vol.%, at least 99.99 vol.%, or at least 99.999 vol.%). Equations 1, 2, 3, and 4 show four example chemical reactions that can occur in the ODH reaction unit 204. Fewer or additional chemical reactions may occur in the ODH reaction unit 204. The ODH product stream 216 may include acetic acid. In some implementations, the ODH product stream 216 has an acetic acid content in a range of from 0 mol. % to about 10 mol. %, from about 0.01 mol. % to about 10 mol. %, from about 0.01 mol. % to about 5 mol. %, or from about 1 mol. % to about 5 mol. %. The ODH product stream 216 can flow from the ODH reaction unit 204 to the acetic acid/water scrubber 209.

The acetic acid/water scrubber 209 is configured to receive the ODH product stream 216. The acetic acid/water scrubber 209 is configured to spray water (or an aqueous solution) from the top of the acetic acid/water scrubber 209. As the ODH product stream 216 (in a gaseous state) flows up through the acetic acid/water scrubber 209, the ODH product stream 216 comes into contact with the water. The water causes acetic acid to condense from the ODH product stream 216 and drop out as a liquid along with the water from the bottom of the acetic acid/water scrubber 209. The acetic acid/water scrubber 209 is configured to discharge the liquid product stream 226 from the bottom of the acetic acid/water scrubber 209. The liquid product stream 226 includes the water that was sprayed from the top of the acetic acid/water scrubber 209 and the acetic acid that condensed and separated from the gaseous portion of the ODH product stream 216. In some implementations, the liquid product stream 226 is an aqueous solution of acetic acid having an acetic acid concentration in a range of from about 0.01 weight percent (wt. %) to about 30 wt. %. The liquid product stream 226 can flow from the acetic acid/water scrubber 209 to the acetic acid hydrogenation unit 211. The acetic acid/water scrubber 209 is configured to discharge the gas product stream 228 from the top of the acetic acid/water scrubber 209. The gas product stream 228 includes a remaining gaseous portion of the ODH product stream 216 after the acetic acid has condensed and separated out as liquid. The gas product stream 228 can include ethylene. The gas product stream 228 exiting the acetic acid/water scrubber 209 has a reduced acetic acid concentration (in some cases, negligible or zero amount) in comparison to the ODH product stream 216 entering the acetic acid/water scrubber 209. The gas product stream 228 can flow from the acetic acid/water scrubber 209 to the separation unit 213.

The acetic acid hydrogenation unit 211 is configured to receive the hydrocracking product stream 212 and the liquid product stream 226. The combined hydrocracking product stream 212 and liquid product stream 226 make up the mixed product stream 230. The acetic acid hydrogenation unit 211 is configured to hydrogenate the acetic acid in the mixed product stream 230 using the residual hydrogen from the hydrocracking product stream 212 to form ethanol. The acetic acid hydrogenation unit 211 includes an acetic acid hydrogenation catalyst. Contacting the hydrocracking product stream 212 and the liquid product stream 226 with the acetic acid hydrogenation catalyst within the acetic acid hydrogenation unit 211 under acetic acid hydrogenation conditions converts the acetic acid into ethanol. The mixed product stream 230 includes the ethanol that is formed in the acetic acid hydrogenation unit 211. The mixed product stream 230 includes a remaining portion

of the hydrocracking product stream 212 after the residual hydrogen has been used to hydrogenate the acetic acid. The mixed product stream 230 includes a remaining portion of the liquid product stream 226 after the acetic acid has been hydrogenated to produce the ethanol. The mixed product stream 230 includes ethylene, LPGs, and ethanol. The acetic acid hydrogenation unit 211 is configured to discharge the mixed product stream 230. The mixed product stream 230 can flow from the acetic acid hydrogenation unit 211 to the separation unit 213. By utilizing the residual hydrogen from the hydrocracking product stream 212 to hydrogenate the acetic acid from the ODH product stream 216, the system 200B reduces the load on the separation unit 213 by eliminating the need to separate hydrogen from other components.

In some implementations, a reaction temperature maintained in the acetic acid hydrogenation unit 211 is in a range of from about 150°C to about 350°C, from about 200°C to about 350°C, or from about 250°C to about 350°C. In some implementations, a reaction inlet pressure in the acetic acid hydrogenation unit 211 is in a range of from 0 kPag (atmospheric pressure) to about 2,500 kPag or from 0 kPag to about 100 kPag. In some implementations, the acetic acid hydrogenation catalyst includes a metallic component and a support. For example, the metallic component of the acetic acid hydrogenation catalyst can include a transition metal (such as platinum, ruthenium, or copper) or an alloy of transition metals. For example, the support of the acetic acid hydrogenation catalyst can include a naturally occurring zeolite that is mined or synthetically manufactured (such as mordenite, cancrinite, gmelinite, faujasite, or clinoptilolite) or a man-made zeolite (such as a synthetic zeolite), or any of their acidic forms. As another example, the support of the acetic acid hydrogenation catalyst can include silica, titania, or alumina.

The separation unit 213 is configured to receive the gas product stream 228 and the mixed product stream 230. The separation unit 213 is configured to separate the gas product stream 228 and the mixed product stream 230 into various, individual product streams. For example, the separation unit 213 is configured to separate ethylene from the gas product stream 228 and the mixed product stream 230 to produce and discharge an ethylene stream 232. In some implementations, the ethylene stream 232 has an ethylene content of at least 99 wt.% (for example, at least 99.5 wt.%, at least 99.9 wt.%, at least 99.99 wt.%, or at least 99.999 wt.%). In some implementations, the ethylene stream 232 has an ethylene content of at least 95 volume percent (vol.%) (for example, at least 96 vol.%, at least 97 vol.%, at least 98 vol.%, at least 99 vol.%, at least 99.5 vol.%, at least 99.9 vol.%, at least 99.99 vol.%, or at least 99.999 vol.%). As another example, the

separation unit 213 can be configured to separate LPGs from the mixed product stream 230 to produce and discharge an LPG stream 234. In some implementations, the LPG stream 234 has an LPGs content (that is, combined content of ethane, propane, and butane (and any isomers thereof)) of at least 99 wt.% (for example, at least 99.5 wt.%, at least 99.9 wt.%, at least 99.99 wt.%, or at least 99.999 wt.%). In some implementations, the separation unit 213 is configured to separate ethane from heavier hydrocarbons, such as propane and butane. For example, the separation unit 213 can include a de-ethanizer column. The ethane separated from the de-ethanizer column can be discharged from the separation unit 213 and can, for example, be recycled to the hydrocracking unit 202, the ODH reaction unit 204, or both. In some implementations, the separation unit 213 is configured to separate ethanol from the mixed product stream 230 to produce and discharge an ethanol stream 236.

Figure 2C is a block diagram of an example system 200C that integrates an ethane ODH process with a hydrocracking process in parallel that also incorporates an acetic acid hydrogenation process and a hydrogen oxidation process. The system 200C includes a hydrocracking unit 202, an ODH reaction unit 204, an acetic acid/water scrubber 209, an acetic acid hydrogenation unit 211, a hydrogen oxidation unit 215, and a separation unit 217. The system 200A includes a hydrocracking feed stream 210, a hydrocracking product stream 212, an ethane feed stream 214, an ODH product stream 216, a liquid product stream 226, a gas product stream 228, a first mixed product stream 238, and a second mixed product stream 240. The hydrocracking unit 202 can be substantially similar to the hydrocracking unit 102 of system 100 (Figure 1). The ODH reaction unit 204 can be substantially similar to the ODH reaction unit 106 of system 100 (Figure 1). The hydrocracking feed stream 210 can be substantially similar to the hydrocracking feed stream 110 of system 100 (Figure 1). The hydrocracking product stream 212 can be substantially similar to the hydrocracking product stream 112 of system 100 (Figure 1). The ethane feed stream 214 can be substantially similar to the ethane feed stream 114 of system 100 (Figure 1). The ODH product stream 216 can be substantially similar to the ODH product stream 118 of system 100 (Figure 1). The hydrogen oxidation unit 215 can be substantially similar to the hydrogen oxidation unit 206 of system 200A (Figure 2A).

