the supply of renewable alcohols having a carbon footprint low enough to enable the resultant hydrocarbon to have an attractive carbon footprint.

[0013] Provided herein are, *inter alia*, solutions to the above discussed and other problems in the field.

SUMMARY

[0013a] In an aspect, there is provided a system for producing renewable hydrocarbons, comprising:

a fractionation subsystem for processing a biomass that contains a carbohydrate;

a fermentation subsystem for converting the carbohydrate to a fermentation product;

an alcohol enrichment subsystem for receiving a second portion of the fermentation product;

a hydrocarbon production subsystem for receiving a first portion of the fermentation product, which is an alcohol, and producing the renewable hydrocarbons;

an energy management subsystem for receiving a fuel stream from the system and for delivering power to the system; and the energy management subsystem further comprising at least one of the following to reduce the energy demand or carbon intensity (CI) of the system:

a. a water treatment subsystem for receiving a part of the first portion of the fermentation product;

b. combustion of at least one of light oxygenate, fusel oil, vegetable oil, biomass or derivative, hydrocarbon co-products, and combinations thereof;

c. using warm water sources and waste heat from the fermentation and hydrocarbon production subsystems for biomass processing;

d. using a mechanical vapor recompression (MVR) system to pressurize rectifier column overheads, a condensate of which provides heat to a beer reboiler and produces a purified alcohol suitable for conversion to hydrocarbons; and

e. a thin stillage evaporation system that use the heat from a partially condensed stream of 190 proof alcohol from the rectifier column overheads as well as the MVR system to produce a syrup that is at least about 35% to at least about 45% dry solids without any additional application of steam.

[0014] This disclosure describes, among other things, a system for producing renewable hydrocarbons. The system includes a fractionation subsystem for processing a biomass that contains a carbohydrate; a fermentation subsystem for converting the carbohydrate to a fermentation product; a water treatment subsystem for receiving a first portion of the fermentation product; an alcohol enrichment subsystem for receiving a second portion of the fermentation product; a hydrocarbon production subsystem for receiving an alcohol and producing the renewable hydrocarbons; and an energy management subsystem for receiving fuel stream from the system and for delivering power to the system.

[0015] In some examples, one or more of the following features may be included in any feasible combination. For example, the fractionation subsystem may include at least one of: a storage vessel for storing the biomass; a pulverizer for breaking apart the biomass; a pretreatment vessel for pretreating the biomass; a treatment vessel for treating the biomass to produce the carbohydrate; and a high-temperature-short-time (HTST) vessel for pasteurizing the carbohydrate.

[0016] In some examples, the fermentation subsystem may include at least one of: a fermenter for converting the carbohydrate to the fermentation product; a nutrient addition subsystem; a pH adjustment subsystem; and an inoculum propagation subsystem.

[0017] In some examples, the water treatment subsystem may include at least one of: a beer well for receiving the first portion of the fermentation product; a microorganism separation

device for removing microorganisms from the first portion of the fermentation product; a first distillation column for separating the first portion of the fermentation product into an alcohol and a bottom product; a digester for receiving a portion of the bottom product and for producing a biogas; and a biogas removal subsystem for removing a pollutant from the biogas.

[0018] In some examples, the alcohol enrichment subsystem may include at least one of: a flash tank for separating a condensate from the second portion of the fermentation product; a separation vessel for separating the condensate into a light phase and a heavy phase; an ion exchange vessel for purifying the light phase; a membrane separator for separating the light phase into an alcohol-high retentate and a water-rich permeate; a second distillation column for separating water from the alcohol-high retentate; and an alcohol storage vessel.

[0019] In some examples, the hydrocarbon production subsystem may include at least one of: a denitrogination subsystem for separating nitrogen from the alcohol; a dehydration subsystem for converting the alcohol to an olefin; a hydrocarbon pretreatment subsystem for conditioning an olefin feed; a hydrogen supply subsystem for providing hydrogen; and a hydrocarbon processing subsystem for converting the olefin feed to at least one of an iso-octane fraction, a C_{12} alkane fraction, and/or C_{16} alkane fraction.

[0020] In some examples, the hydrocarbon processing subsystem may include at least one of: a first reactor; a debutanizer; a second reactor; a separator; a first splitter; and/or a second splitter.

