



US 20170240832A1

(19) **United States**

(12) **Patent Application Publication**
HAHN et al.

(10) **Pub. No.: US 2017/0240832 A1**

(43) **Pub. Date: Aug. 24, 2017**

(54) **ENGINE OILS FROM RENEWABLE
ISOPARAFFINS**

Related U.S. Application Data

(60) Provisional application No. 62/063,236, filed on Oct. 13, 2014.

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Publication Classification

(51) **Int. Cl.**
C10M 105/04 (2006.01)

(52) **U.S. Cl.**
CPC **C10M 105/04** (2013.01); **C10M 2203/003**
(2013.01); **C10N 2220/021** (2013.01); **C10N**
2230/04 (2013.01); **C10N 2230/06** (2013.01);
C10N 2230/12 (2013.01); **C10N 2230/10**
(2013.01); **C10N 2230/74** (2013.01); **C10N**
2230/64 (2013.01); **C10N 2240/10** (2013.01)

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(21) Appl. No.: **15/518,878**

(22) PCT Filed: **Oct. 13, 2015**

(86) PCT No.: **PCT/US15/55249**

§ 371 (c)(1),

(2) Date: **Apr. 13, 2017**

(57) **ABSTRACT**

An engine oil comprising a biobased hydrocarbon base oil.