The hydrocracking unit 202 is configured to receive the hydrocracking feed stream 210. The hydrocracking unit 202 is configured to convert, in the presence of hydrogen, the hydrocracking feed stream 210 into the hydrocracking product stream 212. The hydrocracking unit 202 is configured to discharge the hydrocracking product stream 212. An example composition of the hydrocracking product stream 212 is provided in Table 1.

The hydrocracking product stream 212 can be processed to separate components from the hydrocracking product stream 212 prior to being discharged by the hydrocracking unit 202. For example, methane and C4+ hydrocarbons (that is, hydrocarbons having a number of carbon atoms greater than 4) can be separated from the hydrocracking product stream 212, such that a majority of the hydrocracking product stream 212 is C2-C4 alkanes prior to undergoing hydrogen combustion in the hydrogen oxidation unit 206. In some implementations, C4+ hydrocarbons are recycled to the hydrocracking unit 202 to improve overall cracking efficiency of the hydrocracking unit 202. The hydrocracking product stream 212 may include residual hydrogen that was not reacted in the hydrocracking unit 202. In some implementations, the hydrocracking product stream 212 has a residual hydrogen content in a range of from about 0.01 molar percent (mol. %) to about 80 mol. %, from about 0.01 mol. % to about 70 mol. %, from about 0.01 mol. % to about 60 mol. %, or from about 0.01 mol. % to about 50 mol. %. The hydrocracking product stream 212 can flow from the hydrocracking unit 202 to the acetic acid hydrogenation unit 211.

The ODH reaction unit 204 is configured to receive the ethane feed stream 214. The ODH reaction unit 204 is configured to convert the ethane feed stream 214 into the ODH product stream 216. The ODH reaction unit 204 converts the ethane feed 214 into the ODH product stream 216 by dehydrogenating the ethane in the ethane feed 214 into ethylene. In some implementations, the ethane feed stream 214 is diluted with an oxidant (for example, oxygen) to form an ODH feed stream, and the ODH feed stream is contacted with the ODH catalyst within the ODH reaction unit 204 under ODH conditions to convert the ethane in the ODH feed stream (from the ethane feed stream 214) into ethylene. The ODH reaction unit 204 is configured to discharge the ODH product stream 216. The ODH product stream 216 includes the ethylene produced in the ODH reaction unit 204. In some implementations, the ODH product stream 216 has an ethylene content of at least 99 wt.% (for example, at least 99.5 wt.%, at least 99.9 wt.%, at least 99.99 wt.%, or at least 99.999 wt.%). In some implementations, the ODH product stream 216 has an ethylene content of at least 95 volume percent (vol.%) (for example, at least 96 vol.%, at least 97 vol.%, at least 98 vol.%, at least 99 vol.%, at least 99.5 vol.%, at least 99.9 vol.%, at least 99.99 vol.%, or at least 99.999 vol.%). Equations 1, 2, 3, and 4 show four example chemical reactions that can occur in the ODH reaction unit 204. Fewer or additional chemical reactions may occur in the ODH reaction unit 204. The ODH product stream 216 may include acetic acid. In some implementations, the ODH product stream 216 has an acetic acid content in a range of from 0 mol. % to about 10 mol. %, from about 0.01 mol. % to about 10 mol. %, from about

0.01 mol. % to about 5 mol. %, or from about 1 mol. % to about 5 mol. %. The ODH product stream 216 may include residual oxygen that was not reacted in the ODH reaction unit 204. In some implementations, the ODH product stream 216 has a residual oxygen content in a range of from about 0.0001 mol. % to about 1 mol. %, from about 0.001 mol. % to about 1 mol. %, or from about 0.01 mol. % to about 1 mol. %. The ODH product stream 216 can flow from the ODH reaction unit 204 to the acetic acid/water scrubber 209.

The acetic acid/water scrubber 209 is configured to receive the ODH product stream 216. The acetic acid/water scrubber 209 is configured to spray water (or an aqueous solution) from the top of the acetic acid/water scrubber 209. As the ODH product stream 216 (in a gaseous state) flows up through the acetic acid/water scrubber 209, the ODH product stream 216 comes into contact with the water. The water causes acetic acid to condense from the ODH product stream 216 and drop out as a liquid along with the water from the bottom of the acetic acid/water scrubber 209. The acetic acid/water scrubber 209 is configured to discharge the liquid product stream 226 from the bottom of the acetic acid/water scrubber 209. The liquid product stream 226 includes the water that was sprayed from the top of the acetic acid/water scrubber 209 and the acetic acid that condensed and separated from the gaseous portion of the ODH product stream 216. In some implementations, the liquid product stream 226 is an aqueous solution of acetic acid having an acetic acid concentration in a range of from about 0.01 weight percent (wt. %) to about 30 wt. %. The liquid product stream 226 can flow from the acetic acid/water scrubber 209 to the acetic acid hydrogenation unit 211. The acetic acid/water scrubber 209 is configured to discharge the gas product stream 228 from the top of the acetic acid/water scrubber 209. The gas product stream 228 includes a remaining gaseous portion of the ODH product stream 216 after the acetic acid has condensed and separated out as liquid. The gas product stream 228 can include ethylene. The gas product stream 228 exiting the acetic acid/water scrubber 209 has a reduced acetic acid concentration (in some cases, negligible or zero amount) in comparison to the ODH product stream 216 entering the acetic acid/water scrubber 209. The gas product stream 228 can flow from the acetic acid/water scrubber 209 to the hydrogen oxidation unit 215.

The acetic acid hydrogenation unit 211 is configured to receive the hydrocracking product stream 212 and the liquid product stream 226. The combined hydrocracking product stream 212 and liquid product stream 226 make up the first mixed product stream 238. The first mixed product stream 238 can be evaporated, such that it is in a gas state prior to entering the acetic acid hydrogenation unit 211. The acetic acid hydrogenation unit

211 is configured to hydrogenate the acetic acid in the first mixed product stream 238 using the residual hydrogen from the hydrocracking product stream 212 to form ethanol. The acetic acid hydrogenation unit 211 includes an acetic acid hydrogenation catalyst. Contacting the hydrocracking product stream 212 and the liquid product stream 226 with the acetic acid hydrogenation catalyst within the acetic acid hydrogenation unit 211 under acetic acid hydrogenation conditions converts the acetic acid into ethanol. The first mixed product stream 238 includes the ethanol that is formed in the acetic acid hydrogenation unit 211. The first mixed product stream 238 includes a remaining portion of the hydrocracking product stream 212 after the residual hydrogen has been used to hydrogenate the acetic acid. The first mixed product stream 238 includes a remaining portion of the liquid product stream 226 after the acetic acid has been hydrogenated to produce the ethanol. The first mixed product stream 238 includes ethylene, LPGs, and ethanol. The acetic acid hydrogenation unit 211 is configured to discharge the first mixed product stream 238. The first mixed product stream 238 can flow from the acetic acid hydrogenation unit 211 to the hydrogen oxidation unit 215. By utilizing the residual hydrogen from the hydrocracking product stream 212 to hydrogenate the acetic acid from the ODH product stream 216, the system 200C reduces the load on the separation unit 217 by eliminating the need to separate hydrogen from other components.

In some implementations, a reaction temperature maintained in the acetic acid hydrogenation unit 211 is in a range of from about 150°C to about 350°C, from about 200°C to about 350°C, or from about 250°C to about 350°C. In some implementations, a reaction inlet pressure in the acetic acid hydrogenation unit 211 is in a range of from about 0 kPag (atmospheric pressure) to about 2,500 kPag or from about 0 kPag to about 100 kPag. In some implementations, the acetic acid hydrogenation catalyst includes a metallic component and a support. For example, the metallic component of the acetic acid hydrogenation catalyst can include a transition metal (such as platinum, ruthenium, or copper) or an alloy of transition metals. For example, the support of the acetic acid hydrogenation catalyst can include a naturally occurring zeolite that is mined or synthetically manufactured (such as mordenite, cancrinite, gmelinite, faujasite, or clinoptilolite) or a man-made zeolite (such as a synthetic zeolite), or any of their acidic forms. As another example, the support of the acetic acid hydrogenation catalyst can include silica, titania, or alumina.