[0021] In some examples, the energy management subsystem may include at least one of: a fuel gas system for distributing fuel gas received from the hydrocarbon processing subsystem; a low pressure boiler for generating steam; a high pressure boiler for generating steam;

a combined heat and power unit for generating steam and electricity; a wind turbine for generating electricity;

an electric boiler for receiving renewable electricity and for heating water to produce steam; a biomass boiler for combusting biomass for heating water to produce steam; and/or a steam turbine for generating electricity.

[0022] In some examples, the biomass is corn, wheat, and/or sorghum. In some examples, the biomass has a negative carbon footprint. In some examples, the biomass is grown using strip till or no till. In some examples, the pulverizer is a mill. In some examples, the biomass is grown using agricultural practices to increase soil organic carbon. In some examples, the pretreatment vessel may include a recycled water input. In some examples, pretreating the biomass may include pretreating the biomass with an enzyme. In some examples, the treatment vessel may include a non-fermentable solids output. In some examples, the non-fermentable solids output may include dried distillers grain output and/or corn oil output. In some examples, a portion of the corn oil output may be used as fuel for a boiler.

[0023] In some examples, the fermenter is a continuous fermenter. In some examples, the fermentation product may include an alcohol. In some examples, the alcohol is isobutanol.

[0024] In some examples, the inoculum propagation subsystem is configured to provide a microorganism to the fermenter. In some examples, the microorganism is yeast. In some examples, the first portion of the fermentation product may include an alcohol. In some examples, the first portion of the fermentation product may include isobutanol. In some examples, the first portion of the fermentation product may include water. In some examples, the microorganism separation device may

include a centrifuge. In some examples, the microorganism separation device may include a filter. In some examples, the microorganism separation device may include a settling tank.

[0025] In one exampleof the present disclosure, the first distillation column includes at least one vapor recompression subsystem. In another exampleof the present disclosure, the first distillation column includes at least one mechanical vapor recompression (MVR). In another exampleof the present disclosure, the first distillation column includes at least one thermal vapor recompression (TVR).

[0026] In one exampleof the present disclosure, the bottom product may include stillage. In some examples, the digester is an anaerobic digester. In another exampleof the present disclosure, the digester is a continuous digester. In another exampleof the present disclosure, the biogas removal subsystem may include a scrubber. In another exampleof the present disclosure, the pollutant is hydrogen sulfide.

[0027] In some examples, the flash tank receives the second portion of the fermentation product from the fermentation subsystem and returns part of the second portion of the fermentation product back to the fermentation subsystem. In some examples, the second portion of the fermentation product is a broth and an isobutanol lean broth is returned back to the fermentation subsystem. In some examples, the flash tank operates at atmospheric pressure. In some examples, the flash tank operates under a vacuum at a reduced pressure below atmospheric pressure. In some examples, the flash tank operates at a temperature below a temperature of the second portion of the fermentation product received from the fermentation subsystem. In some examples, the separation vessel is a liquid/liquid separator for separating the condensate into the light phase and the heavy phase. In some examples, the light phase contains a greater amount of alcohol than the heavy phase. In some examples, the alcohol is isobutanol and the liquid/liquid separator

form a biphasic system. In some examples, the ion exchange vessel contains an ion exchange resin and receives the light phase received from the separation vessel

and removes impurities from the light phase by trapping ions in the ion exchange resin. In some examples, the ion exchange vessel receives a caustic solution to regenerate the ion exchange resin by flushing the impurities to a beer well.

[0028] In some examples, the hydrocarbon production subsystem further includes at least one of: an oil and water separator for separating wastewater from the hydrocarbon processing subsystem; and a hydrocarbon storage vessel for storing at least one of iso-octane, C_{12} blend, or C_{16} blend from the hydrocarbon processing subsystem.

[0029] In some examples, the denitrogenation subsystem receives the alcohol from the alcohol enrichment subsystem. In some examples, the alcohol is a fuel grade isobutanol. In some examples, the dehydration subsystem receives the alcohol from the denitrogination subsystem and sends water and/or purge products to a beer well. In some examples, the olefin is a four carbon olefin.