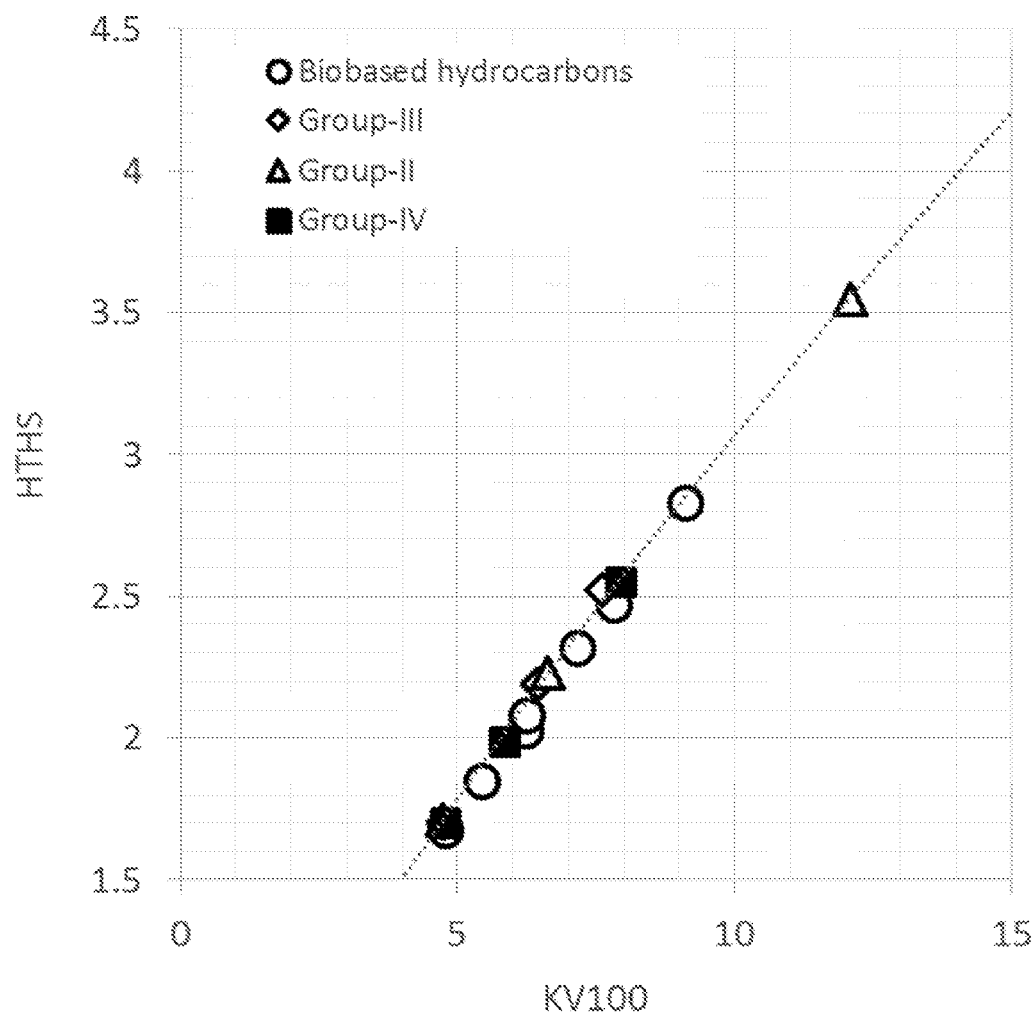


Fig. 1

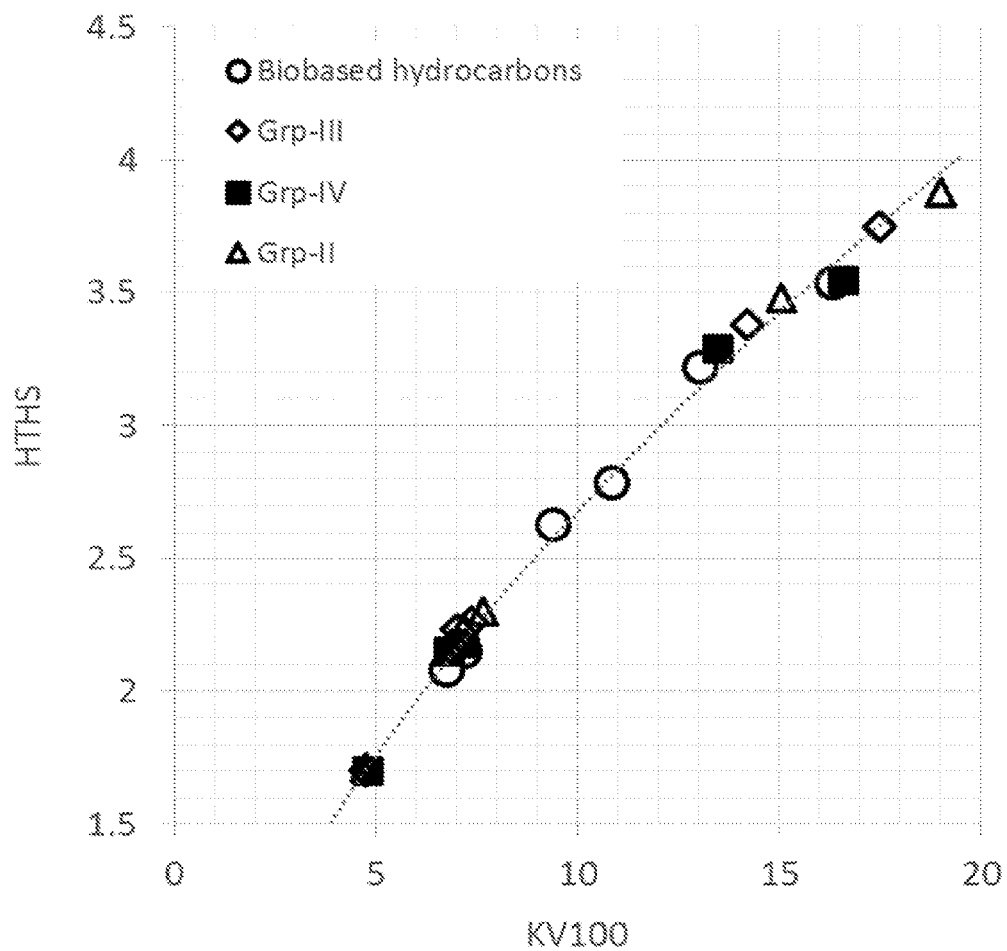


Fig. 2

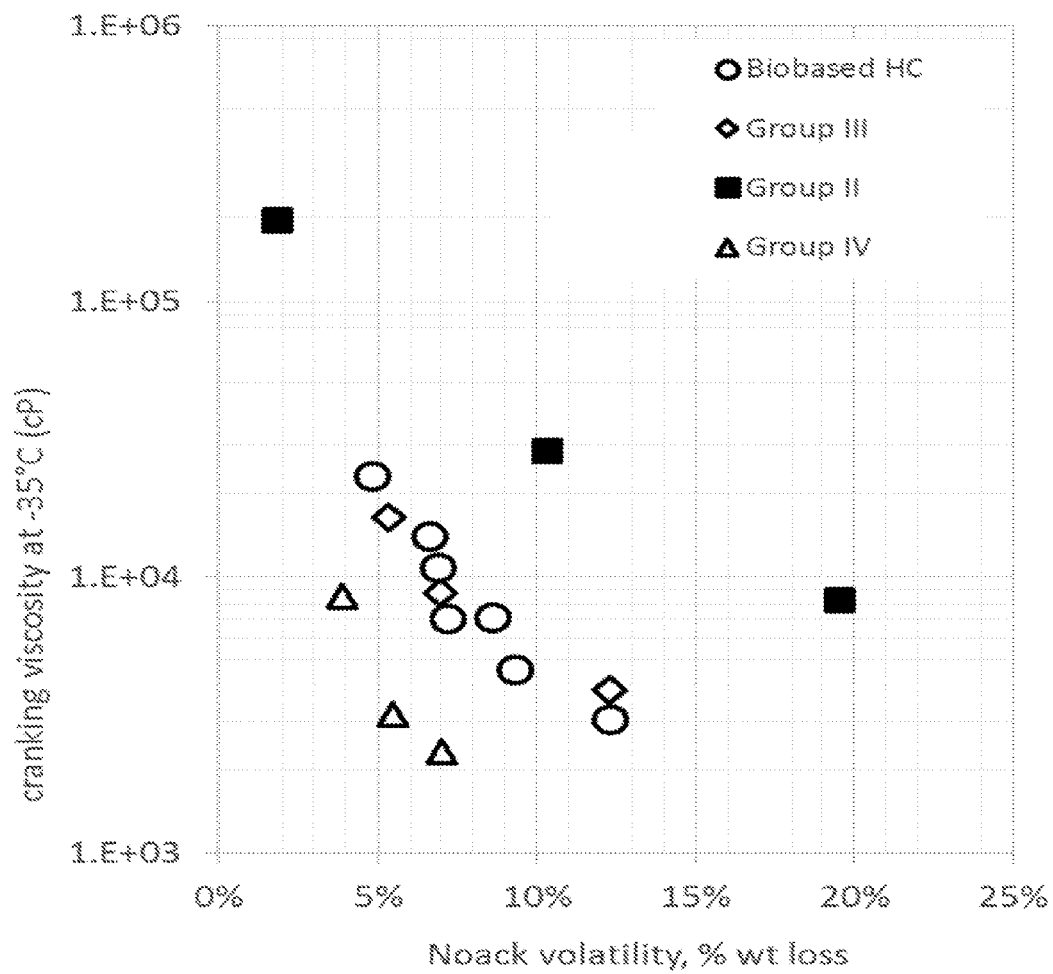


Fig. 3

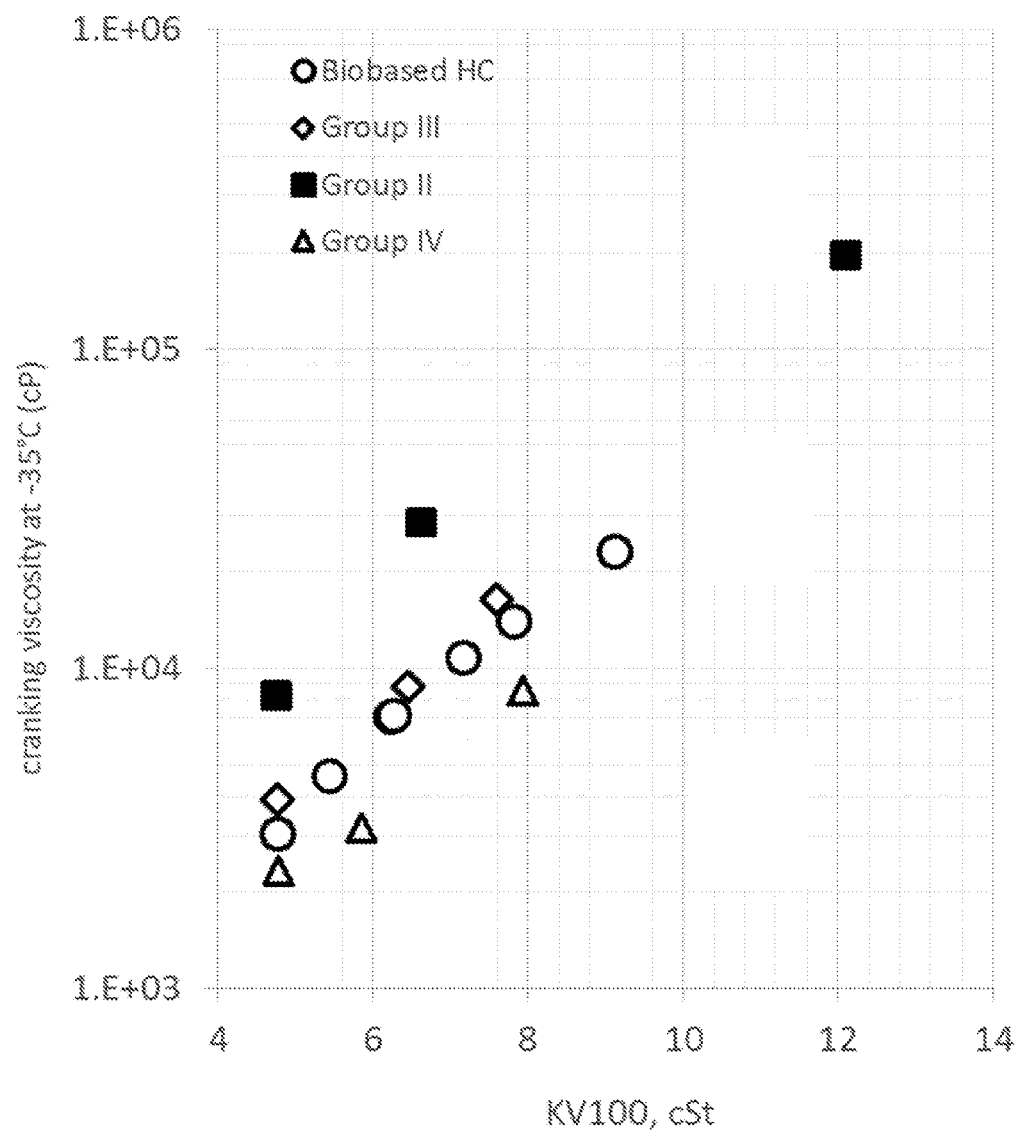


Fig. 4

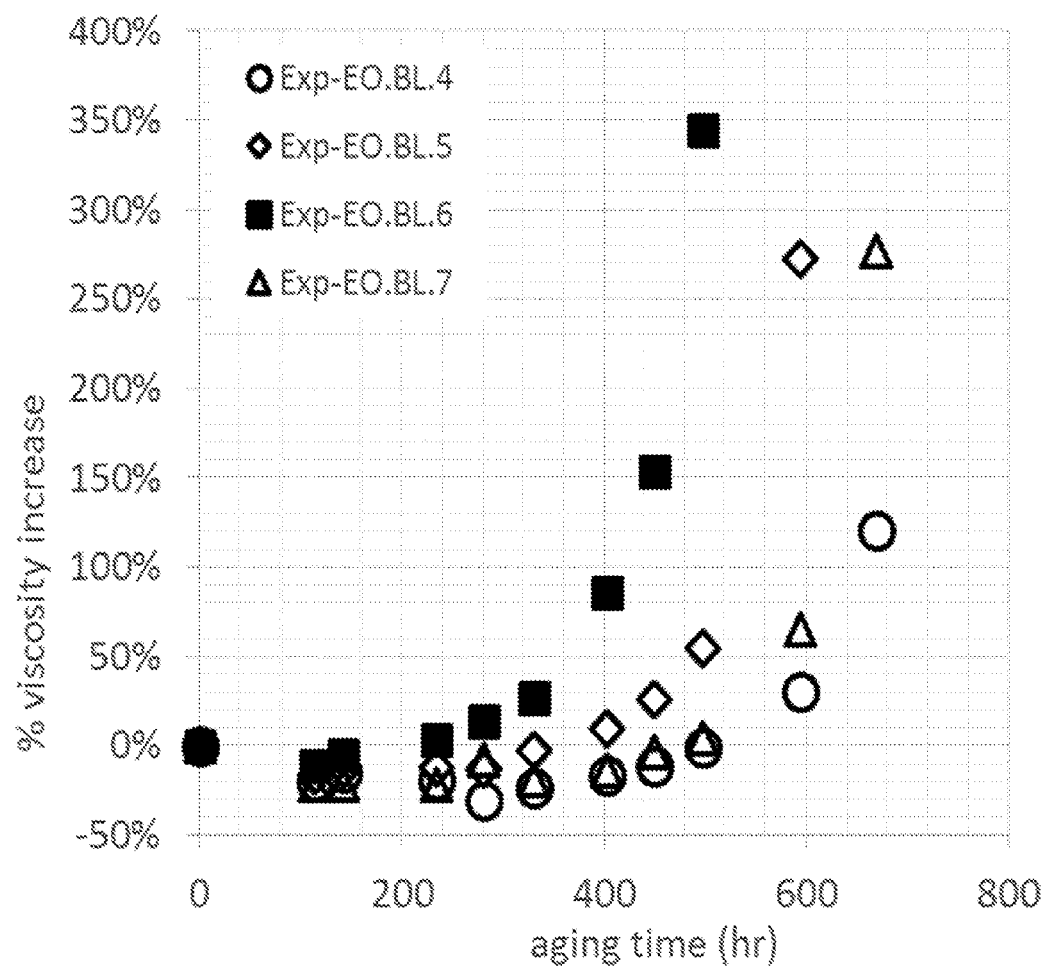


Fig. 5

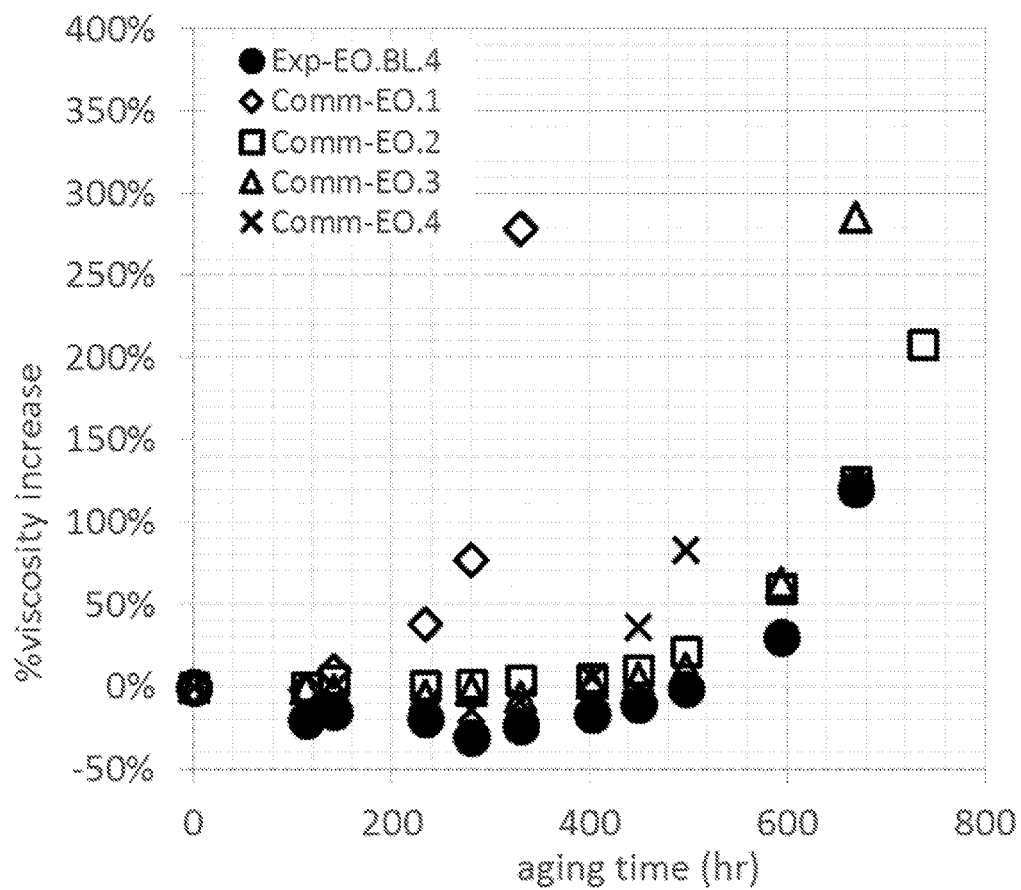


Fig. 6

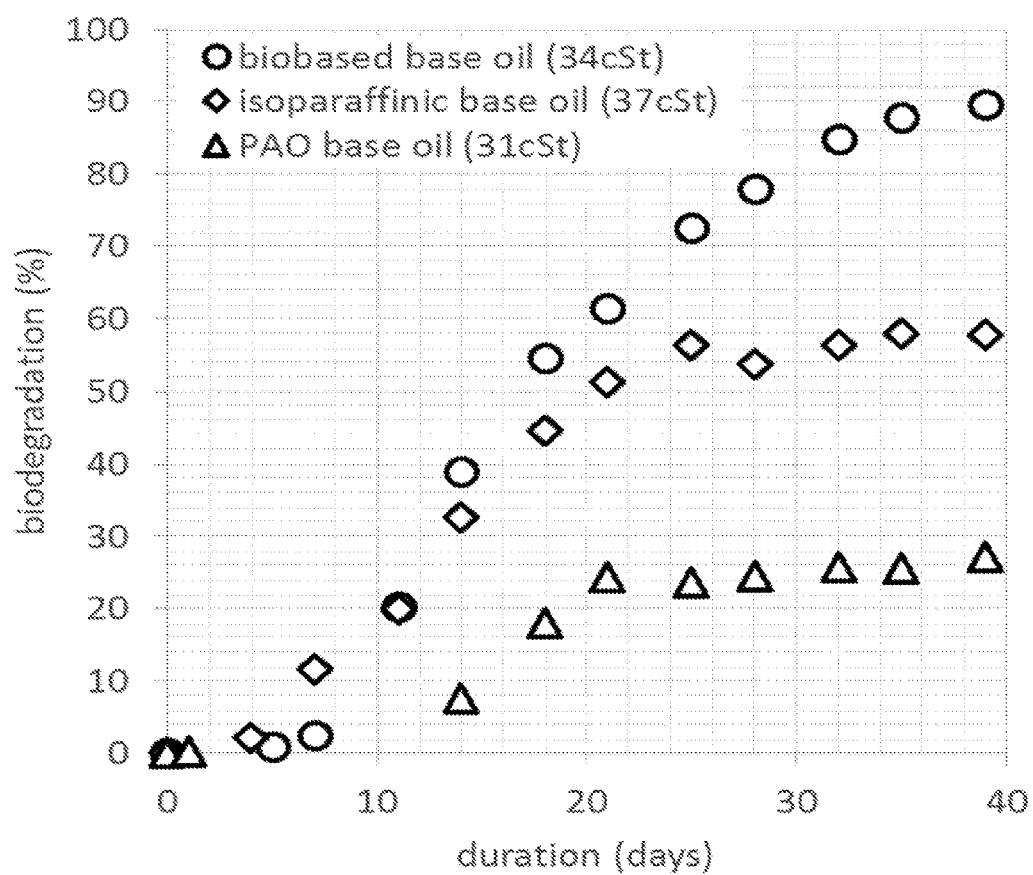


Fig. 7

ENGINE OILS FROM RENEWABLE ISOPARAFFINS

[0001] The present disclosure generally relates to engine oils. In one embodiment, the disclosure relates to biobased engine oils comprising a biobased hydrocarbon such as isoparaffinic hydrocarbon derived from hydrocarbon terpenes such as myrcene, ocimene and farnesene.

[0002] In 2013, the global consumption of lubricant was about 40 million tons. Crankcase oils, commonly referred as an engine oil, constitutes about 40–50% of global lubricant market and is often considered as a focal point for research, development, and marketing effort of lubricant industry.

[0003] Biobased engine oils, while limited in market, have traditionally been based on natural or synthetic ester products (e.g., vegetable oils). Vegetable oils, for example, are renewable and biodegradable, but they breakdown and oxidize at high temperatures and are not hydrolytically stable. As a result, when incorporated into a passenger car engine oil, vegetable oils are typically blended with synthetic oils at a proportion of about 5–30%.

[0004] Automotive OEMs, national trade associations (such as API and ACEA), and international standardization committee (such as ILSAC) have been playing major role in overseeing the development and implementation of standard engine oil related test methods. They also provide official classifications and labeling program for engine oils (such as ILSAC GF-5, API-SN, ACEA A3/B4, and dexos) in order to provide consumers a guidance for choosing the correct engine oils for their vehicles. These classifications require a series of engine tests and bench top performance tests which are designed to evaluate engine oil's performance in providing desired protection including longevity, corrosion and wear protection, resistance to the formation of sludge and deposits, ability to retain its viscosity in right range, etc. For example, ILSAC GF-5 which was approved in January 2010 and became sole basis for issuance of a license to use the API certification mark, requires 5 engine tests (i.e. sequence III, IV, V, VI, and VIII) and series bench tests (i.e. catalyst compatibility, phosphorus content, Noack volatility, high temperature deposit tests, filterability, foaming characteristic, aged oil low temperature viscosity, shear stability, homogeneity, miscibility, ball rust test, emulsion retention, and elastomer compatibility test).

[0005] The ultimate assessment of an engine oil's performance must be evaluated through fleet test covering various style of vehicles and range of driving conditions. However, various classifications mentioned above specifies engine sequence tests to minimize testing time and costs. The relationships between engine sequence tests and vehicle fleet tests are judged valid based on the range base oils and additive technologies investigated. Therefore, the introduction of base oils or additive with different chemistry constitute a significant departure from existing practice and requires sufficient supporting vehicle fleet testing data to ensure that there is no adverse effect to vehicle components or to emission control systems. Hence, if new engine oil with improved environmental performances (i.e. biodegradability, carbon footprint neutrality, renewability, and etc.) can be obtained using base oils and additives with well-known chemistry, it will provide significant benefits to the developers and consumers.

[0006] Biobased base oil penetration on the engine oil market is currently relatively low, due at least in part to the inherent performance disadvantages of the ester materials

that have been used as well as the rules and regulations in the segment. There are a number of industry and OEM standards like the API SN and ILSAC GF-5 that are required to have a certified product on market. Due to the high replacement cost of an engine users are hesitant to use products that do not meet certification standards and OEM's will not endorse. Ester-based products have not been able to meet the standards and gain the required certifications at a cost or value proposition that makes sense in the market.

[0007] Biobased engine oils have traditionally been based on natural or synthetic ester products. This has allowed the products to be strong in the areas of renewability and biodegradability but weak in some of the classical performance areas of an engine oil as provided by the more typical hydrocarbon base oils. These main limitations are around hydrolytic stability, seal and material compatibility, oxidation stability, cold weather performance, and compatibility with existing non-biobased engine oils.

[0008] The market demand and importance of biobased engine oils is growing and a technology that can provide the engine oil performance that is required by the industry along with green characteristics is sorely needed. Commonly used base oils often fail to bring together a high level of environmental performance such as renewability and biodegradability with traditional lubricant performance characteristics. Thus, there continues to be interest in new fluids that can provide better environmental performance while also providing sound lubricant performance.

[0009] Among the various aspects of the disclosure, therefore, may be noted the provision of an engine oil offering certain environmental performance characteristics, the provision of an engine oil formulated with vegetable oil based base oil, the provision of an engine oil comprising a biobased hydrocarbon, and the provision of clean biodegradable alternative hydrocarbon products which have improved environmental performance and/or physical properties such as better oxidative stability, better cold flow, low volatility, improved separation of oil from water (and air), and improved anti-wear properties.

[0010] Briefly, therefore, one aspect of the present disclosure is an engine oil comprising a biobased hydrocarbon base oil that meets the requirements of Engine Oil Viscosity Classification (J300 2009-01) set by SAE and has a volatile loss of less than 13% when measured by ASTM D5800-10.

[0011] Another aspect of the present disclosure is an engine oil comprising a biobased base oil, wherein the biobased base oil has greater than 90% saturates as measured by ASTM-D2007-11, less than 0.03% sulfur as measured by ASTM-D1552-08(2014)e1, ASTM D2622-10, ASTM D3120-08, ASTM D4294-10, ASTM D4927-10 or equivalent method, a viscosity index as measured by ASTM D2270-10e1 greater than 120, a renewable carbon content greater than 25% as measured by ASTM-D6866-12, contains a dispersant, a detergent, a corrosion inhibitor, an antioxidant, an antifoaming agent, an antiwear agent, and a friction modifier, and wherein the engine oil has, when determined by ASTM-D7320-13, (a) a kinematic viscosity increase, at 40° C., of no more than 150%, (b) an average weighted piston deposit rating greater than 4.0, and (c) an average cam plus lifter wear of less than 60 μm .

[0012] Another aspect of the present disclosure is an engine oil comprising a biobased Group III base oil, wherein the biobased Group III base oil has a renewable carbon content greater than 25% as measured by ASTM-D6866-12,

contains a dispersant, a detergent, a corrosion inhibitor, antioxidant, an antifoaming agent, an antiwear agent, and a friction modifier, and wherein the engine oil has, when determined by ASTM-D7320-13, (a) a kinematic viscosity increase, at 40° C., of no more than 150%, (b) an average weighted piston deposit rating greater than 4.0, and (c) an average cam plus lifter wear of less than 60 μm .

[0013] Another aspect of the present disclosure is an engine oil comprising a dispersant, a detergent, a corrosion inhibitor, antioxidant, an antifoaming agent, an antiwear agent, a friction modifier, and a biobased base oil, wherein the biobased base oil having the molecular structure:



wherein,

[0014] [B] is a biobased hydrocarbon repeating unit;

[0015] [P] is a non-biobased hydrocarbon repeating unit;

[0016] n is greater than 1, and m is less than 4;

[0017] the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic;

[0018] the sequential arrangement of [B] and [P] is block, alternating or random;

[0019] the molecular weight of the biobased base oil is in the range of 300 g/mol to 1500 g/mol; and

[0020] the biobased content of the engine oil is greater than 25%, as measured by ASTM D6866-12.

[0021] Another aspect of the present disclosure is an engine oil comprising a group III base oil, wherein the engine oil does not contain pour point depressant but contains a dispersant, a detergent, a corrosion inhibitor, an antioxidant, an antifoaming agent, an anti-wear agent, and a friction modifier, and wherein the engine oil has, when determined by ASTM-D7320-13, (a) a kinematic viscosity increase, at 40° C., of no more than 150%, (b) an average weighted piston deposit rating greater than 4.0, and (c) an average cam plus lifter wear of less than 60 μm .

[0022] Another aspect of the present disclosure is an engine oil comprising: (a) at least 50 wt % of a biobased base oil having a weight average molecular weight in the range of 300 to 1500 g/mol and a viscosity index greater than 120; and (b) wherein the engine oil has (i) a cold cranking viscosity less than 6200 cP at -35° C. by ASTM D 5293-14, (ii) a low temperature pumping viscosity less than 60000 at -40° C. by ASTM D4684-14, and (iii) a kinematic viscosity greater than 3.8cSt at 100° C. by ASTM D445-14E2.

[0023] Another aspect of the present disclosure is an engine oil comprising a biobased base oil, wherein the biobased base oil has greater than 50% of biodegradation in 28 days according to OECD 301B test method, the biobased base oil constitutes at least 50 wt % of the engine oil, and wherein the engine oil has, when determined by ASTM-D7320-13, (a) a kinematic viscosity increase, at 40° C., of no more than 150%, (b) an average weighted piston deposit rating greater than 4.0, and (c) an average cam plus lifter wear of less than 60 μm .

[0024] Another aspect of the present disclosure is an engine oil comprising a biobased base oil and an additive package wherein (i) the engine oil and an otherwise identical engine oil comprising the additive package and a Group I, Group II or Group III base oil but no biobased base oil each satisfy the requirements of Engine Oil Viscosity Classification (J300) set by SAE and has a volatile loss of less than 13% when measured by ASTM D5800-10 and (ii) the engine

oil even in the absence of additional solubilizer, co-base oil or co-solvent outperforms the otherwise identical engine oil in the Engine Oil Viscosity Classification (J300) and ASTM D5800-10 tests.

[0025] Another aspect of the present disclosure is an engine oil comprising a biobased base oil and at least 0.1 wt % of a dispersant inhibitor, wherein the engine oil is compatible with engine oils formulated using Group I, Group II, or Group III base oil, meets requirements of Engine Oil Viscosity Classification (J300) set by SAE and has a volatile loss of less than 13% when measured by ASTM D5800-10.

[0026] Another aspect of the present disclosure is an engine oil satisfying the performance requirements of Engine Oil Viscosity Classification (J300), wherein the engine oil comprises: (a) 1 to 95 wt % of a biobased hydrocarbon base oil; (b) up to 80 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from Group I, Group II, Group III, Group IV, and Group V base oils and combinations thereof, and (c) up to 30 wt % of one or more additives selected from the group consisting of anti-foaming agents, anti-wear agents, anti-oxidants, demulsifiers, detergents, dispersants, extreme pressure agents, friction modifiers, metal deactivators, pour point depressants, rust and corrosion inhibitors, viscosity modifiers, and combinations thereof.

[0027] Another aspect of the present disclosure is an internal combustion engine lubricated by an engine oil, the improvement comprising an engine oil according to any of the preceding paragraphs.

[0028] Another aspect of the present disclosure is a process for formulating an engine oil, the process comprising combining a biobased base oil with an additive mixture and a viscosity modifier to form a first combination that meets or exceeds the performance requirements of one or more of the following engine oil certification programs: ILSAC GF-5, ILSAC GF-6, API SN, dexos, CJ-4, ACEA-A1, ACEA-A2, ACEA-A3, ACEA-B1, ACEA-B2, ACEA-B3, ACEA-B4, ACEA-E1, ACEA-E2, ACEA-E3, ACEA-E4, and PC-11, wherein

[0029] (a) the additive mixture comprises two or more additives selected from the group consisting of anti-foaming agents, anti-wear agents, anti-oxidants, demulsifiers, detergents, dispersants, extreme pressure agents, friction modifiers, metal deactivators, pour point depressants, rust and corrosion inhibitors, viscosity modifiers, and combinations thereof, and

[0030] (b) the additive mixture without variation of the combination of additives or the relative proportions thereof within the additive mixture may alternatively be combined with a non-biobased Group I, a Group II, a Group III or a Group IV base oil, or a combination thereof, and a viscosity modifier to form a second combination that meets or exceeds the performance requirements of one or more of the following engine oil certification programs: ILSAC GF-5, ILSAC GF-6, API SN, dexos, CJ-4, ACEA-A1, ACEA-A2, ACEA-A3, ACEA-B1, ACEA-B2, ACEA-B3, ACEA-B4, ACEA-E1, ACEA-E2, ACEA-E3, ACEA-E4, and PC-11.

[0031] Another aspect of the present disclosure is an engine oil wherein at least about 25% of the carbon atoms in the biobased base oil originate from renewable carbon sources and the engine oil has a pour point of less than -40° C. in the absence of a pour point depressant additive.