The hydrogen oxidation unit 215 is configured to receive the gas product stream 228 and the first mixed product stream 238. The hydrogen oxidation unit 215 is configured to

combine the gas product stream 228 with the first mixed product stream 238. The hydrogen oxidation unit 215 is configured to oxidize the residual hydrogen that may be present in the first mixed product stream 238 (originating from the hydrocracking product stream 212) using the residual oxygen that may be present in the gas product stream 228 (originating from the ODH product stream 216). The combined gas product stream 228 and first mixed product stream 238 make up the second mixed product stream 240. The residual oxygen (from the gas product stream 228) oxidizes at least a portion of the second mixed product stream 240, such as the residual hydrogen from the mixed product stream 238. In some implementations, the hydrogen oxidation unit 215 includes a combustion reactor that combusts the residual hydrogen from the mixed product stream 238 using the residual oxygen from the gas product stream 228. In some implementations, the hydrogen oxidation unit 215 includes an adiabatic reactor (for example, a shell-and-tube adiabatic reactor) that oxidizes the residual hydrogen from the mixed product stream 238 using the residual oxygen from the gas product stream 228. The adiabatic reactor can be used instead of the combustion reactor (which can result in capital and operating cost savings), for example, in cases where the residual oxygen content of the gas product stream 228 is equal to or less than about 0.1 mol. %. The residual hydrogen from the mixed product stream 238 oxidizes into water in the hydrogen oxidation unit 215. The second mixed product stream 240 includes the water that is formed in the hydrogen oxidation unit 215. The second mixed product stream 240 includes a remaining portion of the first mixed product stream 238 after the residual hydrogen has been oxidized. The second mixed product stream 240 includes a remaining portion of the gas product stream 228 after the residual oxygen has been used to oxidize the residual hydrogen. The second mixed product stream 240 includes ethylene, LPGs, ethanol, and water. The hydrogen oxidation unit 215 is configured to discharge the second mixed product stream 240. The second mixed product stream 240 can flow from the hydrogen oxidation unit 215 to the separation unit 217. By utilizing the residual oxygen from the gas product stream 228 to oxidize the residual hydrogen from the mixed product stream 238, potential oxidation of other, more useful compounds (such as carbon monoxide or hydrocarbons (including ethylene)) can be avoided. Thus, the system 200C reduces and/or eliminate potential product waste (by oxidation) and additional greenhouse gas production.

In some implementations, a reaction temperature maintained in the combustion reactor of the hydrogen oxidation unit 215 is in a range of from about 200°C to about 400°C or from about 250°C to about 350°C. In some implementations, a reaction inlet pressure in

the combustion reactor of the hydrogen oxidation unit 215 is in a range of from about 50 kPag to about 150 kPag or from about 75 kPag to about 125 kPag. In some implementations, the combustion reactor of the hydrogen oxidation unit 215 includes a hydrogen combustion catalyst that is configured to selectively combust hydrogen over
5 different compounds (such as hydrocarbons). The hydrogen combustion catalyst of the hydrogen oxidation unit 215 can be substantially similar to the hydrogen combustion catalyst of the hydrogen oxidation unit 206 of system 200A (Figure 2A).

The separation unit 217 is configured to receive the second mixed product stream 240. The separation unit 217 is configured to separate the second mixed product stream 240
10 into various, individual product streams. For example, the separation unit 217 is configured to separate ethylene from the second mixed product stream 240 to produce and discharge an ethylene stream 242. In some implementations, the ethylene stream 242 has an ethylene content of at least 99 wt.% (for example, at least 99.5 wt.%, at least 99.9 wt.%, at least 99.99 wt.%, or at least 99.999 wt.%). In some implementations, the ethylene stream 242
15 has an ethylene content of at least 95 volume percent (vol.%) (for example, at least 96 vol.%, at least 97 vol.%, at least 98 vol.%, at least 99 vol.%, at least 99.5 vol.%, at least 99.9 vol.%, at least 99.99 vol.%, or at least 99.999 vol.%). As another example, the separation unit 217 can be configured to separate LPGs from the second mixed product stream 240 to produce and discharge an LPG stream 244. In some implementations, the
20 LPG stream 244 has an LPGs content (that is, combined content of ethane, propane, and butane (and any isomers thereof)) of at least 99 wt.% (for example, at least 99.5 wt.%, at least 99.9 wt.%, at least 99.99 wt.%, or at least 99.999 wt.%). In some implementations, the separation unit 217 is configured to separate ethane from heavier hydrocarbons, such as propane and butane. For example, the separation unit 217 can include a de-ethanizer
25 column. The ethane separated from the de-ethanizer column can be discharged from the separation unit 217 and can, for example, be recycled to the hydrocracking unit 202, the ODH reaction unit 204, or both. In some implementations, the separation unit 217 is configured to separate water from the second mixed product stream 240 to produce and discharge a water stream 246. The water stream 246 can, for example, be split into
30 hydrogen and oxygen (for example, by electrochemical water splitting). The hydrogen produced by water splitting can be recycled and flowed to the hydrocracking unit 202. The oxygen produced by water splitting can be recycled and flowed to the ODH reaction unit 204. In some implementations, the separation unit 217 is configured to separate ethanol from the second mixed product stream 230 to produce and discharge an ethanol stream 248.

Figure 3 is a block diagram of an example system 300 that integrates a steam cracking process with a hydrocracking process. The system 300 includes a steam cracker 302 and a hydrocracking unit 304. The system 300 includes a steam cracking feed 306, a steam cracking product stream 308, and a hydrocracking product stream 310. The steam cracker 302 can be substantially similar to the steam cracker 108 of the system 100 (Figure 1). The hydrocracking unit 304 can be substantially similar to the hydrocracking unit 102 of system 100 (Figure 1).

The steam cracking feed 306 includes hydrocarbons diluted with steam. The steam cracking feed 306 can include, for example, ethane, propane, and naphtha. In some implementations, the steam cracking feed 306 is separated into a C3 feed stream (for example, including propane) and a C4 feed stream (for example, including one or more isomers of butane). In some implementations, the steam cracking feed 306 is diluted with ethane, propane, butane, or any combinations thereof. In some implementations, a mass ratio of steam to hydrocarbons in the steam cracking feed 306 is in a range of from about 2:10 to about 8:10 or from about 3:10 to about 7:10. In some implementations, the hydrocarbon portion of the steam cracking feed 306 has an ethane content in a range of from about 25 vol. % to about 40 vol. %. In some implementations, the hydrocarbon portion of the steam cracking feed 306 has a propane content in a range of from about 30 vol. % to about 50 vol. %. In some implementations, the hydrocarbon portion of the steam cracking feed 306 has a naphtha content in a range of from about 50 vol. % to about 80 vol. %. The steam cracker 302 is configured to receive and heat at least a portion of the steam cracking feed 306 to convert at least a portion of the steam cracking feed 306 to ethylene. The heating in the steam cracker 302 is performed in the absence of oxygen, so that combustion of the hydrocarbons in the steam cracking feed 306 is avoided. In some implementations, the steam cracking feed 306 is heated to a temperature in a range of from about 700°C to about 1,000°C, from about 800°C to about 900°C, or from about 800°C to about 850°C. In some implementations, the operating pressure in the steam cracker 302 is in a range of from about 150 kPag to about 200 kPag. In some implementations, the residence time of the steam cracking feed 306 through the steam cracker 302 is less than about 1.5 seconds or less than about 1 second. For example, the residence time of the steam cracking feed 306 through the steam cracker 302 can be a few milliseconds. The ethylene from the steam cracker 302 is separated (for example, by distillation or membrane separation) to form the steam cracking product stream 308. In some implementations, the steam cracking product stream 308 has an ethylene content of at least 8 wt.%. In some

implementations, the stream cracking product stream 308 has an ethylene content in a range of from about 8 wt.% to about 35 wt.%. In some implementations, unreacted ethane from the steam cracker 302 is separated and recycled back to the steam cracker 302 for improving overall conversion to ethylene.