[0030] In some examples, the hydrocarbon pretreatment subsystem may include at least one of: a coalescer for receiving the olefin from the dehydration subsystem; an adsorber for removing unreacted alcohols, water, and nitrogen; and a feed receiver.

[0031] In some examples, the coalescer further receives wash water and sends waste water to a surge tank and/or a dehydration unit. In some examples, the coalescer further receives wash water and sends waste water to a surge tank and/or a dehydration unit. In some examples, the olefin is a C_4 olefin. In some examples, the unreacted alcohol is isobutanol.

[0032] In some examples, the feed receiver receives the olefin from the adsorber. In some examples, the first reactor is a solid acid catalyzed oligomerization (e.g.

Polynaptha™ as one commercial example) reactor. In some examples, the first reactor receives the olefin from the

feed receiver and oligomerizes the olefin to a polyolefin. In some examples, the debutanizer receives a polyolefin from the first reactor. In some examples, the debutanizer recycles an unreacted olefin and/or paraffin to the first reactor. In some examples, the second reactor is a hydrogenation reactor. In some examples, the second reactor receives a polyolefin from the debutanizer. In some examples, the second reactor further receives hydrogen from a hydrogen supply subsystem and hydrogenates the polyolefin to a C_8-C_{16} alkane. In some examples, the separator removes an unreacted olefin and/or paraffin from the C_8-C_{16} alkane. In some examples, the unreacted olefins and/or paraffins include C_4 products. In some examples, the separator recycles a portion of the C_8-C_{16} alkane to the second reactor. In some examples, the first splitter separates the isooctane fraction from the C_8-C_{16} alkane.

[0033] In some examples, the isooctane fraction may include about 85%, 90%, 91%, 92%, 93%, 94%, 95, 96%, 97%, 98%, 99% or 100% wt% C_8 alkanes, about 1%, 2%, 3%, 4% or 5 vol% olefins, and/or about 2 ppm, 4 ppm, 6 ppm, 8 ppm or 10 ppm sulfur.

[0034] In other examples, the isooctane fraction may include greater than 95 wt% C_8 alkanes, less than 5 vol% olefins, and/or less than 10 ppm sulfur. In some examples, the first splitter separates an unreacted olefin and/or paraffin from the C_8-C_{16} alkane. In some examples, the unreacted olefins and/or paraffins include C_4 products. In some examples, the second splitter separates the C_{12} alkane fraction from the C_{18} fraction.

[0035] In some examples, the fuel gas system provides fuel gas to the low pressure boiler. In some examples, the fuel gas system provides fuel gas to the high

pressure boiler. In some examples, the fuel gas system provides fuel gas to a fired heater. In some examples, the low pressure boiler is further configured to received natural gas and/or biogas from an anaerobic disgester. In some examples, the combined heat and power unit is further configured to

received natural gas and/or biogas from an anaerobic disgester. In some examples, the low pressure boiler in the fuel gas system is configured to receive corn oil, biomass, or products from the pyrolysis of biomass as low carbon intensity fuels.

[0036] It should be appreciated that all combinations of the foregoing concepts and additional concepts discussed in greater detail below (provided such concepts are not mutually inconsistent) are contemplated as being part of the inventive subject matter disclosed herein. In particular, all combinations of claimed subject matter of this disclosure are contemplated as being part of the examplesdisclosed herein. It should also be appreciated that terminology explicitly employed herein that also may appear in any disclosure incorporated by reference should be accorded a meaning most consistent with the particular concepts disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] FIG. 1 is a flow chart illustrating a low energy production process consistent with embodiments of the current disclosure.

[0038] FIG. 2 is a flow chart illustrating a process for conversion of carbohydrates to hydrocarbons consistent with embodiments of the current disclosure.

[0039] FIG. 3 is a flow chart illustrating an isobutanol production process consistent with embodiments of the current disclosure.

[0040] FIG. 4 is a flow chart illustrating a carbon neutral, zero net energy isobutanol process consistent with embodiments of the current disclosure.

[0041] FIG. 5 is a flow chart illustrating a continuation of the process of FIG. 4.

[0042] FIG. 6 is a flow chart illustrating a hydrocarbon pretreatment and processing system consistent with embodiments of the current disclosure.