[0032] Another aspect of the present disclosure is an engine oil comprising a biobased hydrocarbon base oil, wherein the amount of biobased base oil in the engine oil is greater than 50% and the biobased base oil has a biodegradable rate in excess of 60% according to by OECD 301B.

[0033] Another aspect of the present disclosure is an engine oil formulation comprising at least one engine oil additive and a biobased base oil having the molecular structure:



where,

[0034] [B] is biobased repeating unit;

[0035] [P] is non-biobased hydrocarbon repeating unit;

[0036] n is integer greater than 0, and m is integer greater than or equal to 0;

[0037] the stereoscopical arrangement of [B] and [P] is linear, branched, or cyclic;

[0038] the sequential arrangement of the [B] and [P] repeating units is block or random;

[0039] the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol; and

[0040] the biobased content of the biobased base oil is greater than 20%, as measured by ASTM D6866-12.

[0041] Another aspect of the present disclosure is an engine oil that can be mixed with a Group I, a Group II, a Group III or a Group IV base oil, or a combination thereof and used for engine oil top-off and/or during engine oil change where previous engine oil is formulated with a Group I, a Group II, a Group III or a Group IV base oil, or a combination thereof.

[0042] Another aspect of the present disclosure is an internal combustion engine lubricated by an engine oil as described in any of the preceding paragraphs.

[0043] Another aspect of the present disclosure is a biobased engine oil that can meet the industry specifications of API SN, ILSAC GF-5 when a biobased base oil is combined with an off-the-shelf additive package and viscosity modifier.

[0044] Other aspects, features and embodiments of the present disclosure will be, in part, discussed and, in part, apparent in the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0045] FIG. 1 is a plot comparing high temperature high shear viscosity at 150° C. as a function of kinematic viscosity at 100° C. of commercially available, non biobased base oils compared to those of biobased hydrocarbon base oils.

[0046] FIG. 2 is a plot showing high temperature high shear viscosity at 150° C. as a function of kinematic viscosity at 100° C. of commercially available, non biobased base oils blended with viscosity modifier (VM) commonly used for engine oil formulations compared to those of biobased hydrocarbon base oils with same VM.

[0047] FIG. 3 is a plot comparing cranking viscosity, at -35° C. measured by ASTM-D5293-14, of base oils and their blends as a function of volatile loss measured by ASTM-D5800-10.

[0048] FIG. 4 is a plot comparing cranking viscosity, at -35° C. measured by ASTM-D5293-14, of base oils and their blends as a function of kinematic viscosity at 100° C. measured by ASTM-D445-14E2.

[0049] FIG. 5 is a plot comparing oxidative stability of engine oils formulated using same additives and different base oils.

[0050] FIG. 6 is a plot comparing oxidative stability of 0W-20 engine oil formulated using biobased hydrocarbon base oil to commercially available 0W-20 engine oils and 5W-20 engine oil.

[0051] FIG. 7 is a plot comparing biodegradation curves obtained from biobased base oil, group III base oil, and group IV base oil, with similar kinematic viscosity, using OECD 301B method.

DEFINITIONS

[0052] “Compatible” or “compatibility” as used herein in connection with engine oil lubricants can be defined as the mixing of different fluids will not result in a loss of solubility and/or the responsiveness of the additive ingredients used in either of the two formulations. The mixing of the two formulations does not diminish effectiveness of the additives to perform as intended. Thus, for example, two engine oil lubricants are compatible when, if mixed in any proportion, the mixture will meet or exceed the performance characteristics possessed by at least one of the two formulations immediately prior to the mixing.

[0053] As used herein, biobased base oil is understood to mean any biologically derived oil to be used as a base oil in a engine oil. Such oils may be made, for non-limiting example, from biological organisms designed to manufacture specific oils, as discussed in PCT Patent Application No. PCT/US2012/024926, published as WO 2012/141784, cited above, but do not include petroleum distilled or processed oils such as for non-limiting example mineral oils. A suitable method to assess materials derived from renewable resources is through ASTM D6866-12, “Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis.” Counts from ¹⁴C in a sample can be compared directly or through secondary standards to SRM 4990C. A measurement of 0% ¹⁴C relative to the appropriate standard indicates carbon originating entirely from fossils (e.g., petroleum based). A measurement of 100% ¹⁴C indicates carbon originating entirely from modern sources. See, e.g., WO 2012/141784, incorporated herein by reference.

DETAILED DESCRIPTION

[0054] Base oils, and more particularly isoparaffins, derived from biobased hydrocarbon terpenes such as myrcene, ocimene and farnesene, have been described in PCT Patent Application No. PCT/US2012/024926, entitled “Base Oils and Methods for Making the Same,” filed, Feb. 13, 2012 and published as WO 2012/141784 on Oct. 18, 2012, by Nicholas Ohler, et al., and assigned to Amyris, Inc. in Emeryville, Calif. WO 2012/141784 discloses that terpenes are capable of being derived from isopentyl pyrophosphate or dimethylallyl pyrophosphate and the term “terpene” encompasses hemiterpenes, monoterpenes, sesquiterpenes, diterpenes, sesterterpenes, triterpenes, tetraterpenes and polyterpenes. A hydrocarbon terpene contains only hydrogen and carbon atoms and no heteroatoms such as oxygen, and in some embodiments has the general formula (C₅H₈)_n, where n is 1 or greater. A “conjugated terpene” or “conjugated hydrocarbon terpene” refers to a terpene comprising at

least one conjugated diene moiety. The conjugated diene moiety of a conjugated terpene may have any stereochemistry (e.g., cis or trans) and may be part of a longer conjugated segment of a terpene, e.g., the conjugated diene moiety may be part of a conjugated triene moiety. Hydrocarbon terpenes also encompass monoterpenoids, sesquiterpenoids, diterpenoids, triterpenoids, tetraterpenoids, and polyterpenoids that exhibit the same carbon skeleton as the corresponding terpene but have either a lesser or greater number of hydrogen atoms than the corresponding terpene, e.g., terpenoids having 2 fewer, 4 fewer, or 6 fewer hydrogen atoms than the corresponding terpene, or terpenoids having 2-additional 4-additional, or 6-additional hydrogen atoms than the corresponding terpene. Some non-limiting examples of conjugated hydrocarbon terpenes include isoprene, myrcene, α -ocimene, β -ocimene, α -farnesene, β -farnesene, β -springene, geranyl-farnesene, neophytadiene, cis-phyta-1,3-diene, trans-phyta-1,3-diene, isodehydrosqualene, isosqualane precursor I, and isosqualane precursor II. The terms terpene and isoprenoids may be used interchangeably and are a large and varied class of organic molecules that can be produced by a wide variety of plants and some insects. Some terpenes or isoprenoid compounds can also be made from organic compounds such as sugars by microorganisms, including bioengineered microorganisms, such as yeast. Because terpenes or isoprenoid compounds can be obtained from various renewable sources, they are useful monomers for making eco-friendly and renewable base oils. In some embodiments, the conjugated hydrocarbon terpenes are derived from microorganisms using a renewable carbon source, such as a sugar.

[0055] Further processing of certain of such biobased base oil stocks has been found to yield highly useful and superior engine oils. For example, C15 hydrocarbons containing four double bonds such as Biofene™ β -farnesene, commercially available from Amyris, Inc. (Emeryville, Calif.) may be pre-treated to eliminate impurities and then hydrogenated so that three of the four double bonds are reduced to single bonds. The partially hydrogenated intermediate product is then subjected to an oligomerization reaction with a linear alpha olefin (LAO) using a catalyst such as BF_3 or a BF_3 complex. A further intermediate product, consisting of a mixture of hydrocarbons ranging from C10 to about C75, results. This oligomeric mixture of hydrocarbons is then hydrogenated to reduce the amount of unsaturation. The saturated hydrocarbon mixture is then distilled to obtain the targeted composition and finally blended to meet desirable base oil product specifications (such as kinematic viscosity at 40° C.) for the engine oil. Desirable examples of biobased base oil specifications that can be used to produce blends suitable for engine oil formulation for one embodiment are set forth in Table I. In some embodiments in this disclosure, a commercially available biobased hydrocarbon base oil (a hydrogenated reaction product between a partially hydrogenated β -3,7,11-trimethyldodeca-1,3,6,10-tetraene and a linear C8-C16 alpha olefin, hydrogenated) sold under the commercial designation NOVASPEC (Novvi LLC, Emery-

ville, Calif., United States; (REACH registration number 01-2120031429-59-0000), is used.

TABLE I

Example Biobased Base Oil Specifications					
Properties	Method	3 cSt base oil	4 cSt base oil	7 cSt base oil	12 cSt base oil
Appearance	Visual	Bright and Clear	Bright and Clear	Bright and Clear	Bright and Clear
Color	ASTM D1500-12	0.5	0.5	0.5	0.5
Density, 15° C. (kg/l)	ASTM D4052-11	0.82	0.82	0.82	0.82
Viscosity, 40° C. (cSt)	ASTM D445-14E2	12.5	19.2	46.1	105.5
Viscosity, 100° C. (cSt)	ASTM D445-14E2	3.1	4.2	7.5	12.3
Viscosity Index	ASTM D445-14E2	110	124	126	122
Pour point (° C.)	ASTM D97-12	-60	-42	-51	-42
Flash point (° C.)	ASTM D92-12b	188	226	254	280

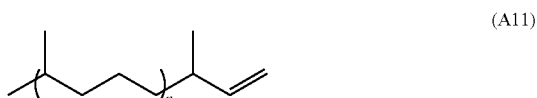
[0056] Advantageously, in certain embodiments, at least about 20% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. For example, in one such embodiment at least about 30% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. By way of further example, in one such embodiment at least about 40% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. By way of further example, in one such embodiment at least about 50% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. By way of further example, in one such embodiment at least about 60% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. By way of further example, in one such embodiment at least about 70% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. By way of further example, in one such embodiment at least about 80% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. By way of further example, in one such embodiment at least about 90% of the carbon atoms in the base oil comprised by an engine oil originate from renewable carbon sources. In some variations, the carbon atoms of the base oil component of the engine oil comprises at least about 95%, at least about 97%, at least about 99%, or about 100% of originate from renewable carbon sources. The origin of carbon atoms in the reaction product adducts may be determined by any suitable method, including but not limited to reaction mechanism combined with analytical results that demonstrate structure and/or molecular weight of adducts, or by carbon dating (e.g., according to ASTM D6866-12 "Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis," which is incorporated herein by reference in its entirety). For example, using ASTM D6866-12 or another suitable tech-

nique, a ratio of carbon 14 to carbon 12 isotopes in the biobased base oil can be measured by liquid scintillation counting and/or isotope ratio mass spectroscopy to determine the amount of modern carbon content in the sample. A measurement of no modern carbon content indicates all carbon is derived from fossil fuels. A sample derived from renewable carbon sources will indicate a concomitant amount of modern carbon content, up to 100%.

[0057] In some embodiments of this disclosure, one or more repeating units of biobased hydrocarbon base oil are specific species of partially hydrogenated conjugated hydrocarbon terpenes. Such specific species of partially hydrogenated conjugated terpenes may or may not be produced by a hydrogenation process. In certain variations, a partially hydrogenated hydrocarbon terpene species is prepared by a method that includes one or more steps in addition to or other than catalytic hydrogenation.

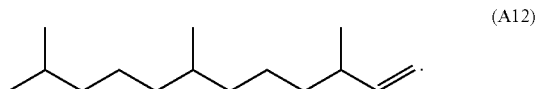
[0058] Non-limiting examples of specific species partially hydrogenated conjugated hydrocarbon terpenes include any of the structures provided herein for dihydrofarnesene, tetrahydrofarnesene, and hexahydrofarnesene; any of the structures provided herein for dihydromyrcene and tetrahydromyrcene; and any of the structures provided herein for dihydroocimene and tetrahydroocimene.

[0059] One example of a particular species of partially hydrogenated conjugated hydrocarbon terpene that may have utility as a feedstock is a terminal olefin having a saturated hydrocarbon tail with structure (A11):



where $n=1, 2, 3, \text{ or } 4$.

[0060] In some variations, a mono-olefinic alpha-olefin having structure A11 may be derived from a conjugated hydrocarbon terpene wherein the conjugated diene is at the 1,3-position of the terpene. Examples include alpha-olefins derived from a 1,3-diene conjugated hydrocarbon terpene (e.g., a C10-C30 conjugated hydrocarbon terpene such as farnesene, myrcene, ocimene, springene, geranyl farnesene, neophytadiene, trans-phyta-1,3-diene, or cz's-phyta-1, 3-diene). Another non-limiting example of an alpha-olefin having the general structure A11 includes 3,7,11-trimethyldodecene having structure A12.

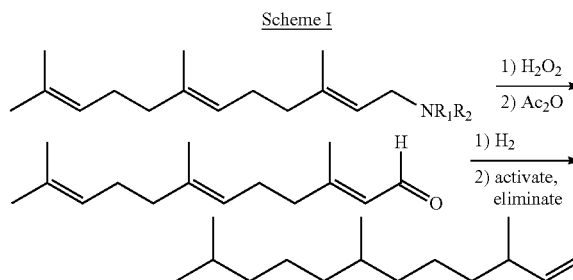


[0061] A mono-olefinic alpha-olefin having structure A11 may be prepared from the appropriate conjugated hydrocarbon terpene using any suitable method. In some variations, the mono-olefinic alpha-olefin having structure A11 is produced from primary alcohol of corresponding to the hydrocarbon terpene (e.g., farnesol in the case of farnesene, or geraniol in the case of myrcene). The methods comprise hydrogenating the primary alcohol, forming a carboxylic acid ester or carbamate ester from the hydrogenated alcohol,

and pyrolyzing the ester (or heating the ester to drive the elimination reaction) to form the alpha-olefin with a saturated hydrocarbon tail, e.g., as described in Smith, L. E.; Rouault, G. F., *J. Am. Chem. Soc.* 1943, 65, 745-750, for the preparation of 3,7-dimethyloctene, which is incorporated by reference herein in its entirety. The primary alcohol of the corresponding hydrocarbon terpene may be obtained using any suitable method.

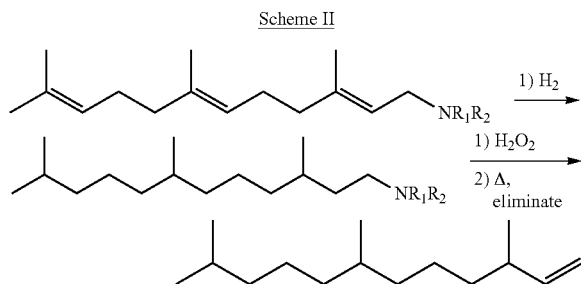
[0062] Alpha-olefins having the general structure A11 from conjugated hydrocarbon terpenes may be prepared via other schemes. For example, in some variations, the hydrocarbon terpene has a conjugated diene at the 1,3-position, and the conjugated diene can be functionalized with any suitable protecting group known to one of skill in the art in a first step (which may comprise one reaction or more than one reaction). The remaining olefinic bonds can be saturated in a second step (which may comprise one reaction or more than one reaction), and the protecting group can be eliminated to produce an alpha-olefin having the general structure A11 in a third step (which may comprise one reaction or more than one reaction).

[0063] Any suitable protecting group and elimination scheme may be used. For example, a hydrocarbon terpene having a 1,3-conjugated diene (e.g., β -farnesene) may be reacted with an amine (e.g., a dialkyl amine such as dimethylamine or diethylamine) in the first step to produce an amine having the formula $N(R_1)(R_2)(R_3)$, where R_1 and R_2 are alkyl groups such as methyl or ethyl, and R_3 is an unsaturated hydrocarbon originating from the conjugated terpene. The resulting amine may be oxidized to the N oxide using hydrogen peroxide (H_2O_2) followed by elimination to the aldehyde using acetic anhydride. Hydrogenation of the aldehyde in the presence of a catalyst may be carried out to saturate any remaining olefinic bonds on the aliphatic tail originating from the hydrocarbon terpene, and the aldehyde functionality may be eliminated to produce an alpha-olefin having structure A11. Scheme I below illustrates an example of such a preparation of an alpha-olefin having structure A11 using β -farnesene as a model compound.



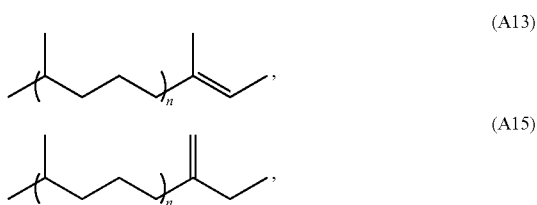
[0064] Another variation of a method to make an alpha-olefin from a hydrocarbon terpene having a 1,3-conjugated diene follows Scheme II below. Here, the hydrocarbon terpene is reacted with a dialkyl amine (e.g., dimethylamine). The resulting amine has the general formula $N(R_1)_2(R_2)$, where R_1 and R_2 are alkyl groups such as methyl and R_3 is an unsaturated hydrocarbon originating from the hydrocarbon terpene. The amine $N(R_1)(R_2)(R_3)$ can be hydrogenated (e.g., using an appropriate catalyst), treated with hydrogen peroxide, and heated to undergo elimination to form an alpha-olefin having structure A11 (e.g., com-

pound A12 if β -farnesene is used as the starting hydrocarbon terpene). Scheme II illustrates this method using β -farnesene as a model compound.



[0065] In another variation, a hydrogenated primary alcohol corresponding to a hydrocarbon terpene (e.g., hydrogenated farnesol or hydrogenated geraniol) can be dehydrated using basic aluminum oxide (e.g., at a temperature of about 250° C.) to make an alpha-olefin having the general structure A11. Any suitable dehydration apparatus can be used, but in some variations, a hot tube reactor (e.g., at 250° C.) is used to carry out a dehydration of a primary alcohol. In one variation, hydrogenated farnesol can be dehydrated using basic aluminum oxide (e.g., in a hot tube reactor at 250° C.) to make compound A12, or an isomer thereof.