5 The hydrocracking unit 304 is configured to receive a portion 308a of the steam cracking product stream 308. The portion 308a of the steam cracking product stream 308 can be referred to as pyrolysis gas. The hydrocracking unit 304 is configured to convert, in the presence of hydrogen, the pyrolysis gas 308a into the hydrocracking product stream 310. In some implementations, the hydrocracking unit 304 is configured to utilize the pyrolysis
10 gas 308a as a quenching medium to cool another stream in the hydrocracking unit 304. The hydrocracking unit 304 is configured to discharge the hydrocracking product stream 310. The hydrocracking product stream 310 include ethylene. In some implementations, the hydrocracking product stream 310 has an ethylene content of at least 99 wt.% (for example, at least 99.5 wt.%, at least 99.9 wt.%, at least 99.99 wt.%, or at least 99.999 wt.%). In some
15 implementations, the hydrocracking product stream 310 has an ethylene content of at least 95 volume percent (vol.%) (for example, at least 96 vol.%, at least 97 vol.%, at least 98 vol.%, at least 99 vol.%, at least 99.5 vol.%, at least 99.9 vol.%, at least 99.99 vol.%, or at least 99.999 vol.%).

By integrating steam cracking with hydrocracking, overall yield of ethylene can be
20 increased in comparison to conventional systems and processes that implement only steam cracking, only hydrocracking, or both processes separately (without integration with one another). Further, waste (such as plastic waste originating from the pyrolysis oil and coke formation) can be reduced, decoking maintenance intervals can be reduced, and yield of lower-value co-products can be reduced. The integration of steam cracking and
25 hydrocracking can also reduce overall energy usage (resulting in operational cost savings) and reduce greenhouse gas production.

Although not shown in Figures 1, 2A, 2B, 2C, and 3, the systems (100, 200A, 200B, 200C, and 300) can (and are expected to) include the typical components included in similar systems. For example, in each of the configurations described, process streams (also
30 referred to as “streams”) are flowed within each unit and between units of the respective system. The process streams can be flowed using one or more flow control systems implemented throughout the respective system. A flow control system can include one or more pumps to flow the process streams, one or more blowers/compressors to flow the process streams, one or more flow pipes through which the process streams are flowed, and

one or more flow elements (such as valves and orifice plates) to regulate the flow of streams through the pipes.

In some implementations, a flow control system can be operated manually. For example, an operator can set a flow rate for each pump by changing the position of a valve (open, partially open, or closed) to regulate the flow of the process streams through the pipes in the flow control system. Once the operator has set the flow rates and the valve positions for all flow control systems distributed across the respective system, the flow control system can flow the streams within a unit or between units under constant flow conditions, for example, constant volumetric or mass flow rates. To change the flow conditions, the operator can manually operate the flow control system, for example, by changing the valve position.

In some implementations, a flow control system can be operated automatically. For example, the flow control system can be connected to a computer system to operate the flow control system. The computer system can include a computer-readable medium storing instructions (such as flow control instructions) executable by one or more processors to perform operations (such as flow control operations). For example, an operator can set the flow rates by setting the valve positions for all flow control systems distributed across the respective system using the computer system. In such implementations, the operator can manually change the flow conditions by providing inputs through the computer system. In such implementations, the computer system can automatically (that is, without manual intervention) control one or more of the flow control systems, for example, using feedback systems implemented in one or more units and connected to the computer system. For example, a sensor (such as a pressure sensor or temperature sensor) can be connected to a pipe through which a process stream flows. The sensor can monitor and provide operating conditions (such as a pressure or temperature) of the process stream to the computer system. In response to the operating condition deviating from a set point (such as a target pressure value or target temperature value) or exceeding a threshold (such as a threshold pressure value or threshold temperature value), the computer system can automatically perform operations to adjust properties of the flow control system. For example, if the pressure or temperature in the pipe exceeds the threshold pressure value or the threshold temperature value, respectively, the computer system can provide a signal to open a valve to relieve pressure or a signal to shut down process stream flow.

Figure 4 is a flow chart of an example process 400 for integrating ethane ODH with hydrocracking in series. The system 100 can, for example, implement the process 400. At

block 402, a hydrocracking feed stream (such as the hydrocracking feed stream 110) is contacted with a hydrocracking catalyst disposed within a hydrocracking unit (such as the hydrocracking unit 102). As described previously, the hydrocracking feed stream 110 includes pyrolysis oil. The hydrocracking feed stream 110 is contacted with the

5 hydrocracking catalyst disposed within the hydrocracking unit 102 at block 402 to convert, in the presence of hydrogen, at least a portion of the pyrolysis oil into a lower alkane to produce a hydrocracking product stream (such as the hydrocracking product stream 112). At block 404, the hydrocracking product stream 112 is separated into an ethane feed stream (such as the ethane feed stream 114) and a C3+ feed stream (such as the C3+ feed stream

10 116). As described previously, the ethane feed stream 114 includes ethane, and the C3+ feed stream 116 includes at least one of a C3 alkane, a C4 alkane, or a higher alkane. At block 406, the C3+ feed stream 116 is diluted with steam (such as the steam 122) to form a steam cracking feed stream. In some implementations, the C3+ feed stream 116 is separated into a C3 feed stream and a C4 feed stream. In some implementations, the C3+

15 feed stream is diluted with ethane, propane, butane, or any combinations thereof. At block 408, the steam cracking feed stream is heated in a steam cracker (such as the steam cracker 108) to convert at least a portion of the C3+ feed stream 116 to ethylene. At block 410, the ethane feed stream 114 is diluted with an oxidant (such as oxygen) to form an ODH feed stream. At block 412, the ODH feed stream is contacted with an ODH catalyst disposed

20 within an ODH reactor (for example, in the ODH reaction unit 106) to convert at least a portion of the ethane (from the ethane feed stream 114) to ethylene.

Figure 5 is a flow chart of an example process 500 for integrating ethane ODH with hydrocracking in parallel. The systems 200A, 200B, 200C can, for example, implement the process 500. At block 502, a hydrocracking feed stream (such as the hydrocracking feed

25 stream 210) is contacted with a hydrocracking catalyst disposed within a hydrocracking unit (such as the hydrocracking unit 202). As described previously, the hydrocracking feed stream 210 includes pyrolysis oil. The hydrocracking feed stream 210 is contacted with the hydrocracking catalyst disposed within the hydrocracking unit 202 at block 502 to convert, in the presence of hydrogen, at least a portion of the pyrolysis oil into a lower alkane to

30 produce a hydrocracking product stream (such as the hydrocracking product stream 212). As described previously, the hydrocracking product stream 212 may include residual hydrogen that did not react in the hydrocracking unit 202. At block 504, an ODH feed stream (such as the ethane feed stream 214 diluted with an oxidant (such as oxygen)) is contacted with an ODH catalyst disposed within an ODH reactor (for example, in the ODH

reaction unit 204) to convert at least a portion of the ethane (from the ethane feed stream 214) to ethylene to produce an ODH product stream (such as the ODH product stream 216). As described previously, the ODH product stream 216 may include residual oxygen that did not react in the ODH reaction unit 204. At block 506, at least a portion of the

5 hydrocracking product stream 212 is combined with at least a portion of the ODH product stream 216 to produce a mixed stream. In some implementations, the residual hydrogen from the hydrocracking product stream 212 reduces at least a portion of the mixed stream. For example, the residual hydrogen from the hydrocracking product stream 212

10 hydrogenates (reduces) the acetic acid from the liquid product stream 226 (which is derived from the ODH product stream 216) (examples are depicted by systems 200B and 200C in Figures 2B and 2C, respectively). In some implementations, the residual oxygen from the ODH product stream 216 oxidizes at least a portion of the mixed stream. For example, the residual oxygen from the ODH product stream 216 can oxidize the residual hydrogen from the hydrocracking product stream 212 (examples are depicted by systems 200A and 200C in

15 Figures 2A and 2C, respectively). At block 508, an ethylene stream (such as the ethylene stream 220, 232, or 242) and an LPG stream (such as the LPG stream 222, 234, or 244) are separated from the mixed stream (such as the mixed product stream 218, 230, or 240).

EXAMPLES

Example 1 (ODH process with Hydrocracking process in series comparative
20 embodiment – Aspen Plus® Simulation)

Aspen Plus® (version 12.1) simulation was used to model the embodiment shown in Figure 1. The simulation model utilized a non-random two-liquid (NRTL) model. The simulation model included a base case including hydrocracking and steam cracking processes without integrated ODH process for comparison. The example feedstock to the

25 steam cracker for the base case (excluding ODH process integration) included 16 kilotons per annum (kta) of methane, 56.1 kta of ethane, 72.1 kta of propane, and 16.2 kta of butane. For the ODH process and hydrocracking process integration embodiment, the feedstock was the same as that of the base case but was separated into an ethane feed and a C3+ feed (for example, by the separation unit 104). In the ODH process and hydrocracking process

30 integration embodiment, the ethane feed was sent to the ODH reaction unit 106, while the C3+ feed was sent to the steam cracker 108. The final product rates for each case are shown in Table 2.

The simulation results of Example 1 show a 2.1% improvement in total ethylene yield for the ODH process and hydrocracking process integration embodiment in

comparison to the base case. The base case produced 120.6 kta of ethylene, while the ODH process and hydrocracking process integration embodiment produced 123.1 kta. In the ODH process and hydrocracking process integration embodiment, 78.4 kta of the ethylene was produced by steam cracking of the C3+ feed, while 44.7 kta of the ethylene was produced by the ODH process. Further, the greenhouse gas emissions associated with the ethane cracking portions of the base case and the ODH process and hydrocracking process integration embodiment were 17.8 kta and 3.4 kta of carbon dioxide equivalent (CO₂-eq), respectively, which translates to an 80.9% reduction in greenhouse gas emissions for the ODH process and hydrocracking process integration embodiment in comparison to the base case.

Table 2: ODH Process with Hydrocracking Process in Series Simulation Results

Comparison

Compound	Base Case (kta) (excluding ODH)	ODH + Hydrocracking (kta) Integration Embodiment
Hydrogen	9.0	5.9
Methane	16.2	10.5
Ethane and Propane	0.0	0.0
Ethylene	120.6	123.1
Propylene	3.7	2.4
Butane (and isomers)	4.5	2.9
C5+	6.4	4.2

Definitions

Pyrolysis oil (pyoil): An organic oil derived as a byproduct of pyrolysis, steam cracking, and/or crude oil purification, in which its aromatics content is less than 40 wt.%. Pyrolysis oil derived from waste plastic can have a boiling point range of from 15°C to 600°C. Pyrolysis oil derived from waste plastic can include carbon-containing compounds with a carbon atom count ranging from C5 to C55. Raw, non-purified pyrolysis oil can include a C5-C15 hydrocarbon content that includes from about 20 wt.% to about 40 wt.% paraffins, up to about 50 wt.% olefins, up to about 40 wt.% naphthenes, and up to about 40 wt.% aromatics. Raw, non-purified pyrolysis oil can include a C15+ hydrocarbon content in a range of from 0% (considered as a light pyoil) to about 50% (considered as a heavy/waxy pyoil). Raw pyrolysis oil can be purified to convert at least about 80% of its olefin content into naphthenes and/or paraffins.

Aromatic compound (aromatic): A chemical compound that includes a conjugated planar ring accompanied by delocalized pi-electron clouds in place of individual alternating double and single bonds.

LPG (C2- C4 alkanes): Liquefied petroleum gas, which is a mixture of alkanes
5 containing 2 to 4 carbon atoms.

Carbon dioxide equivalent (CO₂-eq): a metric measure used to compare emissions from various greenhouse gases on the basis of their global-warming potential, by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.

10 Hydrocracking: A catalytic process in which organic molecules are broken into lighter organic molecules by reaction with hydrogen gas.

LHSV: Liquid hourly space velocity, which is the volumetric flow rate (per hour) of liquid feed entering a catalytic reactor per volume of catalyst in the catalytic reactor.

Residence time: Inverse of LHSV (1/LHSV), which is the total time a fluid parcel
15 has spent inside a control volume, such as a reactor.

Process conditions: Operating pressure and temperature (for example, reactor pressure and reactor temperature).

Overall conversion: A ratio of an amount of feed that has reacted to the initial amount of feed.

20 Conversion =

$$\frac{\text{Feed pyrolysis oil liquid inlet mass flow rate} - \text{Product hydrocarbon condensable liquid outlet mass flow rate}}{\text{Feed pyrolysis oil liquid inlet mass flow rate}} \times 100\%$$

Yield of component A:

$$\text{Yield}_A = \frac{\text{Mass flow rate of Component A in gas product}}{\text{Product gas mass flow rate} - \text{Mass flow rate of hydrogen (H}_2\text{) in product gas}} \times 100\%$$

25

LPG steam cracking: Thermal cracking of LPG in the presence of steam.

As used in this disclosure, the term “about” or “approximately” can allow for a degree of variability in a value or range, for example, within 10%, within 5%, or within 1% of a stated value or of a stated limit of a range.

30 As used in this disclosure, the term “substantially” refers to a majority of, or mostly, as in at least about 50%, 60%, 70%, 80%, 90%, 95%, 96%, 97%, 98%, 99%, 99.5%, 99.9%, 99.99%, or at least about 99.999% or more.

Values expressed in a range format should be interpreted in a flexible manner to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. For example, a range of “0.1% to about 5%” or “0.1% to 5%” should be interpreted to include about 0.1% to about 5%, as well as the individual values (for example, 1%, 2%, 3%, and 4%) and the sub-ranges (for example, 0.1% to 0.5%, 1.1% to 2.2%, 3.3% to 4.4%) within the indicated range. The statement “X to Y” has the same meaning as “about X to about Y,” unless indicated otherwise. Likewise, the statement “X, Y, or Z” has the same meaning as “about X, about Y, or about Z”, unless indicated otherwise.

CLAIMS

1. A process comprising:
contacting a hydrocracking feed stream comprising pyrolysis oil with a hydrocracking catalyst disposed within a hydrocracking unit to convert, in the presence of
5 hydrogen, at least a portion of the pyrolysis oil into a lower alkane to produce a hydrocracking product stream;
separating the hydrocracking product stream into an ethane feed stream and a C3+ feed stream, wherein the ethane feed stream comprises ethane, and the C3+ feed stream comprises at least one of a C3 alkane, a C4 alkane, or a higher alkane;
10 diluting the C3+ feed stream with steam to form a steam cracking feed stream;
heating the steam cracking feed stream in a steam cracker to convert at least a portion of the C3+ feed stream to ethylene;
diluting the ethane feed stream with an oxidant to form an oxidative dehydrogenation (ODH) feed stream; and
15 contacting the ODH feed stream with an ODH catalyst disposed within an ODH reactor to convert at least a portion of the ethane to ethylene.
2. The process of claim 1, wherein the pyrolysis oil is derived from pyrolysis of waste plastic.
3. The process of claim 1 or 2, wherein contacting the hydrocracking feed stream with
20 the hydrocracking catalyst produces a yield of C2-C4 alkanes in a range of from about 40 wt.% to about 100 wt.%.
4. The process of any one of claims 1 to 3, wherein the hydrocracking product stream comprises at least about 90 wt.% of C2-C4 alkanes.
5. The process of any one of claims 1 to 4, wherein the hydrocracking product stream
25 comprises at least about 95 wt.% of C2-C4 alkanes.
6. The process of any one of claims 1 to 5, wherein the pyrolysis oil comprises:
from about 20 wt.% to about 40 wt.% of one or more linear alkanes;
from 0 wt.% to about 40 wt.% of one or more cyclic alkanes;
from 0 wt.% to about 50 wt.% of one or more alkenes;
30 from 0 wt.% to about 40 wt.% of one or more aromatic compounds; and
from 0 wt.% to about 50 wt.% of one or more C15+ hydrocarbons.
7. The process of any one of claims 1 to 6, wherein the hydrocracking catalyst comprises natural zeolites, synthetic zeolites, bauxite, alkali oxides, alkaline metal earth oxides, aluminum phosphates, transition metal oxides, or any combination thereof.