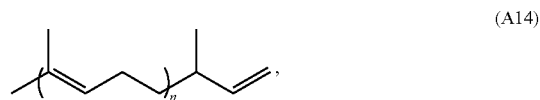
[0066] Other examples of particular species of partially hydrogenated conjugated hydrocarbon terpene that may have utility as a feedstock are mono-olefins having a saturated hydrocarbon tail with structure (A13) or structure (A15):



where $n=1, 2, 3$, or 4. A mono-olefin having the general structure A13, A15 or A11 may in certain instances be derived from a conjugated hydrocarbon terpene having a 1,3-diene moiety, such as myrcene, farnesene, springene, geranyl farnesene, neophytadiene, trans-phyta-1,3-diene, or cis-phyta-1,3-diene. Here again, the conjugated may be functionalized with a protecting group (e.g., via a Diels-Alder reaction) in a first step, exocyclic olefinic bonds hydrogenated in a second step, and the protecting group eliminated in a third step. In one non-limiting example of a method for making mono-olefins having the structure A13, A15 or A11, a conjugated hydrocarbon terpene having a 1,3-diene is reacted with SO_2 in the presence of a catalyst to form a Diels-Alder adduct. The Diels-Alder adduct may be hydrogenated with an appropriate hydrogenation catalyst to saturate exocyclic olefinic bonds. A retro Diels-Alder reaction may be carried out on hydrogenated adduct (e.g., by heating, and in some instances in the presence of an appropriate catalyst) to eliminate the sulfone to form a 1,3-diene. The 1,3-diene can then be selectively hydrogenated using a

catalyst known in the art to result in a mono-olefin having structure A11, A13 or A15, or a mixture of two or more of the foregoing. Non-limiting examples of regioselective hydrogenation catalysts for 1,3-dienes are provided in Jong Tae Lee et al, "Regioselective hydrogenation of conjugated dienes catalyzed by hydridopentacyanocobaltate anion using β -cyclodextrin as the phase transfer agent and lanthanide halides as promoters," *J. Org. Chem.*, 1990, 55 (6), pp. 1854-1856, in V. M. Frolov et al, "Highly active supported palladium catalysts for selective hydrogenation of conjugated dienes into olefins," *Reaction Kinetics and Catalysis Letters*, 1984, Volume 25, Numbers 3-4, pp. 319-322, in Tungler, A., Hegedus, L., Fodor, K., Farkas, G., Furcht, A. and Karancsi, Z. P. (2003) "Reduction of Dienes and Polyenes," in *The Chemistry of Dienes and Polyenes*, Volume 2 (ed. Z. Rappoport), John Wiley & Sons, Ltd, Chichester, UK. doi: 10.1002/0470857226.ch12, and in Tungler, A., Hegedus, L., Fodor, K., Farkas, G., Furcht, A. and Karancsi, Z. P., "Reduction of Dienes and Polyenes" in *Patai's Chemistry of Functional Groups* (John Wiley and Sons, Ltd, published online Dec. 15, 2009, DOI: 10.1002/9780470682531.pat0233), each of which is incorporated herein by reference in its entirety. For example, a catalyst known in the art for 1,4 hydrogen addition to 1,3-dienes results in a mono-olefin having structure A13. In one non-limiting example, 13-farnesene can be reacted with SO_2 in the presence of a catalyst to form a Diels-Alder adduct, which is subsequently hydrogenated, and the sulfone eliminated to form a 1,3-diene, which is subsequently selectively hydrogenated using a catalyst known in the art for regioselective hydrogen additions to 1,3-dienes to form 3,7,11-trimethyldodec-2-ene, 3,7,11-trimethyldodec-1-ene, or 3-methylene-7,11-dimethyldodecane, or a mixture of any two or more of the foregoing.

[0067] In yet another example of a particular species of partially hydrogenated hydrocarbon terpene that may have utility as a feedstock, a terminal olefin of the general structure A14 may be made from a conjugated hydrocarbon terpene having a 1, 3-conjugated diene and at least one additional olefinic bond (e.g., myrcene, farnesene, springene, or geranyl farnesene):



where $n=1, 2, 3$, or 4. In one non-limiting variation, a compound having the structure A14 may be derived from an unsaturated primary alcohol corresponding to the relevant hydrocarbon terpene (e.g., farnesol in the case of farnesene, or geraniol in the case of myrcene). The unsaturated primary alcohol may be exposed to a suitable catalyst under suitable reaction conditions to dehydrate the primary alcohol to form the terminal olefin A 14.

[0068] In one non-limiting example, a stoichiometric deoxygenation-reduction reaction may be conducted to form compounds having structure A14 from a primary alcohol (e.g., farnesol or geraniol) of a hydrocarbon terpene. One prophetic example of such a reaction can be conducted according to a procedure described in Dieguez et al, "Weakening C-O Bonds: Ti(III), a New Reagent for Alcohol Deoxygenation and Carbonyl Coupling Olefination," *J. Am.*

Chem. Soc. 2010, vol. 132, pp. 254-259, which is incorporated by reference herein in its entirety: A mixture of titanocene dichloride ($\eta^5\text{-C}_5\text{H}_5\text{)}_2\text{TiCl}_2$ (Cp_2TiCl_2) (3.88 mmol) and Mn dust (2.77 mmol) in strictly deoxygenated tetrahydrofuran (THF) (7 mL) can be heated at reflux under stirring until the red solution turns green. Then, to this mixture can be added a solution of the primary alcohol (e.g., farnesol or geraniol) (1.85 mmol) in strictly deoxygenated THF (4 mL). After the starting materials disappear, the reaction can be quenched with 1N HCl and extracted with tert-butylmethyl ether (t-BuOMe). The organic phase can be washed with brine, filtered and concentrated in vacuo to yield a crude product, which can be purified, e.g., by column chromatography (hexane/t-BuOMe, 8:1) over silica gel column to afford a compound having structure A14 (e.g., 3,7,11-trimethyldodeca-1,6,10-triene if farnesol is used as the starting material).

[0069] Other reactions may be conducted to form compounds having structure A14 from a primary alcohol (e.g., farnesol or geraniol) of a hydrocarbon terpene. One prophetic example of such a reaction can be conducted according to another procedure described in Dieguez et al, "Weakening C-O Bonds: Ti(III), a New Reagent for Alcohol Deoxygenation and Carbonyl Coupling Olefination," *J. Am. Chem. Soc.* 2010, vol. 132, pp. 254-259, which is incorporated herein by reference in its entirety: a mixture of Cp_2TiCl_2 (0.639 mmol) and Mn dust (17.04 mmol) in thoroughly deoxygenated THF (8 mL) and under Ar atmosphere can be stirred until the red solution turns green. This mixture may then be heated at reflux and the corresponding trimethylsilylchloride (TMSCl) (8.52 mmol) may be added. The primary alcohol (e.g., farnesol) (1.92 mmol) in strictly deoxygenated THF (2 mL) may then be added. After the starting materials disappear, the reaction may be quenched with t-BuOMe, washed with 1 N HCl, brine, dried, and concentrated under reduced pressure. The resulting crude may be purified, e.g., by column chromatography (hexane/t-BuOMe, 8:1) on silica gel to afford compound having structure A14 (e.g., 3,7,11-trimethyldodeca-1,6,10-triene if farnesol is used as the starting material).

[0070] An olefinic feedstock as described herein may comprise any useful amount of the particular species (e.g., alpha-olefinic species having structure A11, A12 or A15, mono-olefinic species having structure A13, or unsaturated terminal olefin species having structure A14), made either by a partial hydrogenation route or by another route, e.g., as described herein. In certain variations, an olefinic feedstock comprises at least about 1%, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% species having structure A11, A12, A13, A14, or A15. In certain variations, an olefinic feedstock comprises at least about 1%, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3,7,11-trimethyldodec-1-ene. In certain variations, an olefinic feedstock comprises at least about 1%, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3-methylene-7,11-dimethyldodecane. In certain variations, an olefinic feedstock comprises at least about 1%, at least about 5%, at least about 10%, at least

about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3,7,11-trimethyldodec-2-ene. In certain variations, an olefinic feedstock comprises at least about 1%, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3,7,11-trimethyldodeca-1,6,10-triene. In certain variations, an olefinic feedstock comprises at least about 1%, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3,7-dimethyloct-1-ene. In certain variations, an olefinic feedstock comprises at least about 1%, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3,7-dimethyloct-2-ene. In certain variations, an olefinic feedstock comprises at least about 1%, at least about 5%, at least about 10%, at least about 20%, at least about 30%, at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% 3,7-dimethylocta-1,6-diene.

[0071] As described herein, in some variations, the hydrocarbon terpene feedstock comprising alpha-olefinic species or internal olefinic species of partially hydrogenated hydrocarbon terpenes are suitable for catalytic reaction with one or more alpha-olefins to form a mixture of isoparaffins comprising adducts of the terpene and the one or more alpha-olefins. In some variations, at least a portion of the mixture of isoparaffins so produced may be used as a base oil.

[0072] Currently, the American Petroleum Institute (API) categorizes base oils into five groups depending on physical and compositional properties as shown in Table II. API Group I, II, and III represent base oils which are differentiated by viscosity index, saturate content, and sulfur content. Group III base oils have greater than 90% saturates, less than 0.03% sulfur and have a viscosity index above 120 due to higher degree of refinement than Group II base oils and generally are severely hydrocracked (higher pressure and heat). Based on physical and compositional properties, the biobased base oils of current disclosure belong to API Group III base oil category.

TABLE II

American Petroleum Institute Base Oil Categories				
Base Oil Category	Sulfur (%)		Saturates (%)	Viscosity Index
Group I (solvent refined)	>0.30	and/or	<90	80 to 120
Group II (hydrotreated)	<0.03	and	>90	80 to 120
Group III (hydrocracked)	<0.03	and	>90	>120
Group IV	PAO Synthetic Lubricants			
Group V	All other base oils not included in Groups I, II, III or IV			

[0073] Base oils from different groups provide distinguishably different performance of engine oil during engine testing. Therefore, simple and straightforward replacement of one base oil with another base oil comes with risks to proper engine operation. The API base oil interchangeability guidelines (BOI) were developed to ensure that the perfor-

mance of engine oil products is not adversely affected when different base oils are used interchangeably by engine oil blenders. The API BOI guidelines are based on actual engine test data, using different base oils, for both gasoline and diesel engine oil performance. API BOI guidelines require the least amount of engine testing when the interchange base oil is selected from same API group as the base oil in the original tested engine oil formulation.

[0074] In preparing an engine oil with the biobased hydrocarbon base oil, about 25 weight percent (wt %) up to about 95 wt % of the biobased hydrocarbon base oil may be used. To this biobased hydrocarbon oil may be added between about 1 ppm to about 50 wt % additives, namely one or more oxidation inhibitors (anti-oxidants), corrosion and rust inhibitors, viscosity modifiers, pour point depressants, metal deactivators, anti-foaming agents, friction modifiers, extreme pressure additives, anti-wear agents, dispersants, detergents, commercially available engine oil additive packages, and mixtures thereof. A range of typical dosage level and preferred dosage level of such additives are shown in Table III. A blend component comprising one or more additional base oils or liquids may also be used as the base oil or co-base oil to formulate or complete the engine oil, or to adjust the viscosity of the engine oil or some other desired characteristic. Such additive oils, co-base oils, or liquids may be selected from one or more of the following: microbial oils, castor oil, lard oil, vegetable oils, seed oils, algal oils, mineral oils, highly refined mineral oils, isoparaffinic hydrocarbon fluids, naphthenic oils, silicone fluids, synthetic esters, poly alpha olefins, PAG's, phosphate esters, silicon oils, diesters, polyol esters, polysiloxanes, pentaerythritol esters, alkylated naphthalene, poly(butene) liquids, polybutylenes, polypropylenes, propylene-isobutylene copolymers, chlorinated polybutylenes, poly(1-hexenes), poly(1-octenes), poly(1-decenes), alkylbenzenes (e.g. dodecylbenzenes, tetradecylbenzenes, dinonylbenzenes, di(2-ethylhexyl) benzenes), estolides, polyphenols (e.g. biphenyls, terphenyls, alkylated polyphenols), alkylated diphenyl ethers, alkylated diphenyl sulfides and combinations thereof.

[0075] Another suitable class of co-base oils comprises the esters of dicarboxylic acids (e.g. phthalic acid, succinic acid, alkyl succinic acids and alkenyl succinic acids, maleic acid, azelaic acid, suberic acid, sebacic acid, fumaric acid, adipic acid, linoleic acid dimer, malonic acid, alkylmalonic acids, alkenylmalonic acids) with a variety of alcohols (e.g. butyl alcohol, hexyl alcohol, dodecyl alcohol, 2-ethylhexyl alcohol, ethylene glycol, diethylene glycol mono ether, propylene glycol). Specific examples of these esters include dibutyl adipate, di(2-ethylhexyl) sebacate, di-n-hexyl fumarate, dioctyl sebacate, diisooctyl azelate, diisodecyl azelate, dioctyl phthalate, didecyl phthalate, dieicosyl sebacate, the 2-ethylhexyl diester of linoleic acid dimer, and the complex ester formed by reacting one mole of sebacic acid with two moles of tetraethylene glycol and two moles of 2-ethylhexanoic acid. Esters useful as synthetic oils also include those made from C5 to C12 monocarboxylic acids and polyols, and polyol ethers such as neopentyl glycol, trimethylolpropane, pentaerythritol, dipentaerythritol and tripentaerythritol.

[0076] Unrefined, refined and re-refined oils can be used as co-base oils in the engine oil compositions of the present disclosure. Unrefined oils are those obtained directly from a natural or synthetic source without further purification treatment. For example, a shale oil obtained directly from

retorting operations, a petroleum oil obtained directly from distillation or ester oil obtained directly from an esterification process and used without further treatment would be unrefined oil. Refined oils are similar to the unrefined oils except they have been further treated in one or more purification steps to improve one or more properties. Many such purification techniques, such as distillation, solvent extraction, acid or base extraction, filtration and percolation are known to those skilled in the art. Re-refined oils are obtained by processes similar to those used to obtain refined oils, but the processes are applied to refined oils which have been already used in service. Such re-refined oils are also known as reclaimed or reprocessed oils and often are additionally processed by techniques for approval of spent additive and oil breakdown products.

[0077] Other examples of co-base oils are gas-to-liquid ("GTL") base oils, i.e. the base oil may be an oil derived from FischerTropsch synthesized hydrocarbons made from synthesis gas containing H₂ and CO using a Fischer-Tropsch catalyst. These hydrocarbons typically require further processing in order to be useful as a base oil. For example, they may, by methods known in the art, be hydroisomerized; hydrocracked and hydroisomerized; dewaxed; or hydroisomerized and dewaxed.

[0078] The particular additives and the quantity of each used are selected with desired performances and intended use in mind. Other biobased oils may be used as a base oil in a similar manner, with attention to viscosity as with the biobased hydrocarbon base oil.

TABLE III

Typical amount and preferred amount of individual additive components in wt %		
additive	typical dosage, wt %	preferred dosage, wt %
ashless dispersant	0.1-20	1-8
metal detergent	0.1-15	0.2-9
rust & corrosion inhibitor	0-5	0-1.5
antioxidant	0-5	0.01-1.5
pour point depressant	0-5	0-1.5
anti-foaming agent	0-5	0-0.15
anti-wear agent	0-0.5	0-0.2
friction modifier	0-5	0-1.5
viscosity modifier	0-10	0-4
co base oil	0-50	0-20

[0079] In formulating the synthetic engine oils of this disclosure, according to one embodiment of this disclosure, the engine oil composition comprises an anti-oxidant. Anti-oxidants are typically free-radical traps, acting as free-radical reaction chain breakers. That is, effective antioxidants may be selected from radical scavengers such as phenolic, aminic antioxidants, or synergistic mixtures of these. Sulfurized phenolic antioxidants and organic phosphites are useful as components of such mixtures. Many antioxidant additives that are known and used in the formulation of lubricant products are suitable for use with the engine oils formulation described in this disclosure. Examples of phenolic antioxidants include 2,6-di-tert-butylphenol, liquid mixtures of tertiary butylated phenols, 2,6-di-tert-butyl-4-methylphenol, 4,4'-methylenebis(2,6-di-tert-butylphenol), 2,2'-methylenebis(4-methyl-6-tert-butylphenol), mixed methylene-bridged polyalkyl phenols, 4,4'-thiobis(2-methyl-6-tert-butylphenol), 4,4'-butylidenebis(3-methyl-6-tert-butylphenol), 4,4'-isopropylidene-bis(2,

6-di-tert-butylphenol), 2,2'-methylene-bis(4-methyl-6-nonylphenol), 2,2'-isobutylidene-bis(4,6-dimethylphenol), 2,6-di-tert-butyl-4-methylphenol, 2,6-di-tert-butyl-4-ethylphenol, 2,4-dimethyl-6-tert-butyl-phenol, 2,6-di-tert-1-dimethylamino-p-cresol, 2,6-di-tert-4-(N,N'-dimethylaminomethylphenol), 4,4'-thiobis(2-methyl-6-tert-butylphenol), 2,2'-thiobis(4-methyl-6-tert-butylphenol), bis(3-methyl-4-hydroxy-5-tert-10-butylbenzyl)-sulfide, bis(3,5-di-tert-butyl-4-hydroxybenzyl), 2,2'-5-methylene-bis(4-methyl-6-cyclohexylphenol), N,N'-di-sec-butylphenylenediamine, 4-isopropylaminodiphenylamine, phenyl- α -naphthyl amine, phenyl- α -naphthyl amine, and ring-alkylated diphenylamines. Examples include the sterically hindered tertiary butylated phenols, bisphenols and cinnamic acid derivatives and combinations thereof. In yet another embodiment, the antioxidant is an organic phosphonate having at least one direct carbon-to-phosphorus linkage. Diphenylamine-type oxidation inhibitors include, but are not limited to, alkylated diphenylamine, phenyl- α -naphthylamine, and alkylated- α -naphthylamine. Other types of oxidation inhibitors include metal dithiocarbamate (e.g., zinc dithiocarbamate), and 15-methylenebis(dibutyl-dithiocarbamate). In another embodiment, class of antioxidants suitable for food grade industrial lubricant formulation are also useful in the compressor oil described in current disclosure. Example of such antioxidants include, without limitation, butylated hydroxyanisole (BHA), di-butyl-paracresol (BHT), phenyl- α -naphthylamine (PANA), octylated/butylated diphenylamine, tocopherol (vitamin-E), β -carotene, sterically hindered alkylthiomethylphenol, 2-(1,1-Dimethylethyl)-1,4-benzenediol, 1,2-dihydro-2,2,4-trimethylquinoline, ascorbyl palmitate, propyl gallate, high molecular weight phenolic antioxidants, hindered bis-phenolic antioxidant, and mixtures of these.