8. The process of any one of claims 1 to 7, wherein the hydrocracking catalyst comprises palladium dispersed on a zeolite support.
9. The process of any one of claims 1 to 8, wherein the ODH reactor operates at a temperature from about 300°C to about 500°C.
- 5 10. The process of any one of claims 1 to 9, wherein the ODH reactor operates at a temperature from about 315°C to about 400°C.
11. The process of any one of claims 1 to 10, wherein the ODH reactor operates at a pressure from about 0.5 psig to about 100 psig.
12. The process of any one of claims 1 to 10, wherein the ODH reactor operates at a pressure from about 15 psig to about 504 psig.
- 10 13. The process of any one of claims 1 to 12, wherein a selectivity to ethylene of the ODH catalyst disposed within the ODH reactor is in a range of from about 75 molar percent (mol. %) to about 99 mol. %.
14. The process of any one of claims 1 to 13, wherein the hydrocracking unit operates at a pressure from about 300 psig to about 1002 psig.
- 15 15. The process of any one of claims 1 to 14, wherein the hydrocracking unit operates at a temperature from about 350°C to about 500°C.
16. The process of any one of claims 1 to 15, wherein the hydrocracking feed stream has a liquid hourly space velocity (LHSV) from about 0.2 per hour (hr^{-1}) to about 5 hr^{-1} in the hydrocracking unit.
- 20 17. The process of any one of claims 1 to 16, wherein a volumetric ratio of hydrogen in a gas phase within the hydrocracking unit to the pyrolysis oil in a liquid phase within the hydrocracking unit is from about 500:1 to about 2000:1.
18. The process of any one of claims 1 to 17, wherein the C3+ feed stream is separated into a C3 feed stream and a C4 feed stream.
- 25 19. The process of any one of claims 1 to 18, wherein the C3+ feed stream is diluted with ethane, propane, butane, or any combinations thereof.
20. The process of any one of claims 1 to 19, comprising recycling a C4+ portion of the hydrocracking product stream to the hydrocracking unit, wherein the C4+ portion comprises at least one of a C5 alkane or a higher alkane.
- 30 21. A system comprising:
a hydrocracking feed stream comprising pyrolysis oil;
a hydrocracking unit comprising a hydrocracking catalyst configured to convert, in the presence of hydrogen, at least a portion of the pyrolysis oil into a lower alkane in

response to contacting the hydrocracking feed stream to produce a hydrocracking product stream;

a separation unit configured to receive the hydrocracking product stream and separate the hydrocracking product stream into an ethane feed stream and a C3+ feed stream, wherein the ethane feed stream comprises ethane, and the C3+ feed stream comprises at least one of a C3 alkane, a C4 alkane, or a higher alkane;

a steam cracker configured to receive and heat at least a portion of the C3+ feed stream diluted with steam to convert the portion of the C3+ feed stream to ethylene; and

an oxidative dehydrogenation (ODH) reactor configured to receive at least a portion of the ethane feed stream and an oxidant, the ODH reactor comprising an ODH catalyst configured to, under ODH conditions and in the presence of the oxidant, convert at least a portion of the ethane from the ethane feed stream to ethylene.

22. The system of claim 21, wherein the pyrolysis oil is derived from pyrolysis of waste plastic.

23. The system of claim 21 or 22, wherein the hydrocracking catalyst is configured to produce a yield of C2-C4 alkanes in a range of from about 40 wt.% to about 100 wt.%.

24. The system of any one of claims 21 to 23, wherein the hydrocracking product stream comprises at least about 90 wt.% of C2-C4 alkanes.

25. The system of any one of claims 21 to 24, wherein the hydrocracking product stream comprises at least 95 about wt.% of C2-C4 alkanes.

26. The system of any one of claims 21 to 25, wherein the pyrolysis oil comprises:
from about 20 wt.% to about 40 wt.% of one or more linear alkanes;
from 0 wt.% to about 40 wt.% of one or more cyclic alkanes;
from 0 wt.% to about 50 wt.% of one or more alkenes;
from 0 wt.% to about 40 wt.% of one or more aromatic compounds; and
from 0 wt.% to about 50 wt.% of one or more C15+ hydrocarbons.

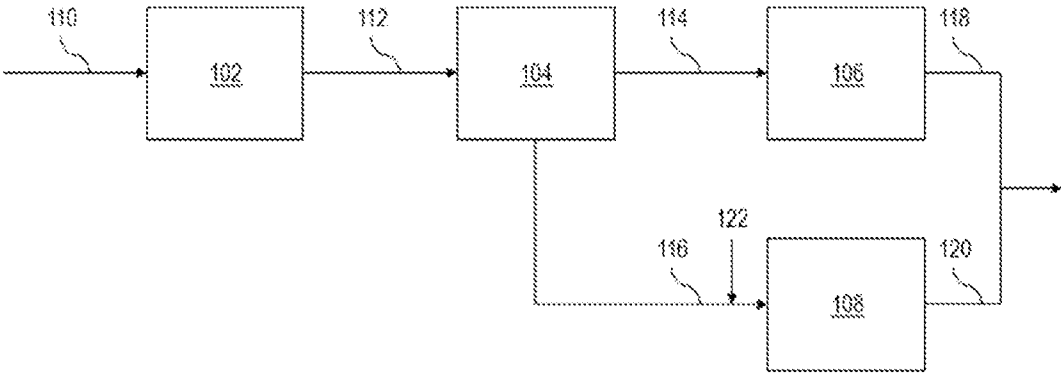
27. The system of any one of claims 21 to 26, wherein the hydrocracking catalyst comprises natural zeolites, synthetic zeolites, bauxite, alkali oxides, alkaline metal earth oxides, aluminum phosphates, transition metal oxides, or any combination thereof.

28. The system of any one of claims 21 to 27, wherein the hydrocracking catalyst comprises palladium dispersed on a zeolite support.

29. The system of any one of claims 21 to 28, wherein the ODH reactor is configured to operate at a temperature from about 300°C to about 500°C.

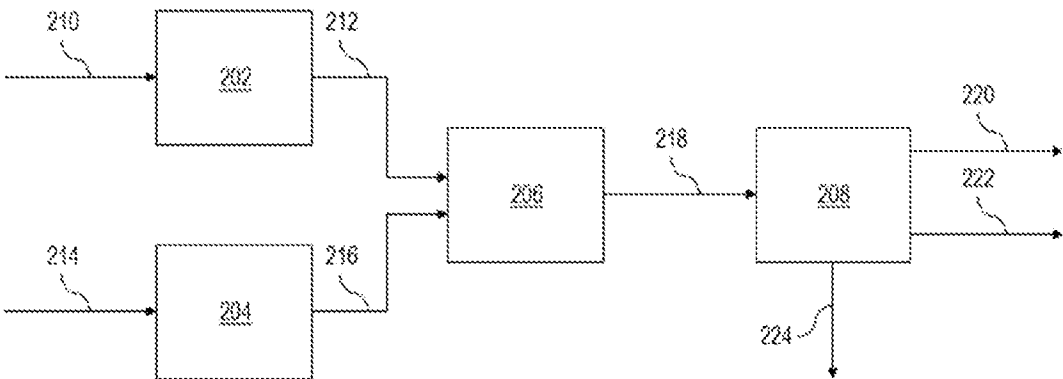
30. The system of any one of claims 21 to 29, wherein the ODH reactor is configured to operate at a temperature from about 315°C to about 400°C.
31. The system of any one of claims 21 to 30, wherein the ODH reactor is configured to operate at a pressure from about 0.5 psig to about 100 psig.
- 5 32. The system of any one of claims 21 to 30, wherein the ODH reactor is configured to operate at a pressure from about 15 psig to about 504 psig.
33. The system of any one of claims 21 to 32, wherein the ODH catalyst is configured to exhibit a selectivity to ethylene in a range of from about 75 molar percent (mol. %) to about 99 mol. %.
- 10 34. The system of any one of claims 21 to 33, wherein the hydrogen is at least partially sourced from the steam cracker.
35. The system of any one of claims 21 to 34, wherein the ODH reactor is configured to receive additional ethane from the steam cracker, pyrolysis oil, or both along with the ethane feed stream.
- 15 36. The system of any one of claims 21 to 35, wherein the hydrocracking unit is configured to operate at a pressure from about 300 psig to about 1002 psig.
37. The system of any one of claims 21 to 36, wherein the hydrocracking unit is configured to operate at a temperature from about 350°C to about 500°C.
38. The system of any one of claims 21 to 37, wherein the hydrocracking feed stream
- 20 has a liquid hourly space velocity (LHSV) from about 0.2 per hour (hr^{-1}) to about 5 hr^{-1} in the hydrocracking unit.
39. The system of any one of claims 21 to 38, wherein a volumetric ratio of hydrogen in a gas phase within the hydrocracking unit to the pyrolysis oil in a liquid phase within the hydrocracking unit is from about 500:1 to about 2000:1.
- 25 40. The system of any one of claims 21 to 39, wherein the separation unit is configured to separate the C3+ feed stream into a C3 feed stream and a C4 feed stream.
41. The system of any one of claims 21 to 40, wherein the C3+ feed stream is diluted with ethane, propane, butane, or any combinations thereof.
42. The system of any one of claims 21 to 40, wherein a C4+ portion of the
- 30 hydrocracking product stream is recycled to the hydrocracking unit, wherein the C4+ portion comprises at least one of a C5 alkane or a higher alkane.