[0080] In one embodiment, such an antioxidant in an amount of 0.01 wt % to ~10 wt % of the engine oil may be added to the biobased base oil and other additive mixture comprising the engine oil described in the current disclosure.

[0081] Metal deactivators/passivator may also be used in addition to or as an alternative to an antioxidant. In one embodiment, the list of useful metal deactivators include imidazole, benzimidazole, pyrazole, benzotriazole, tolutriazole, 2-methyl benzimidazole, 3,5-dimethyl pyrazole, and methylene bis-benzotriazole. Commercial examples used in some embodiments of the disclosure include, without limitation, triazole derivative metal deactivators, such as Irgamet® 30 (available from BASF), and tolutriazole derivative metal deactivators, such as Irgamet® 39 (available from BASF). An amount of metal deactivators up to about 100 ppm is used in some embodiments. In one embodiment, the metal passivator is food grade and complies with FDA regulations. One of such useful additive is the N-acyl derivative of sarcosine, such as an N-acyl derivative of sarcosine. One example is N-methyl-N-(1-oxo-9-octadecenyl) glycine. This derivative is commercially available from BASF under the trade name SARKOSYL™ O. Another additive is an imidazoline such as Amine O™, also, commercially available from BASF.

[0082] In one embodiment, the engine oils of the present disclosure comprise a foam inhibitor. Examples of foam inhibitors include but are not limited to alkylpolysiloxanes, dimethyl polycyclohexane and polyacrylates. Commercial examples useful foam inhibitors in some embodiments of

the disclosure include, without limitation, PC-1344 (Cytec), PC-1844 (Cytec), PC-2544 (Cytec), PC-3144 (Cytec), HiTec2030 (Afton), AC AMH2 (BASF), 889D (Lubrizol), and mixtures thereof.

[0083] In one embodiment, the engine oils of the present disclosure comprise a viscosity modifier/viscosity index improver. Viscosity modifiers (or viscosity index improvers) are polymeric materials, typical examples of these being hydrogenated styrene-isoprene block copolymers, hydrogenated copolymers of styrene-butadiene, copolymers of ethylene and propylene, acrylic polymers produced by polymerization of acrylate and methacrylate esters, hydrogenated isoprene polymers, polyalkyl styrenes, hydrogenated alkenyl arene conjugated diene copolymers, polyolefins, esters of maleic anhydride-styrene copolymers, and polyisobutylene. These polymeric thickeners are added to bring the viscosity of the base fluid mixture up to the required level of SAE J300 viscosity grade (see, e.g., Table IV).

[0084] In various embodiments, the viscosity modifier/viscosity index improver may be a polymer with linear, radial or star architecture, such as those described in Schober et al., US Patent Application No. 2011/0306529, which is incorporated by reference in its entirety, and in the references cited therein, all of which are incorporated herein in their entirety. Such viscosity modifiers may have a random, tapered, di-block, tri-block, or multi-block architecture and may have weight average molecular weights of about 100,000 to about 800,000 g/mol. As a non-limiting example, a disclosed embodiment in US Patent Application No. 2011/0306529 is prepared from 50 wt % to about 100 wt % of an alkyl methacrylate, wherein the alkyl group has about 10 to about 20 carbon atoms up to about 40 wt % of an alkyl methacrylate, wherein the alkyl group has about 9 carbon atoms; and up to about 10 wt % of a nitrogen-containing monomer. Other examples of viscosity modifiers that are star polymers include isoprene/styrene/isoprene triblock polymers.

[0085] Examples of commercially available viscosity modifier/viscosity index improver for use in some embodiments of the disclosure include, without limitation, TPC1285 (TPC group), TPC175 (TPC group), TPC1105 (TPC group), TPC1160 (TPC group), SV260 (Infineum), SV261 (Infineum), SV265 (Infineum), V534 (Infineum), 7308 (Lubrizol), 7723 (Lubrizol), 87705 (Lubrizol), HiTec5754 (Afton), HiTec5751 (Afton), HiTec5748 (Afton), HiTec5825A (Afton), Viscoplex 8-100 (Evonik), Viscoplex 8-112 (Evonik), Viscoplex 8-200 (Evonik), Viscoplex 8-219 (Evonik), Viscoplex 8-220 (Evonik), Viscoplex 8-251 (Evonik), Viscoplex 8-310 (Evonik), Viscoplex 8-400 (Evonik), Viscoplex 8-407 (Evonik), Viscoplex 8-450 (Evonik), Viscoplex 8-944 (Evonik), Viscoplex 8-954 (Evonik), Viscoplex 10-250 (Evonik), Viscoplex 10-930 (Evonik), Viscoplex 10-950 (Evonik), Viscoplex 7-302 (Evonik), Viscoplex 7-305 (Evonik), Viscoplex 7-310 (Evonik), Viscoplex 7-510 (Evonik), and mixture thereof.

[0086] In one embodiment, the engine oils of the present disclosure comprise detergents or dispersants which can be anionic, cationic, zwitterionic or non-ionic. A dispersant is typically an additive whose primary function is to hold solid and liquid contaminations in suspension, thereby passivating them and reducing engine deposits at the same time as reducing sludge depositions. For example, a dispersant maintains in suspension oil-insoluble substances that result from oxidation during use of the lubricant, thus preventing

sludge flocculation and precipitation or deposition on metal parts of the engine. Dispersants are usually “ashless”, as mentioned above being non-metallic organic materials that form substantially no ash on combustion, in contrast to metal-containing, and hence ash-forming materials. They comprise a long hydrocarbon chain with a polar head, the polarity being derived from inclusion of e.g. an O, P, or N atom. The hydrocarbon is an oleophilic group that confers oil-solubility, having, for example 40 to 500 carbon atoms. Thus, ashless dispersants may comprise an oil-soluble polymeric backbone. A preferred class of olefin polymers is polybutenes, specifically polyisobutenes (PIE) or poly-n-butenes, such as may be prepared by polymerization of a C4 refinery stream.

[0087] Dispersants include, for example, derivatives of long-chain hydrocarbon-substituted carboxylic acids, examples being derivatives of high molecular weight hydrocarbyl-substituted succinic acid. A noteworthy group of dispersants are hydrocarbon-substituted succinimides, made, for example, by reacting the above acids (or derivatives) with a nitrogen-containing compound, advantageously by a polyalkylene polyamine, such as a polyethylene polyamine. Particularly preferred are the reaction products of polyalkylene polyamines with alkenyl succinic anhydrides, such as described in U.S. Pat. Nos. 3,202,678; 3,154,560; 3,172,892; 3,024,195; 3,024,237, 3,219,666; and 3,216,936; and BE-A-66,875 that may be post-treated to improve their properties, such as borated (as described in U.S. Pat. Nos. 3,087,936 and 3,254,025) fluorinated and oxylated. For example, boration may be accomplished by treating an acyl nitrogen-containing dispersant with a boron compound selected from boron oxide, boron halides, boron acids and esters of boron acids.

[0088] Lubricant dispersants stabilize contaminants during lubrication cycle resulting in protection against problem such as viscosity increase, wear, and filter plugging. The surfactant or dispersant may be used alone or in combination with other types of surfactants or dispersants. Examples include, but not limited to, metal-containing compounds such as phenates, salicylates, thiophosphonates, and sulfonates. Examples also include, but not limited to, ashless dispersants such as alkyl succinic anhydrides, succinimide dispersants, succinic ester dispersants, and succinic esteramide dispersants. In one embodiment, the dispersant is selected from the group of alkenyl succinimides, alkenyl succinimides modified with other organic compounds, alkenyl succinimides modified by post-treatment with ethylene carbonate or boric acid, pentaerythritols, phenate-salicylates and their post-treated analogs, alkali metal or mixed alkali metal, alkaline earth metal borates, dispersions of hydrated alkali metal borates, dispersions of alkaline-earth metal borates, polyamide ashless dispersants and the like or mixtures of such dispersants. Examples of metallic detergents include an oil-soluble neutral or overbased salt of alkali or alkaline earth metal with one or more of the following acidic substance (or mixtures thereof): a sulfonic acid; a carboxylic acid; a salicylic acid; an alkyl phenol; a sulfurized alkyl phenol; and an organic phosphorus acid characterized by at least one direct carbon-to-phosphorus linkage, such as phosphonate.

[0089] A detergent is an additive that reduces formation of piston deposits, for example high-temperature varnish and lacquer deposits, in engines; it normally has acid-neutralizing properties and is capable of keeping finely divided solids

in suspension. Most detergents are based on metal “soaps”, that is, metal salts of acidic organic compounds. Lubricant detergents are metal salts of organic surfactants giving corrosion protection, deposit prevention, and other formulation enhancement.

[0090] Detergents generally comprise a polar head with a long hydrophobic tail, the polar head comprising a metal salt of an acidic organic compound. The salts may contain a substantially stoichiometric amount of the metal when they are usually described as normal or neutral salts and would typically have a total base number or TBN (as may be measured by ASTM D2896-11) of from 0 to 80. Large amounts of a metal base can be included by reacting an excess of a metal compound, such as an oxide or hydroxide, with an acidic gas such as 15 carbon dioxide. The resulting overbased detergent comprises neutralized detergent as an outer layer of a metal base (e.g., carbonate) micelle. Such overbased detergents may have a TBN of 150 or greater, typically from 250 to 500 or more.

[0091] Detergents that may be used include oil-soluble neutral and acids, overbased sulfonates, phenates, sulfurized phenates, iophosphonates, salicylates, and naphthenates and other oil-soluble carboxylates of a metal, particularly the alkali or alkaline earth metals, e.g. sodium, potassium, lithium, calcium and magnesium. The most commonly used metals are calcium and magnesium, which may both be present in detergents used in a lubricant, and mixtures of calcium and/or magnesium with sodium. Particularly convenient metal detergents are neutral and overbased calcium sulfonates and sulfurized phenates having a TBN of from 50 to 450.

[0092] In one embodiment, the engine oils of the present disclosure further comprise at least one rust or corrosion inhibitor. Examples of suitable ferrous metal corrosion inhibitors are the metal sulfonates such as calcium petroleum sulfonate, barium dionyl-naphthalene sulfonate and basic barium dioxynaphthalene sulfonate, carbonated or non-carbonated. Other examples are selected from thiazoles, triazoles, and thiadiazoles. Examples of such compounds include benzotriazole, tolyltriazole, octyltriazole, decyltriazole, dodecyltriazole, 2-mercapto benzothiazole, 2,5-dimercapto-1,3,4-thiadiazole, 2-mercapto-5-hydrocarbylthio-1,3,4-thiadiazoles, 2-mercapto-5-hydrocarbyldithio-1,3,4-thiadiazoles, 2,5-bis(hydrocarbylthio)-1,3,4-thiadiazoles, and 2,5-bis(hydrocarbyldithio)-1,3,4-thiadiazoles. Suitable compounds include the 1,3,4-thiadiazoles, a number of which are available as articles of commerce, and also combinations of triazoles such as tolyltriazole with a 1,3,5-thiadiazole such as 2,5-bis(alkyldithio)-1,3,4-thiadiazole. The 1,3,4-thiadiazoles are generally synthesized from hydrazine and carbon disulfide by known procedures. See, for example, U.S. Pat. Nos. 2,765,289; 2,749,311; 2,760,933; 2,850,453; 2,910,439; 3,663,561; 3,862,798; and 3,840,549.

[0093] In one embodiment, the rust or corrosion inhibitors are selected from the group of monocarboxylic acids and polycarboxylic acids. Examples include octanoic acid, decanoic acid and dodecanoic acid. Suitable polycarboxylic acids include dimer and trimer acids produced from acids such as tall oil fatty acids, oleic acid, linoleic acid, or the like. Another useful type of rust inhibitor may comprise alkenyl succinic acid and alkenyl succinic anhydride corrosion inhibitors, for example, tetrapropenylsuccinic acid, tetrapropenylsuccinic anhydride, tetradecenylsuccinic acid,

tetradecenylsuccinic anhydride, hexadecenylsuccinic acid, hexadecenylsuccinic anhydride, and the like. Also useful are the half esters of alkenyl succinic acids having 8 to 24 carbon atoms in the alkenyl group with alcohols such as the polyglycols. Other suitable rust or corrosion inhibitors include ether amines; acid phosphates; amines; polyethoxylated compounds such as ethoxylated amines, ethoxylated phenols, and ethoxylated alcohols; imidazolines; aminosuccinic acids or derivatives thereof, and the like. Mixtures of such rust or corrosion inhibitors can be used. Other examples of rust inhibitors include a polyethoxylated phenol, neutral calcium sulfonate and basic calcium sulfonate.

[0094] In one embodiment, the engine oils of the present disclosure further comprise at least a friction modifier selected from the group of succinimide, a bis-succinimide, an alkylated fatty amine, an ethoxylated fatty amine, an amide, a glycerol ester, a glycerol mono-oleates, an imidazoline, fatty alcohol, fatty acid, amine, borated ester, other esters, phosphates, phosphites, phosphonates, and mixtures thereof.

[0095] Extreme pressure/anti-wear agents useful for present disclosure may be selected from library of molecules deemed suitable/preferable by those who are skilled in art of engine oil formulation. Such molecules and compounds can reduce friction and/or wear by forming protective-film layer between two sliding surfaces. Such compounds include oxygen-containing organic compounds with polar head group, organic sulphur compounds which can form reacted films at surfaces, organic phosphorus compounds, organic boron compounds, organic molybdenum compounds, zinc dialkyldithiophosphates (ZDDP), and mixture thereof. In one embodiment, the engine oils further comprise at least an extreme pressure/anti-wear agent in the range of from 100 ppm to 1 wt %, based on the total weight of engine oil composition. Examples of such agents include, but are not limited to, phosphates, carbamates, esters, molybdenum-containing compounds, boron-containing compounds and ashless anti-wear additives such as substituted or unsubstituted thiophosphoric acids, and salts thereof. In one embodiment, the anti-wear agents are selected from the group of zinc dialkyl-1-dithiophosphate (primary alkyl, secondary alkyl, and aryl type), diphenyl sulfide, methyl trichlorostearate, chlorinated naphthalene, fluoroalkylpolysiloxane, lead naphthenate, neutralized phosphates, dithiophosphates, and sulfur-free phosphates. In another embodiment, the anti-wear agent is selected from the group of a zinc dialkyl dithiophosphate (ZDDP), an alkyl phosphite, a trialkyl phosphite, and amine salts of dialkyl and mono-alkyl phosphoric acid. Examples of molybdenum-containing compounds that may serve as anti-wear agents include molybdenum dithiocarbamates, trinuclear molybdenum compounds, for example as described in WO1998026030, sulphides of molybdenum and molybdenum dithiophosphate. Boron-containing compounds that may be used as anti-wear agents include borate esters, borated fatty amines, borated epoxides, alkali metal (or mixed alkali metal or alkaline earth metal) borates and borated overbased metal salts.

[0096] In one embodiment, the engine oils of the present disclosure further comprise at least one seal compatibility agent. It is well known those who skilled in the art of engine oil and lubricant formulation that, when major portion of engine oil consists of highly paraffinic base oils, it is necessary to include seal compatibility agents in order to

meet the specification. Seal compatibility agents may be selected from, but not limited to, various commercial grade aromatic esters.

[0097] In one embodiment, the engine oils of the present disclosure comprise a pour point depressant. Such additives are well known. Typical pour point depressant can be selected from C8 to C18 dialkyl fumarate/vinyl acetate copolymers and polyalkylmethacrylates.

[0098] In one embodiment, the additional or additive components to the engine oil are added as a fully formulated additive package designed to meet various regional and global engine oil specifications. Some of the above-mentioned additives can provide a multiplicity of effects; thus for example, a single additive may act as a dispersant as well as an oxidation inhibitor. In one embodiment, when the engine oil contains one or more of the above-mentioned additives, each additive is typically blended into the base oil in an amount that enables the additive to provide its desired function. It may be desirable, although not essential, to prepare one or more additive concentrates comprising additives (concentrates containing at least one of above-mentioned additives sometimes being referred to as "additive packages") to add to the engine oil composition. The final composition may employ from about 0.001 to 20 wt. % of the concentrate, the remainder being the oil of lubricating viscosity. The components can be blended in any order and can be blended as combinations of components.

[0099] Additives used in formulating the engine oil composition can be blended into the base oil individually or in various sub-combinations to subsequently form the engine oil. In one embodiment, all of the components are blended concurrently using an additive concentrate (i.e., additives plus a diluent, such as a group III base oils or group V base oils). The use of an additive concentrate takes advantage of the mutual compatibility afforded by the combination of ingredients when in the form of an additive concentrate.

[0100] In another embodiment, the engine oil composition is prepared by mixing the base oil with the separate additives or additive package(s) at an appropriate temperature, such as approximately 25–80° C., until homogeneous.

[0101] The engine oils of the present disclosure can be used in various types of internal combustion engines.

[0102] High temperature high shear (HTHS) viscosity of engine oils can serve as a fundamental indicator of fuel economy index (FEI) improvement and protection against mechanical wear inside modern day automotive engines. HTHS viscosity may be measured by standardized method such as ASTM-D4683-13 or equivalent. Lower HTHS viscosity tends to improve FEI but can be correlated to less protection against mechanical wear. Therefore, careful balance must be maintained in order to achieve best FEI while providing optimum protection against mechanical wear. FIG. 1 compares HTHS value of base oils that belongs to different API group as a function of kinematic viscosity at 100° C. These base oils are main ingredients of commercial engine oils currently sold in the market. Regardless of identity of base oils, they exhibit uniform trend between kinematic viscosity and HTHS values. Biobased hydrocarbon base oil also show same trend as other commercially utilized base oils for engine oils. FIG. 2 show same trend obtained from mixture of base oils mentioned above and viscosity modifier commercially used for engine oil formulations. FIG. 2 shows existence of unique relationship between kinematic viscosity at 100° C. and HTHS at 150°

C. regardless of identity of commercial engine oil grade hydrocarbon base oils used in blend with VMs. Blend of such VMs with biobased hydrocarbon base oils falls into same unique trend.

[0103] Commercial engine oils are commonly classified according specification system devised by Society of Automotive Engineers (SAE) ratings, SAE J300 (SAE J300 2009-01). Classification is based on kinematic viscosity at 100° C., low temperature cranking viscosity, high temperature high shear viscosity, and low temperature pumping viscosity (Table IV). The first step in comparing fuel efficiency starts with comparing high temperature high shear (HTHS) viscosity. FIG. 1 plots the HTHS value of different base oils as a function of kinematic viscosity at 100° C. As is clear from this comparison, a uniform relationship is observed regardless of the type of base oil (Group II, petroleum based isoparaffinic base oil, PAO, or biobased isoparaffinic base oils). In turn, such observation suggests that the biobased base oil of the current disclosure can bring a similar degree of enhancement in fuel efficiency as well as other synthetic base oils listed above.

cranking viscosity at subzero temperature was measured using ASTM-D5293-14 and Noack volatility was measured using the procedure of ASTM-D5800-10. Group II base oils and their blends show highest cranking viscosity per given value of % volatile loss while group IV base oils and their blends show lowest cranking viscosity per given value of % volatile loss. Biobased hydrocarbon base oils and Group III base oils show trend set between Group II and Group IV base oils.

[0105] Typical 0W-grade engine oil formulations that utilize commercially available additive packages require a cranking viscosity value of the base oil blends to be less than or equal to 3000 cP at -35° C. Table V shows the advantage of biobased isoparaffinic hydrocarbon base oils over petroleum based isoparaffinic hydrocarbon base oils. At given % volatile loss, 13%, Group II base oil blends have a much higher cranking viscosity, 16,668 cP, than the required 3,000 cP for 0W-grade engine oil formulations while Group IV based base oil blends have the lowest cranking viscosity, 540 cP. The biobased hydrocarbon base oil blend with 13% volatile loss has a cranking viscosity lower than the required

TABLE IV

Engine Oil classification by Society of Automotive Engineers SAE Viscosity Grades For Engine Oils ^{(1), (2)} (SAE J300 2009-01)					
SAE Viscosity Grade	Low-Temperature (° C.) Cranking Viscosity ⁽³⁾ , mPa-s MAX	Low- Temperature (° C.) Pumping Viscosity ⁽⁴⁾ , mPa-s Max with No Yield Stress ⁽⁴⁾	Low-Shear- Rate Kinematic Viscosity ⁽⁵⁾ (mm 2/s) at 100° C. Min	Low-Shear- Rate Kinematic Viscosity ⁽⁵⁾ (mm 2/s) at 100° C. Max	High-Shear-Rate Viscosity ⁽⁶⁾ , mPa-s at 150° C. Min
0W	6200 at -35	60000 at -40	3.8	—	—
5W	6600 at -30	60000 at -35	3.8	—	—
10W	7000 at -25	60000 at -30	4.1	—	—
15W	7000 at -20	60000 at -25	5.6	—	—
20W	9500 at -15	60000 at -20	5.6	—	—
25W	13000 at -10	60000 at -15	9.3	—	—
20	—	—	5.6	<9.3	2.6
30	—	—	9.3	<12.5	2.9
40	—	—	12.5	<16.3	3.5 (SAE 0W-40, 5W-40, 10W-40 grades)
40	—	—	12.5	<16.3	3.7 (SAE 15W-40, 20W-40, 25W-40, 40 grades)
50	—	—	16.3	<21.9	3.7
60	—	—	21.9	<26.1	3.7

⁽¹⁾Notes - 1 cP = 1 mPa-s; 1 mm 2/5 = 1 cSt

⁽²⁾ All values, with the exception of the low-temperature cranking viscosity, are critical specifications as defined by ASTM D3244 (see text, Section 3)

⁽³⁾ASTM D5293: Cranking viscosity - The non-critical specification protocol in ASTM D3244 shall be applied with a P value of 0.95

⁽⁴⁾ASTM D4684: Note that the presence of any yield stress detectable by this method constitutes a failure regardless of viscosity

⁽⁵⁾ASTM D445

⁽⁶⁾ASTM D4683, CEC L-36-A-90 (ASTM D4741), or ASTM D5481

[0104] Most specifications on engine oils have more stringent requirement on volatile loss at an elevated temperature (e.g., 250° C.). For example, specification published on 2012 by European Automobile Manufacturers' Association (ACEA) allows no more than 13% loss for any new engine oil certified after December 2013, when tested by ASTM-D5800-10 or equivalent methods. FIG. 3 plots cranking viscosity, (in cP at -35° C.), as a function of Noack volatility, measured as % weight loss. The graph shows data of base oils selected from Group II, Group III and Group IV, as well as data for biobased hydrocarbon base oils; the

3,000 cP. Petroleum based isoparaffinic hydrocarbon base oils, Group III, with same amount of volatile loss have higher cranking viscosities than the required value for 0W-grade engine oil formulations. The third column of Table V shows % volatile loss of base oil blends with cranking viscosities of 3,000 cP at -35° C. Once again, the Group IV base oil blend has the lowest volatile loss, 6.0%, and the Group II base oil blend has the highest volatile loss, 49.4%. The biobased hydrocarbon base oil blend with 3,000 cP of cranking viscosity has a % volatile loss lower than the required 13% while the petroleum based isoparaffinic hydro-

carbon base oil, Group III, with the same cranking viscosity has a higher % volatile loss, 14.2%, and exceeds the required 13%. In order to compensate for high volatility of base oils in the engine oil formulation, a higher amount of non/low-volatile ingredients (i.e. viscosity modifiers and/or higher viscosity grade base oils) are required. However, inclusion of such non-volatile ingredients typically comes with a disadvantages such as increased base kinematic viscosity and/or increased cranking viscosity at lower temperature. Such disadvantages typically limits the range of viscosity grades that can be formulated (i.e. limited in formulating lower viscosity grades or lower winter grades) according to the SAE-J300 specification.

TABLE V

Comparison of Cranking Viscosity and Volatile Loss at a Critical Composition		
	Cranking viscosity, cP, of base oil blends with 13% volatile loss*	% volatile loss of base oil blends with cranking viscosity = 3000 cP**
Group II base oil blend	16668	49.4%
Group III base oil blend	3480	14.2%
Biobased hydrocarbon base oil blend	2519	12.0%
Group IV base oil blend	540	6.0%

*cranking viscosity was measured at -35° C. using ASTM-D5293-14

**volatile loss was measured using ASTM-D5800-10 method B

[0106] FIG. 4 compares cranking viscosity, at -35° C., of base oils selected from Group II, Group III and Group IV to cranking viscosity of biobased hydrocarbon base oil as a function of kinematic viscosity at 100° C.; cranking viscosity was measured using the procedure of ASM-D5293-14 and kinematic viscosity was measured using the procedure of ASTM-D445-14E2. Within the Groups II, III, and IV base oils, per given value of kinematic viscosity, cranking viscosity at -35° C. ranks Group II>Group III>Group IV (from high value to low value). Biobased hydrocarbon base oils and Group III base oils show trend set between Group II and Group IV base oils.

TABLE VI

Comparison of Cranking Viscosity and Kinematic Viscosity at a Critical Composition*		
	Cranking viscosity, cP, of base oil blends with kinematic viscosity = 4.7 cSt	Kinematic viscosity of base oil blends with cranking viscosity = 3000 cP
Group II base oil blend	8438	3.46
Group III base oil blend	3675	4.39
Biobased hydrocarbon base oil blend	2916	4.74
Group IV base oil blend	2052	5.44

*cranking viscosity was measured at -35° C. using ASTM-D5293-14 method and kinematic viscosity was measured at 100° C. using ASTM-D445-14E2 method

[0107] Kinematic viscosity at 100° C. is another important parameter in classifying engine oils (see, e.g., Table IV). The simplest engine oil formulation that consists of an engine oil additive package and a base oil blend typically yields a SAE viscosity grade of between 20 or 30. The addition of a

viscosity modifier is necessary in order to formulate a higher viscosity grade engine oil such as grade 40 through 60 with the same base oil blend. Viscosity modifier can easily boost kinematic viscosity with little or no increase on low temperature cranking viscosity. However, such benefit comes with a penalty of lower shear stability and higher formulation cost. In general, a base oil with lower cranking viscosity is preferred over a base oil having a greater cranking viscosity at a given kinematic viscosity at 100° C. and a base oil having a greater kinematic viscosity at 100° C. is preferred over a base oil having a lesser kinematic viscosity at 100° C. at a given cranking viscosity. The second column of Table VI lists the cranking viscosity, at -35° C., of base oil blends with a kinematic viscosity, at 100° C., value fixed at 4.7cSt. Base oil blends made with Group II base oils has the highest cranking viscosity, 8438 cP and a base oil blend made with Group IV base oils has the lowest cranking viscosity, 2052 cP. Petroleum based isoparaffinic hydrocarbon base oils, Group III, with the same kinematic viscosity (4.7cSt at 100° C.) has a higher cranking viscosity than 3000 cP, the required value for a 0W-grade engine oil formulation. While a biobased hydrocarbon base oil blend with the same kinematic viscosity has a cranking viscosity of 2916 cP, this is lower than the requirement. The last column of Table VI shows the kinematic viscosities at 100° C. of base oil blends with the same cranking viscosity, 3000 cP at -35° C. The Group IV base oil blend has the highest kinematic viscosity, 5.44cSt and the Group II base oil blend has the lowest kinematic viscosity, 3.46cSt. Such a difference in the kinematic viscosity of the base oil blends typically requires additional 2~3 weight % of viscosity modifier in order to produce a final formulation with same kinematic viscosity. However, as discussed earlier, the more viscosity modifier contained in a blend comes at the cost of lower shear stability and increased formulation cost. The biobased hydrocarbon base oil blend with 3,000 cP of cranking viscosity has kinematic viscosity, at 100° C., of 4.74cSt which is higher than the base oil blend made with petroleum based isoparaffinic hydrocarbon, Group III, base oil that has a kinematic viscosity of 4.39cSt at 100° C. When formulating engine oil with the biobased base oil, it requires a lower amount of viscosity modifiers since it provides a higher starting point in kinematic viscosity than Group II or Group III base oil blends at the same cranking viscosity.

[0108] Table VII shows test results from bench top performance evaluation of exemplary engine oils formulated with biobased hydrocarbon base oils, commercial viscosity modifier, and commercially available engine oil additive packages. Three 10W-30 engine oils have cranking viscosity at -25° C. well below 7,000 cP and low temperature pumping viscosity well under 60,000 cP at -30° C. which are required by SAE J300 specification. Shear stability of all three examples were measured using ASTM-D6278-12E1 method and all fluids stay-in-grade after extensive shearing process prescribed by method. High shear rate viscosity at 150° C. of all three formulation achieved minimum 3.5 cP as required by specification published under ACEA-A3/B3 and ACEA-A3/B4 which are intended for a use in high performance gasoline and light duty diesel engines and are typically used in newer vehicles.

TABLE VII

10W-30 Engine Oils Formulated using Biobased Hydrocarbon Base Oil			
Formula	Exp-EO.BL1	Exp-EO.BL.2	Exp-EO.BL.3
Biobased hydrocarbon 4		11.06 wt %	11.04 wt %
Biobased hydrocarbon 7	83.69 wt %	67.51 wt %	67.41 wt %
engine oil additive package.1			19.3 wt %
engine oil additive package.2		19.3 wt %	
engine oil additive package.3	12.6 wt %		
viscosity modifier.1	3.71 wt %	2.13 wt %	2.25 wt %
kinematic viscosity at 40° C. (cSt)	83.89	86.47	86.34
kinematic viscosity at 100° C. (cSt)	12.24	12.40	12.38
viscosity index	141	139	139
cranking viscosity at -25° C. (CP)	6117	6452	6400
low temperature pumping viscosity at -30° C., mPa · s	16,100	16,400	16,600
high shear rate viscosity at 150° C., mPa · s	3.5	3.58	3.56
stay in grade after shear field applied*	yes	yes	yes

*shear stability determined using ASTM-D6278-12E1 method

[0109] Table VIII compares test results from bench top performance evaluation of exemplary engine oils formulated with biobased hydrocarbon base oils to engine oils formulated with Group II, Group III, and Group IV base oils. To demonstrate the effect of different types of base oil, each was formulated with same amount of a commercial available viscosity modifier, and commercially available engine oil additive package. All formulations except Exp-EO.BL.6 meet the requirements of 0W-20 viscosity grade engine oil viscometric specifications. The engine oil formulated using Group II base oil, Exp-EO.BL.6 has a cranking viscosity at -35° C. higher than the requirement of 6200 cP and therefore can only meet the requirement of 5W-20 viscosity grade.

TABLE VIII

0W-20 Engine Oils Formulated Using Biobased Hydrocarbon Base Oil, Group II, Group III, and Group IV base oils**				
	Exp-EO.BL.4	Exp-EO.BL.5	Exp-EO.BL.6	Exp-EO.BL.7
Biobased hydrocarbon base oil, 4 cSt	81.9 wt %			
engine oil additive package.4	12.5 wt %	12.5 wt %	12.5 wt %	12.5 wt %
viscosity modifier.2	5.6 wt %	5.6 wt %	5.6 wt %	5.6 wt %
Group III base oil, 4 cSt		81.9 wt %		
Group II base oil, 4 cSt			81.9 wt %	
Group IV base oil, 4 cSt				81.9 wt %
kinematic viscosity at 40° C. (cSt)	47.26	48.38	54.11	44.86
kinematic viscosity at 100° C. (cSt)	8.899	9.143	9.443	8.710
viscosity index	171	200	159	177
cranking viscosity at -25° C., cP	1525	1771	2790	1174
cranking viscosity at -30° C., cP	2461	3064	5185	1854
cranking viscosity at -35° C., cP	4049	5642	10533	2972

TABLE VIII-continued

0W-20 Engine Oils Formulated Using Biobased Hydrocarbon Base Oil, Group II, Group III, and Group IV base oils**				
	Exp-EO.BL.4	Exp-EO.BL.5	Exp-EO.BL.6	Exp-EO.BL.7
% volatile loss at 250° C.*	11.5%	12.4%	20.4%	9.2%

*% volatile loss determined by ASTM-D5800-10 method

**all formulations met 0W-20 viscosity grade definition by SAE-J300 except Exp-EO.BL.6. Due to its high cranking viscosity at -35° C., Exp-EO.BL.6 could only meet 5W-20 requirement

[0110] The influence of a base oil's cranking viscosity on the final formulation of an engine oil is evident. The ranking of cranking viscosities at -35° C. of the formulations on Table VIII reflects the same ranking of the cranking viscosities at -35° C. seen in FIG. 1. Exp-EO.BL.6, formulated with Group II base oil, had the highest cranking viscosity at -25° C. to -35° C. while Exp-EO.BL.7, formulated with Group IV base oil had the lowest cranking viscosity. Exp-EO.BL.4, formulated with biobased isoparaffinic hydrocarbon base oil, has a lower cranking viscosity than Exp-EO.BL.5, formulated with petroleum based isoparaffinic hydrocarbon base oil (Group III) at all temperatures examined.

[0111] All formulations, except Exp-EO.BL.6, had volatile loss less than 13%. The ranking of % volatile loss of the formulations reflects a ranking of % volatile loss of the base oils seen in FIG. 3. Exp-EO.BL.7, formulated with Group IV base oil, had the lowest volatile loss, 9.2%. Exp-EO.BL.4, formulated with a biobased hydrocarbon base oil, had the second lowest volatile loss, 11.5%. Exp-EO.BL.5, formulated with a Group III base oil, had the second highest volatile loss, 12.4%.