FIGURE 1



100

FIGURE 2A



200A

FIGURE 2B

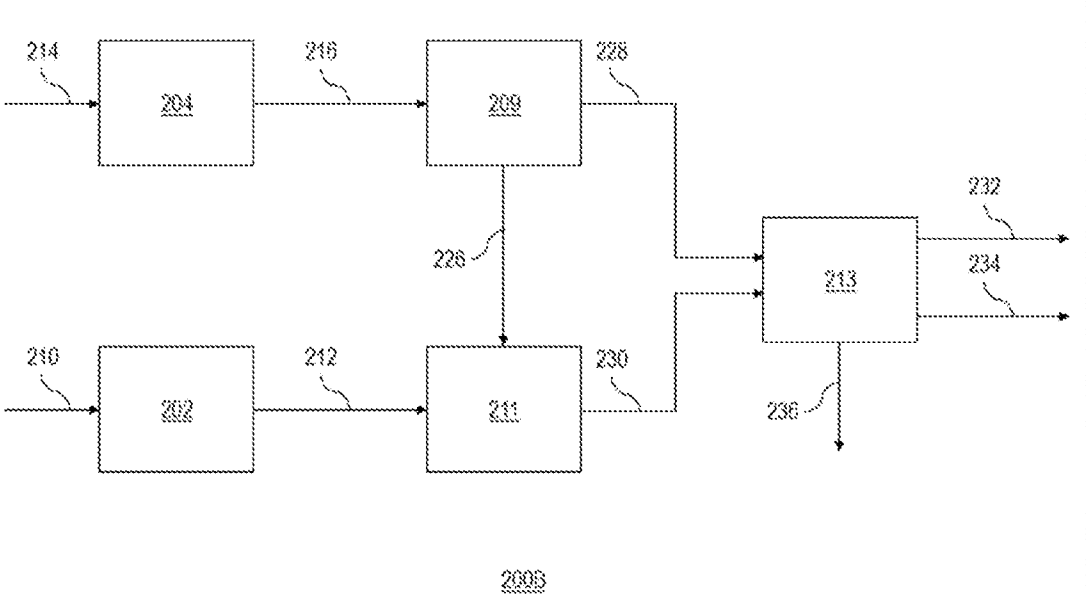


FIGURE 2C

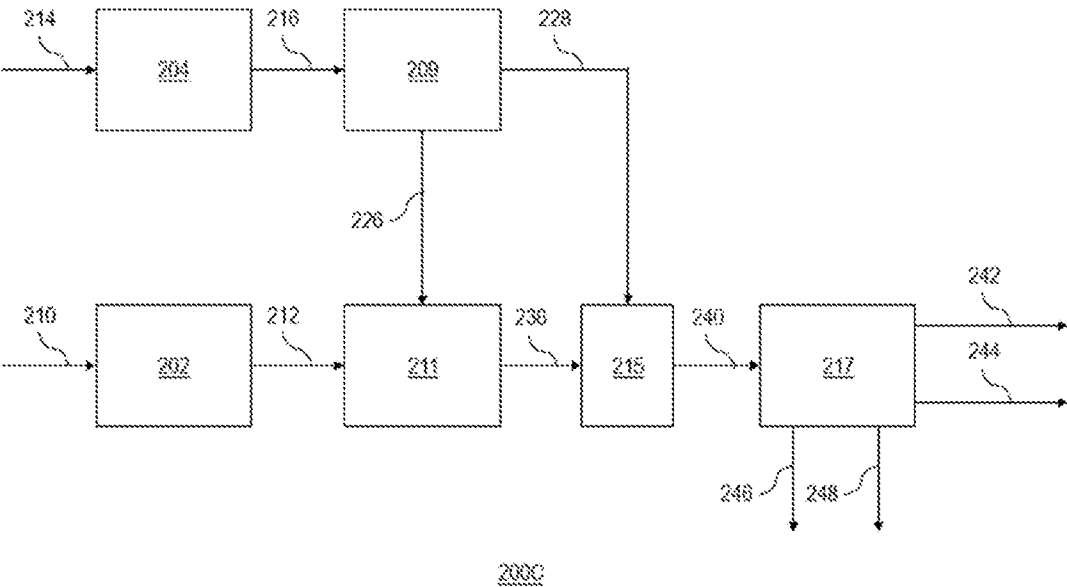


FIGURE 3

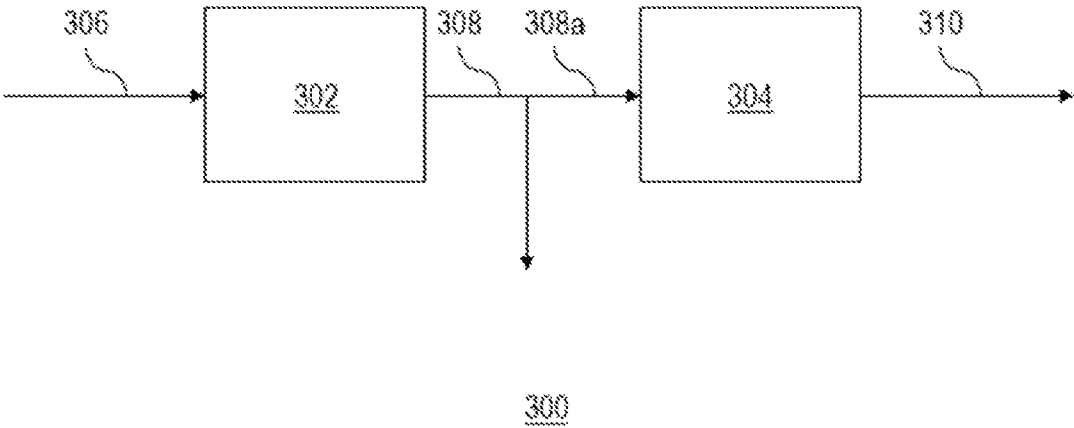
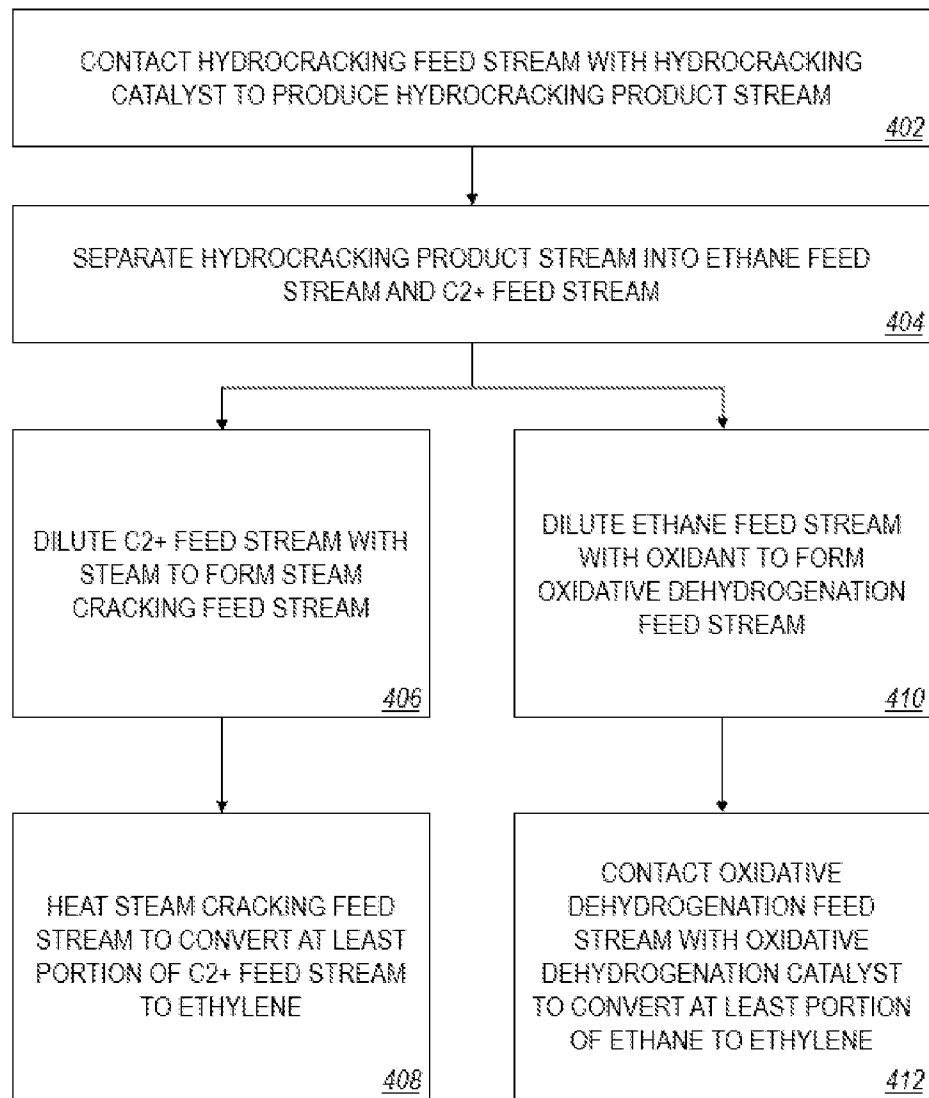
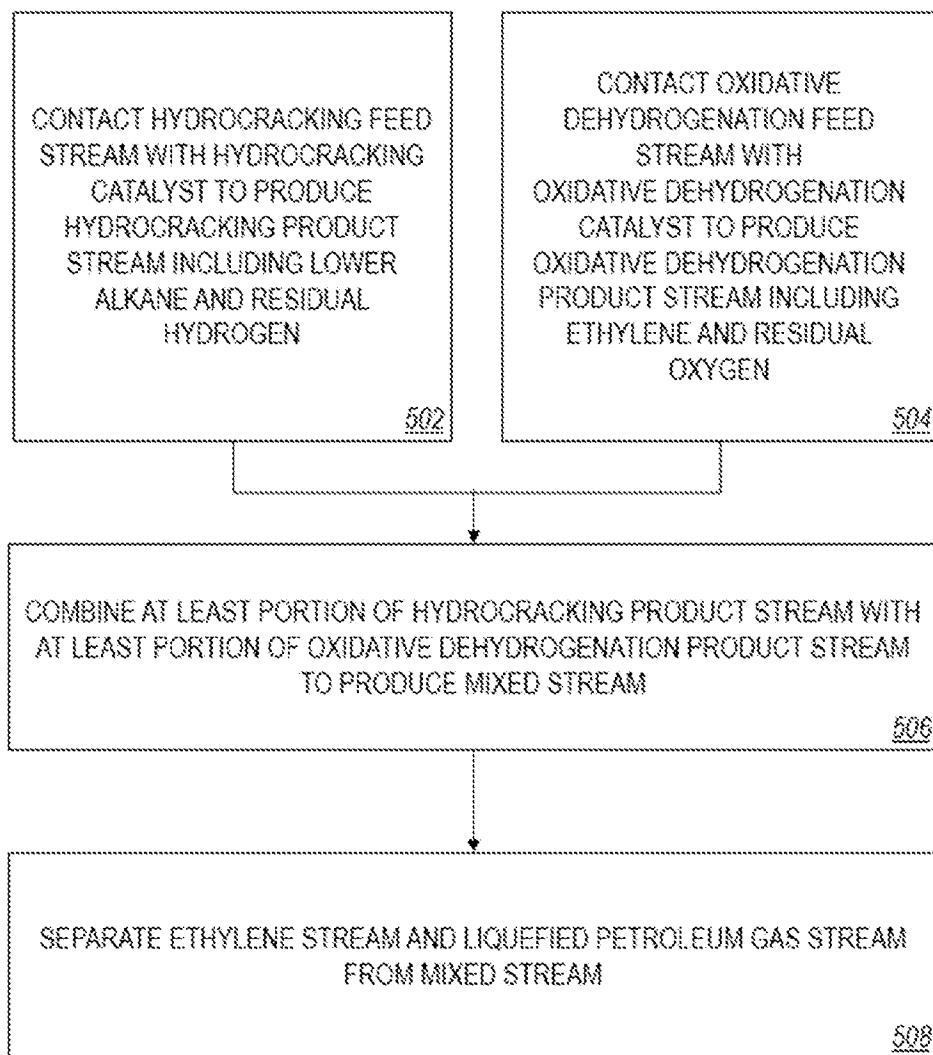


FIGURE 4



400

FIGURE 5



500

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2024/056732

A. CLASSIFICATION OF SUBJECT MATTER

INV. C10G1/10 C10G9/36 C10G11/00 C10G47/00 C10G47/16
C10G69/00 C10G69/04 C10G69/06

ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

C10G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2016/264885 A1 (NARAYANASWAMY RAVICHANDER [IN] ET AL) 15 September 2016 (2016-09-15) paragraph [0024] - paragraphs [0030], [0045], [0047]; claims 1,4,6; figure 1; example 1 -----	1 - 42
Y	WO 2021/144753 A1 (NOVA CHEM INT SA [CH]) 22 July 2021 (2021-07-22) paragraphs [0306], [0535], [0744], [0952], [1316] - paragraph [1319]; claims 15,20,22 -----	1 - 42



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

8 October 2024

Date of mailing of the international search report

24/10/2024

Name and mailing address of the ISA/

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Authorized officer

Deurinck, Patricia

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2024/056732

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2016264885 A1	15-09-2016	US 2016264885 A1	15-09-2016
		WO 2016142808 A1	15-09-2016

WO 2021144753 A1	22-07-2021	NONE	