TABLE IX

0W-20 Engine Oils Formulated Using Biobased Hydrocarbon Base Oil Compared to Commercial Grade 0W-20 and 5W-20 Engine Oils					
	Exp-EO.BL.4	Comm-EO.1	Comm-EO.2	Comm-EO.3	Comm-EO.4
viscosity grade	0W-20	5W-20	0W-20	0W-20	0W-20
kinematic viscosity at 40° C. (cSt)	47.26	49.52	44.21	46.74	45.49
kinematic viscosity at 100° C. (cSt)	8.899	8.626	8.472	8.5005	8.746
viscosity index	171	153	172	161	175
cranking viscosity at -25° C., cP	1525	2909	1762	1692	1492
cranking viscosity at -30° C., cP	2461	5273	2931	2992	2375
cranking viscosity at -35° C., cP	4049	10474	5175	5535	3926
cranking viscosity at -35° C., cP, difference between	-7%	178%	50%	58%	-2%

TABLE IX-continued

0W-20 Engine Oils Formulated Using Biobased Hydrocarbon Base Oil Compared to Commercial Grade 0W-20 and 5W-20 Engine Oils					
	Exp- EO.BL.4	Comm- E0.1	Comm- E0.2	Comm- E0.3	Comm- E0.4
reference fluid* and test sample					
TGA-Noack, volatile loss, wt %	11%	14%	13%	13%	9%
note on base oil used for engine oil formulation	biobased base oil	group II	group III	group III	group IV

*Reference fluid: reference fluid consists of base oil blends with viscosity modifiers that yields following relationship between kinematic viscosity at 100° C. and cranking viscosity at -35° C.: cranking viscosity@-35° C. = 0.118602 * (kinematic viscosity at 100° C.) 4.810648

[0112] High temperature and low temperature viscometric performances of 0W-20 engine oils formulated with biobased hydrocarbon base oils are compared to commercially available premium grade 0W-20 engine oils and 5W-20 engine oil in Table IX. 0W-20 engine oil formulated with biobased hydrocarbon base oil of current disclosure compares well with low temperature and high temperature viscometric performance of commercially available premium grade 0W-20 engine oils. Cranking viscosities at low temperatures are a strong function of kinematic viscosity at 100° C. In order to provide a direct comparison each test sample was paired with a reference fluid that had a matching kinematic velocity at 100° C. Then, the % difference between the cranking viscosity (at -35° C.) of the test sample and that of its matching reference fluid were compared. The 0W-20 engine oil formulated with biobased hydrocarbon base oils of the current disclosure show improved performance over the commercially available engine oils tested. Also, the 0W-20 engine oil formulated with biobased base oil provides less volatile loss than the Group II or Group III based commercial engine oils.

[0113] In 2013, the SAE added SAE grade 16 to the existing J300 Engine Oil Viscosity Classification Standard in response to growing demand from automotive industry for lower viscosity grade engine oil. Table X lists changes made to J300 (for the viscosity grade lower than 20). Table X also lists lower viscosity grades that are proposed but not approved as of 2014 (i.e. viscosity grade 12, 10, and 8). Lower viscosity grade engine oils will help the automobile manufacturers to achieve improved fuel economy and meet more stringent corporate average fuel economy (CAFE) requirements due to the fact that lower viscosity engine oil circulates more readily during cold starts and improves fuel economy due to reduced internal friction at elevated temperatures.

TABLE X

Lower Viscosity Grade Engine Oils Classification by Society of Automotive Engineers and Proposed Future Addition as of August 2014				
SAE Grade	KVcST@100° C.		HTHS Vis cP	
	Min	Max	@150° C., Min	Remarks
30	9.3	<12.5	2.9	
20	5.6 ^b 6.9 ^a	<9.3	2.6	Changed
16	6.1	<8.2	2.3	New
12	5.0	<7.1	2.0	Not Approved
8	4.0	<6.1	1.7	
4	3.0	<5.1	1.4	

^aAfter April 2013

^bUntil April 2013

[0114] Table XI provides a comparison of test results from the bench top performance evaluation of an exemplary 0W-16 grade engine oils formulated with biobased hydrocarbon base oils to engine oil formulated with Group II, Group III, and Group IV base oils. To highlight and demonstrate the effect of different types of base oil on the performance of engine oil, each of the formulations was formulated with same amount of a commercial viscosity modifier, and an engine oil additive package designed for mineral oil based engine oil formulation. Exp-EO.BL.10 (Group III) meets all of the SAE J300 requirements but the volatile loss (Noack) was higher than the 13% limit. Exp-EO.BL.11 (Group II) could not meet the SAE J300 specifications due to a higher than required cranking viscosity at -35° C. and it also had higher volatility than 13%. Exp-EO.BL.12 (Group IV) met all of the requirements of 0W-16 except the high shear rate viscosity at 150° C. was lower than required, 2.3 mPa-s. The engine oil formulated using the biobased hydrocarbon base oils (Exp-EO.BL.6.) met all of the requirements and had lower than 13% volatile loss (Noack) and the lowest high shear rate viscosity at 150° C. among compared samples that meet the requirement (>2.3 mPa-s). This observation, in turn, provides the insight that the engine oil formulated with biobased hydrocarbon base oil (Exp-EO.BL.9) can have improved fuel economy over engine oils that are formulated with other mineral oils (Exp-EO.BL.10 and Exp-EO.BL.11).

TABLE XI

0W-16 Engine Oils Formulated Using Biobased Hydrocarbon Base Oil, Group II, Group III, and Group IV Base Oils**				
	Exp- EO.BL.9	Exp- EO.BL.10	Exp- EO.BL.11	Exp- EO.BL.12
Biobased hydrocarbon base oil, 4 cSt	84.5 wt %			
Group III base oil, 4 cSt		84.5 wt %		
Group II base oil, 4 cSt			84.5 wt %	
Group IV base oil, 4 cSt				84.5 wt %
engine oil additive package.4	12.5 wt %	12.5 wt %	12.5 wt %	12.5 wt %
viscosity modifier.2	3 wt %	3 wt %	3 wt %	3 wt %
kinematic viscosity at 40° C. (cSt)	37.315	38.375	41.93	35.405
kinematic viscosity at 100° C. (cSt)	7.244	7.449	7.550	7.108
viscosity index	162	164	149	168
Noack*	12.0%	13.3%	21.9%	9.7%
cranking viscosity at -35° C., cP	3704	5177	9838	2724

TABLE XI-continued

0W-16 Engine Oils Formulated Using Biobased Hydrocarbon Base Oil, Group II, Group III, and Group IV Base Oils**				
	Exp- EO.BL.9	Exp- EO.BL.10	Exp- EO.BL.11	Exp- EO.BL.12
high shear rate viscosity at 150° C., mPa · s	2.33	2.44	2.42	2.27
low temperature pumping viscosity at -40° C., mPa · s	10800	20700	50000	7100

*% volatile loss determined by ASTM-D5800-10 method

**all formulation met 0W-16 viscosity grade definition by SAE-J300 except Exp-EO.BL.12. Due to its low high shear rate viscosity at 150° C., Exp-EO.BL.12 could not meet 0W-16 requirement

>13% loss while Exp-EO.BL.15 has a passing level <13% loss.

[0116] In order to produce a 0W-12 engine oil with passing level volatility, using group III base oil, the formulation needs to include a heavier cut of base oil (6cSt @100C). Exp-EO.BL.14 shows improved volatility (meaning less volatile loss) than Exp-EO.BL.16 while maintaining passing grade viscometric performances. A formulation with matching kinematic viscosities (at 40° C. and 100° C.) using a 7cSt biobased hydrocarbon base oil, Exp-EO.BL.13, also shows improved volatility over Exp-EO.BL.15 while maintaining good passing level viscometric properties. Exp-EO.BL.13 also shows lower cranking viscosity, lower volatile loss, better low temperature pumpability, and better fuel economy index based on high shear rate viscosity than Exp-EO.BL.14.

TABLE XII

0W-12 Engine Oils Formulated Using Biobased Hydrocarbon Base Oil, Group II, Group III, and Group IV Base Oils**				
	TS13620 Exp- EO.BL.13	TS13621 Exp- EO.BL.14	TS13596 Exp- EO.BL.15	TS13597 Exp- EO.BL.16
Biobased hydrocarbon base oil, 4 cSt	74.42 wt %		87.50 wt %	
Biobased hydrocarbon base oil, 7 cSt	13.08 wt %			
Group III base oil, 4 cSt		73.07 wt %		87.50 wt %
Group III base oil, 6 cSt		14.43 wt %		
Infineum P5711	12.5 wt %	12.5 wt %	12.5 wt %	12.5 wt %
kinematic viscosity at 40° C. (cSt)	31.89	31.86	28.53	28.99
kinematic viscosity at 100° C. (cSt)	6.127	6.191	5.720	5.833
viscosity index	143	147	147	150
Noack*	10.9%	12.8%	11.4%	13.6%
cranking viscosity at -35° C., cP	4544	5930	3597	4299
high shear rate viscosity at 150° C., mPa · s	2.04	2.14	2.00	2.06
low temperature pumping viscosity at -40° C., mPa · s	9900	17700	8200	16100

*% volatile loss determined by ASTM-D5800-10 method

**0W-12 viscosity grade definition is not covered by SAE-J300 as of August 2014

[0115] Table XII provides a comparison between 0W-12 grade engine oils formulated with biobased hydrocarbon base oils and the same grade engine oils formulated with Group III base oils. All of the listed formulations in Table XII do not use a viscosity modifier as the blend between base oil(s) and the additive package provides the correct viscosities to be qualified as 0W-12 grade engine oil. Exp-EO.BL.15 and Exp-EO.BL.16 are the simplest blends to produce as they have only two ingredients, base oil and additive package. Both formulations may qualify for the proposed 0W-12 grade engine formulation based on the viscometric properties. However, Exp-EO.BL.15 produced with the biobased isoparaffinic hydrocarbon base oil, shows improved performance over Exp-EO.BL.16, which was produced with Group III base oil (isoparaffinic hydrocarbon base oil produced from petroleum). Exp-EO.BL.15 has lower cranking viscosity, lower volatile loss, and a better fuel economy index based on high shear rate viscosity. Another thing to note is the volatile loss of Exp-EO.BL.16 is at a failing level

[0117] Oxidative stability of an engine oil and its ability to endure harsh condition inside a modern internal combustion engine is another important performance parameter for engine oils. The oxidative stability comparison of engine oils on Table VIII and Table IX were performed in an open-air reactor at an elevated temperature, 167° C., with soluble iron catalyst. FIG. 5 shows the % viscosity increase as a function of time under conditions described above on Exp-EO.BL.4, Exp-EO.BL.5, Exp-EO.BL.6, and Exp-EO.BL.7. In such tests, the sample is typically considered to have failed to maintain its original functionality as an engine oil when viscosity increase is more than 200% from its starting viscosity. Exp-EO.BL.6, engine oil formulated with Group II base oil, shows more than 200% viscosity increase around 480 hrs of aging. Exp-EO.BL.5, 0W-20 engine oil formulated with Group III base oil, had more than 200% viscosity increase after 560 hrs of aging. Exp-EO.BL.4, 0W-20 engine oil formulated with biobased hydrocarbon,

passed 200%-viscosity increase time mark around 550 hrs together with Exp-EO.BL.7, engine oil formulated with Group IV base oil.

[0118] FIG. 6 compares the oxidative stability of 0W-20 engine oil formulated with biobased hydrocarbon base oils, Exp-EO.BL.4, to commercially available premium grade 0W-20 engine oils and 5W-20 engine oil using the same conditions described in previous paragraph. Comm-EO.1 is a standard grade 5W-20 engine oil, exhibited more than 200% viscosity increase around 310 hrs of aging. Comm-EO.4 is a premium grade 0W-20 engine oil with advanced fuel economy label it had more than 200% viscosity increase after 510 hrs of aging. Both Comm-EO.2 and Comm-EO.3, premium grade commercial 0W-20 engine oil, have shown similar oxidative stability as Exp-EO.BL.4, 0W-20 engine oil formulated with biobased hydrocarbon, passing 200%-viscosity increase time mark around 700 hrs.

[0119] Table XIII lists the bench top tests required by American Petroleum Institute (API) on passenger car engine oils for SN and GF-5 specification by International Lubricant Standardization and Approval Committee (ILSAC). A 5W-30 engine oil formulated with 82.3 wt % biobased hydrocarbon base oils described in the current disclosure and a commercially available engine oil additive package and viscosity modifier, Exp-EO.BL.8, shows excellent performance against each test.

TABLE XIII

Laboratory/Bench Test Results for 5W-30 Viscosity Grade Engine Oil and Comparison to Specifications for API SN/ILSAC GF-5 categories		
Tests	Exp-EO.BL.8	Limits
Biobased hydrocarbon base oil content	82.3 wt %	n/a
kinematic viscosity at 100° C. (cSt)	10.1	>/=9.3
cranking viscosity at -30° C., cP	4130	</=6600
high shear rate viscosity at 150° C., cP	3.0	>/=2.9
% volatile loss at 250° C. (ASTM D5800-10)	9	</=15
BRT (ASTM D6557-13), Gray	116	>/=100
% volatile loss at 371° C. (ASTM D6417-09)	1	</=10
GMEOFT (ASTM D6795-13), % Flow change	-6	</=50
EOWT (ASTM D6794-14), % Flow Change w/0.6% water	-4	</=50
EOWT (ASTM D6794-14), % Flow Change w/1.0% water	-9	</=50
EOWT (ASTM D6794-14), % Flow Change w/2.0% water	-7	</=50
EOWT (ASTM D6794-14), % Flow Change w/3.0% water	-9	</=50
Phosphorus, D4951-09, % m	0.075	0.06-0.08
Sulfur, D2622-10, % m	0.212	</=0.5
Homogeneity & Miscibility	Pass	Pass
Shear Stability (ASTM D6278-12E1), kinematic viscosity at 100° C. after Shear, cSt	9.8	>/=9.3
MTEOS (ASTM D7097-09), Total Deposit Weight, mg	23	</=35
Scanning Brookfield (ASTM D5133-13), Gelation Index	<6	</=12
Foaming Characteristics (ASTM D892-13(A))	0/0/0/0-0/0	≤10/0-50/0-10/0
Foaming Characteristics (HTFT-D6082-12 opt A) (ASTM D6082-12(A))		
Sequence IV Tendency, Static Foam, mL	20	<100
Sequence IV Stability, 1 min settling, mL	0	0
Emulsion characteristic with E85 (ASTM D7563-10)		
Separation 24 hr at 0° C.	NO	No Water Separation
Separation 24 hr at 25° C.	NO	No Water Separation
ROBO (ASTM D7528-13)	13200	</=60000
ILSAC GF-5 Seals	Pass	Pass

[0120] Table XIV shows the composition and performance of an exemplary 0W-30 engine oil formulated using biobased isoparaflinic hydrocarbon base oils discussed in the current disclosure. Performance was evaluated using a series of engine tests required to be certified for API SN/ILSAC GF-5 engine oil. The engine oil in this example demonstrates great viscometric properties and passes Sequence IIIG with an outstanding viscosity retention result. The same engine oil also passed Sequence IVA and VG with strong performances.

TABLE XIV

Engine Test Results and Composition of a 0W-30 Viscosity Grade Engine Oil Formulation Using Biobased Isoparaflinic Hydrocarbon Base Oils		
	0W-30 engine oil	limits
Biobased hydrocarbon base oil, 4 cSt	65.0	n/a
Biobased hydrocarbon base oil, 7 cSt	15.0	n/a
Infineum P5711, wt %	12.5	n/a
Infineum SV265, wt %	7.5	n/a
kinematic viscosity at 100° C. (cSt)	10.4	>=9.3 and <12.5
cranking viscosity at -35° C., cP	5200	<6200
high shear rate viscosity at 150° C., mPa · s	3.0	>2.9

TABLE XIV-continued

Engine Test Results and Composition of a 0W-30 Viscosity Grade Engine Oil Formulation Using Biobased Isoparaffinic Hydrocarbon Base Oils		
	0W-30 engine oil	limits
low temperature pumping viscosity at -40° C., mPa · s	27,500	60,000
Sequence IIIG/IIIGA		
Viscosity Increase, 40° C., %, max.	45	150
Weighted Piston Deposits, min.	4.3	4.0
Hot Stuck Rings	none	None
Average Cam + Lifter Wear, µm, max.	41	60
Sequence IIIGB		
Phosphorus Retention, %	84	79
Sequence IVA		
Average Cam Wear, µm, max.	19	90
Sequence VG		
Average Engine Sludge, min.	9.0	8.0
Rocker Arm Cover Sludge, min.	9.5	8.3
Average Engine Varnish, min.	9.4	8.9
Average Piston Skirt Varnish, min.	8.7	7.5
Oil Screen Sludge, %, max.	0	15

[0121] The engine oils of this disclosure provide a number of advantages. In some embodiments, they are more biodegradable and have significantly more renewable content than Group I, Group II, Group III, and Group IV petroleum or natural gas derived oils based engine oil. In some embodiments, they have lower toxicity than Group I, Group II, Group III, and Group IV based oil engine oils. In some embodiments, they also demonstrate better hydrolytic stability and oxidation resistance than ester or vegetable oil based engine oils. In some embodiments, the engine oils of this disclosure also have better low temperature performance (lower cranking viscosity at -35° C. and lower pour point as measured by ASTM-D5293-14) than esters/vegetable oil engine oils and also than some mineral oil based engine oils. In some embodiments, the engine oils of this disclosure also have lower Noack volatility than Group I, Group II, Group III, and IV petroleum or natural gas derived oils based engine oil as determined by ASTM-D5800-10 method B. Additionally, in some embodiments the engine oils of this disclosure provide better seal compatibility than vegetable or ester derived engine oils.

[0122] While comparing degree of biodegradation of base oil using OECD 301B method provides comparison of environmental performance of different types of base oil, the effect of the viscosity of the base oil on the degradation behavior should also be noted. For example, poly alpha olefin (PAO), classified as a Group IV base oil by The American Petroleum Institute (API), can achieve greater than 60% of biodegradation in 28 days when the base oil mainly consists of PAO with kinematic viscosity (at 40° C.) of about 5.1cSt. However, PAO base oil can only achieve less than 35% of biodegradation in 28 days when its kinematic viscosity (at 40° C.) is greater than 31cSt.

[0123] FIG. 7 compares biodegradability of different types of base oils using the OECD 301B method, which is considered to be part of the environmental performance matrix. In order to provide a fair comparison, base oils with similar kinematic viscosity are compared (31cSt 37cSt at 40° C., noted in FIG. 7). Tests were extended to 40 days to

prove long term behavior rather than the standard period of 28 days. Slightly greater than 10 days of lag phase was observed from the biodegradation of PAO. PAO showed 22% of biodegradation by 21 days and reached a plateau value, 27% biodegradation, by 25 days. Isoparaffinic base oil, classified as Group III base oil according to API classification, showed improved biodegradation behavior over PAO. For the isoparaffinic base oil, duration of the lag phase was less than 6 days, and the plateau value of 56% was reached by 25 days. In contrast, biobased hydrocarbon base oil showed 78% biodegradation at 28 days, and by 40 days, achieved 90% biodegradation and had not entered the plateau phase (FIG. 7, open circle symbol).

[0124] The biobased base oils discussed in the test examples comprise a biobased hydrocarbon base oil. However, it is contemplated that other biobased base oils, not necessarily hydrocarbon based, but synthesized to have favorable properties, would also have the benefits of the biobased hydrocarbon base oil when used in engine oils formulation. The foregoing examples demonstrate that the engine oils disclosed herein provide an engine oil that has superior or competitive properties to engine oils previously available.

[0125] The present disclosure further includes the following enumerated embodiments.

[0126] Embodiment 1. An engine oil comprising a biobased hydrocarbon base oil, wherein the engine oil meets the requirements of Engine Oil Viscosity Classification (J300) set by SAE and has a volatile loss of less than 13% when measured by ASTM D5800-10.

[0127] Embodiment 2. The engine oil of Embodiment 1 wherein the biobased hydrocarbon base oil has a molecular weight (weight average) between 300 g/mol and 1500 g/mol.

[0128] Embodiment 3. The engine oil of Embodiment 1 or 2 wherein at least about 25% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.

[0129] Embodiment 4. An engine oil comprising a biobased base oil, wherein the biobased base oil has greater than 90% saturates as measured by ASTM-D2007-11, less than 0.03% sulfur as measured by ASTM-D1552-08(2014) e1, ASTM D2622-10, ASTM D3120-08, ASTM D4294-10, ASTM D4927-10 or equivalent method, a viscosity index as measured by ASTM D2270-10e1 greater than 120, a renewable carbon content greater than 25% as measured by ASTM-D6866-12, contains a dispersant, a detergent, a corrosion inhibitor, an antioxidant, an antifoaming agent, an anti-wear agent, and a friction modifier, and wherein the engine oil has, when determined by ASTM-D7320-13, (a) a kinematic viscosity increase, at 40° C., of no more than 150%, (b) an average weighted piston deposit rating greater than 4.0, and (c) an average cam plus lifter wear of less than 60 µm.

[0130] Embodiment 5. An engine oil comprising a biobased Group III base oil, wherein the biobased Group III base oil has a renewable carbon content greater than 25% as measured by ASTM-D6866-12, contains a dispersant, a detergent, a corrosion inhibitor, antioxidant, an antifoaming agent, an anti-wear agent, and a friction modifier, and wherein the engine oil has, when determined by ASTM-D7320-13, (a) a kinematic viscosity increase, at 40° C., of no

more than 150%, (b) an average weighted piston deposit rating greater than 4.0, and (c) an average cam plus lifter wear of less than 60 μm .

[0131] Embodiment 6. An engine oil comprising a dispersant, a detergent, a corrosion inhibitor, antioxidant, an antifoaming agent, an antiwear agent, a friction modifier, and a biobased base oil, wherein the biobased base oil having the molecular structure:



wherein,

[0132] [B] is a biobased hydrocarbon repeating unit;

[0133] [P] is a non-biobased hydrocarbon repeating unit;

[0134] n is greater than 1, and m is less than 4;

[0135] the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic;

[0136] the sequential arrangement of [B] and [P] is block, alternating or random;

[0137] the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol; and

[0138] the biobased content of the engine oil is greater than 25%, as measured by ASTM D6866-12.

[0139] Embodiment 7. The engine oil of Embodiment 6 wherein the molecular weight of the biobased base oil is in range of 300 g/mol to 800 g/mol.

[0140] Embodiment 8. The engine oil of Embodiment 6 wherein the molecular weight of the biobased base oil is in range of 390 g/mol to 510 g/mol.

[0141] Embodiment 9. An engine oil comprising a group III base oil, wherein the engine oil does not contain pour point depressant but contains a dispersant, a detergent, a corrosion inhibitor, an antioxidant, an antifoaming agent, an anti-wear agent, and a friction modifier, and wherein the engine oil has, when determined by ASTM-D7320-13, (a) a kinematic viscosity increase, at 40° C., of no more than 150%, (b) an average weighted piston deposit rating greater than 4.0, and (c) an average cam plus lifter wear of less than 60 μm .

[0142] Embodiment 10. An engine oil comprising: (a) at least 50 wt % of a biobased base oil having a weight average molecular weight in the range of 300 to 1500 g/mol and a viscosity index greater than 120; and (b) wherein the engine oil has,

[0143] (i) a cold cranking viscosity less than 6200 cP at -35° C. by ASTM D 5293-14,

[0144] (ii) a low temperature pumping viscosity less than 60000 at -40° C. by ASTM D4684-14, and

[0145] (iii) a kinematic viscosity greater than 3.8cSt at 100° C. by ASTM D445-14E2.

[0146] Embodiment 11. The engine oil of Embodiment 10 wherein the engine oil has

[0147] (a) a kinematic viscosity at 100° C. that is greater than or equal to 9.3cSt by ASTM D445-14E2,

[0148] (b) a kinematic viscosity at 100° C. that is less than or equal to 12.5cSt by ASTM D445-14E2, and

[0149] (c) a high shear rate viscosity at 150° C. that is greater than 2.9 cP by ASTM D4683-13.

[0150] Embodiment 12. The engine oil of Embodiment 10 wherein the engine oil has,

[0151] (a) a kinematic viscosity at 100° C. that is greater than or equal to 6.9cSt by ASTM D445-14E2,

[0152] (b) a kinematic viscosity at 100° C. that is less than or equal to 9.3cSt by ASTM D445-14E2, and

[0153] (c) a high shear rate viscosity at 150° C. that is greater than 2.6 cP by ASTM D4683-13.

[0154] Embodiment 13. The engine oil of Embodiment 10 wherein the engine oil has

[0155] (a) a kinematic viscosity at 100° C. that is greater than or equal to 6.1cSt by ASTM D445-14E2

[0156] (b) a kinematic viscosity at 100° C. that is less than or equal to 8.2cSt by ASTM D445-14E2, and

[0157] (c) a high shear rate viscosity at 150° C. that is greater than 2.3 cP by ASTM D4683-13.

[0158] Embodiment 14. The engine oil of Embodiment 10 wherein the engine oil has

[0159] (a) a kinematic viscosity at 100° C. that is greater than or equal to 5.0cSt by ASTM D445-14E2,

[0160] (b) a kinematic viscosity at 100° C. that is less than or equal to 7.1cSt by ASTM D445-14E2, and

[0161] (c) a high shear rate viscosity at 150° C. that is greater than 2.0 cP by ASTM D4683-13.

[0162] Embodiment 15. The engine oil of Embodiment 10 wherein the engine oil has

[0163] (a) a kinematic viscosity at 100° C. that is greater than or equal to 4.0cSt by ASTM D445-14E2,

[0164] (b) a kinematic viscosity at 100° C. that is less than or equal to 6.1cSt by ASTM D445-14E2, and

[0165] (c) a high shear rate viscosity at 150° C. that is greater than 1.7 cP by ASTM D4683-13.

[0166] Embodiment 16. The engine oil of Embodiment 10 wherein the engine oil has

[0167] (a) a kinematic viscosity at 100° C. that is greater than or equal to 3.0cSt by ASTM D445-14E2,

[0168] (b) a kinematic viscosity at 100° C. that is less than or equal to 5.1cSt by ASTM D445-14E2, and

[0169] (c) a high shear rate viscosity at 150° C. that is greater than 1.4 cP by ASTM D4683-13.

[0170] Embodiment 17. The engine oil of any of Embodiments 10-16, wherein the engine oil does not contain a pour point depressant.

[0171] Embodiment 18. The engine oil of any of Embodiments 10-16, wherein the engine oil does not contain a viscosity index improver or a viscosity modifier.

[0172] Embodiment 19. The engine oil of any of Embodiments 10-16, wherein the engine oil has less than 13% Noack volatility as measured by ASTM-D5800-10 method B.

[0173] Embodiment 20. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil comprises at least 95% non-cyclic isoparaffins having a molecular structure in which 25-34% of total carbon atoms are contained in the branches and less than half of the total isoparaffin branches contain two or more carbon atoms and the engine oil has a renewable hydrocarbon content greater than 25%, as measured by ASTM-D6866 method.

[0174] Embodiment 21. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 7.

[0175] Embodiment 22. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 8.

[0176] Embodiment 23. The engine oil of any of the preceding enumerated Embodiments wherein the biobased

base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 9.

[0177] Embodiment 24. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 10.

[0178] Embodiment 25. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 11.

[0179] Embodiment 26. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 15.

[0180] Embodiment 27. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 20.

[0181] Embodiment 28. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 22.

[0182] Embodiment 29. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 24.

[0183] Embodiment 30. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 26.

[0184] Embodiment 31. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 27.

[0185] Embodiment 32. The engine oil of any of the preceding enumerated Embodiments wherein at least 95 wt % of the biobased base oil comprises acyclic isoparaffins and at least 25 wt % of the acyclic isoparaffins are hydrogenated sesquiterpenoid monomer units.

[0186] Embodiment 33. The engine oil of Embodiment 32 wherein at least 30 wt % of the acyclic isoparaffins are hydrogenated sesquiterpenoid monomer units.

[0187] Embodiment 34. The engine oil of Embodiment 32 wherein at least 35 wt % of the acyclic isoparaffins are hydrogenated sesquiterpenoid monomer units.

[0188] Embodiment 35. The engine oil of Embodiment 32 wherein at least 45 wt % of the acyclic isoparaffins are hydrogenated sesquiterpenoid monomer units.

[0189] Embodiment 36. The engine oil of any of the preceding enumerated Embodiments wherein at least about 40% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.

[0190] Embodiment 37. The engine oil of any of the preceding enumerated Embodiments wherein at least about 50% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.

[0191] Embodiment 38. The engine oil of any of the preceding enumerated Embodiments wherein at least about 60% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.

[0192] Embodiment 39. The engine oil of any of the preceding enumerated Embodiments wherein at least about 70% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.

[0193] Embodiment 40. The engine oil of any of the preceding enumerated Embodiments wherein at least about 80% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.

[0194] Embodiment 41. The engine oil of any of the preceding enumerated Embodiments wherein at least about 90% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.

[0195] Embodiment 42. An engine oil comprising a biobased base oil, wherein the biobased base oil has greater than 50% of biodegradation in 28 days according to OECD 301B test method, the biobased base oil constitutes at least 50 wt % of the engine oil, and wherein the engine oil has, when determined by ASTM-D7320-13, (a) a kinematic viscosity increase, at 40° C., of no more than 150%, (b) an average weighted piston deposit rating greater than 4.0, and (c) an average cam plus lifter wear of less than 60 μ m.

[0196] Embodiment 43. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil has greater than 50% of biodegradation in 28 days according to OECD 301B test method.

[0197] Embodiment 44. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil has greater than 60% of biodegradation in 28 days according to OECD 301B test method.

[0198] Embodiment 45. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil has greater than 70% of biodegradation in 28 days according to OECD 301B test method.

[0199] Embodiment 46. An engine oil comprising a biobased base oil and an additive package wherein (i) the engine oil and an otherwise identical engine oil comprising the additive package and a Group I, Group II or Group III base oil but no biobased base oil each satisfy the requirements of Engine Oil Viscosity Classification (J300) set by SAE and has a volatile loss of less than 13% when measured by ASTM D5800-10 and (ii) the engine oil even in the absence of additional solubilizer, co-base oil or co-solvent outperforms the otherwise identical engine oil in the Engine Oil Viscosity Classification (J300) and ASTM D5800-10 tests.

[0200] Embodiment 47. An engine oil comprising a biobased base oil and at least 0.1 wt % of an additive package comprising a dispersant, a detergent, a corrosion inhibitor, an antioxidant, an antifoaming agent, an antiwear agent, and a friction modifier, wherein the engine oil is compatible with engine oils formulated using Group I, Group II, or Group III base oil, meets requirements of Engine Oil Viscosity Classification (J300) set by SAE and has a volatile loss of less than 13% when measured by ASTM D5800-10.

[0201] Embodiment 48. An engine oil meeting performance requirements by SAE J300 specification, the engine oil comprising:

[0202] (a) 1 to 95 wt % of a biobased hydrocarbon base oil;

- [0203] (b) up to 80 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from Group I, Group II, Group III, Group IV, and Group V base oils and combinations thereof, and
- [0204] (c) up to 30 wt % of one or more additives selected from the group consisting of anti-foaming agents, anti-wear agents, anti-oxidants, demulsifiers, detergents, dispersants, extreme pressure agents, friction modifiers, metal deactivators, pour point depressants, rust and corrosion inhibitors, viscosity modifiers, and combinations thereof.
- [0205] Embodiment 49. An engine oil according to any preceding enumerated Embodiment, wherein the biobased base oil is characterized by a viscosity index (VI) greater than 120, as measured in accordance with ASTM D2270-10e1, and has a branch ratio of less than 0.41.
- [0206] Embodiment 50. An engine oil according to any preceding enumerated Embodiment, wherein the biobased base oil is characterized by a viscosity index (VI) greater than 120, as measured in accordance with ASTM D2270-10e1, and greater than 40% of the biobased base oil molecules have more than 3 methyl branch per molecule.
- [0207] Embodiment 51. The engine oil of Embodiment 50 wherein at least 50% of the biobased base oil molecules have more than 3 methyl branch per molecule.
- [0208] Embodiment 52. The engine oil of Embodiment 50 wherein at least 60% of the biobased base oil molecules have more than 3 methyl branch per molecule.
- [0209] Embodiment 53. An engine oil according to any preceding enumerated Embodiment, wherein the biobased base oil is characterized by a viscosity index (VI) greater than 120, as measured in accordance with ASTM D2270-10e1, and greater than 25% of the biobased base oil molecules have more than 6 methyl branch per molecule.
- [0210] Embodiment 54. The engine oil of Embodiment 53 wherein at least 30% of the biobased base oil molecules have more than 3 methyl branch per molecule.
- [0211] Embodiment 55. The engine oil of Embodiment 53 wherein at least 40% of the biobased base oil molecules have more than 3 methyl branch per molecule.
- [0212] Embodiment 56. The engine oil of Embodiment 53 wherein at least 50% of the biobased base oil molecules have more than 3 methyl branch per molecule.
- [0213] Embodiment 57. The engine oil of Embodiment 53 wherein at least 60% of the biobased base oil molecules have more than 3 methyl branch per molecule.
- [0214] Embodiment 58. The engine oil according to any preceding enumerated Embodiment wherein the engine oil contains about 2 to 50 wt % of one or more co-base oils selected from Group I, Group II, Group III, Group IV, Group V, and re-refined base oils, and combinations thereof.
- [0215] Embodiment 59. The engine oil according to any preceding enumerated Embodiment wherein the engine oil contains a Group V co-base oil selected from alkylated aromatics, polyalkylene glycols, esters, estolides, and mixtures thereof.
- [0216] Embodiment 60. The engine oil according to any preceding enumerated Embodiment wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from Group I, Group II, Group III, Group IV, and Group V base oils and combinations thereof.
- [0217] Embodiment 61. The engine oil according to any preceding enumerated Embodiment wherein the engine oil

comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from non biobased Group III base oils and base oil blend has cranking viscosity less than 3000 cP at -35° C. as measured by ASTM-D5293-14 and Noack volatility less than 13% as measured by ASTM-D5800-10.

[0218] Embodiment 62. The engine oil according to any preceding enumerated Embodiment wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from non biobased Group IV base oils and base oil blend has cranking viscosity less than 3000 cP at -35° C. as measured by ASTM-D5293-14 and kinematic viscosity greater than 4cSt at 100° C. as measured by ASTM-D445-14E2, and the engine oil has low temperature pumping viscosity less than 11,000 cP at -40° C. as measured by ASTM-D4684-14.

[0219] Embodiment 63. The engine oil according to any preceding enumerated Embodiment wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from biobased Group IV base oils and base oil blend has cranking viscosity less than 3000 cP at -35° C. as measured by ASTM-D5293-14, and kinematic viscosity greater than 4cSt at 100° C. as measured by ASTM-D445-14E2, wherein the engine oil has low temperature pumping viscosity less than 11,000 cP at -40° C. as measured by ASTM-D4684-14 and has renewable carbon content greater than 50% as measured by ASTM-D6866-12.

[0220] Embodiment 64. The engine oil according to any preceding enumerated Embodiment wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from biobased Group V base oils and base oil blend has cranking viscosity less than 3000 cP at -35° C. as measured by ASTM-D5293-14, and kinematic viscosity greater than 4cSt at 100° C. as measured by ASTM-D445-14E2, wherein the engine oil has low temperature pumping viscosity less than 60,000 cP at -40° C. as measured by ASTM-D4684-14 and has renewable carbon content greater than 50% as measured by ASTM-D6866-12.

[0221] Embodiment 65. The engine oil according to any preceding enumerated Embodiment wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from estolide base oils and base oil blend has cranking viscosity less than 3000 cP at -35° C. as measured by ASTM-D5293-14, and kinematic viscosity greater than 4cSt at 100° C. as measured by ASTM-D445-14E2, wherein the engine oil has less than 11,000 cP at ±40° C. as measured by ASTM-D4684-14 and has renewable carbon content greater than 50% as measured by ASTM-D6866-12.

[0222] Embodiment 66. The engine oil according to Embodiment 63, 64 or 65 wherein the engine oil has a renewable carbon content greater than 60% as measured by ASTM-D6866-12.

[0223] Embodiment 67. The engine oil according to Embodiment 63, 64 or 65 wherein the engine oil has renewable carbon content greater than 70% as measured by ASTM-D6866-12.

[0224] Embodiment 68. The engine oil according to Embodiment 63, 64 or 65 wherein the engine oil has renewable carbon content greater than 80% as measured by ASTM-D6866-12.

[0225] Embodiment 69. The engine oil according to Embodiment 63, 64 or 65 wherein the engine oil has renewable carbon content greater than 90% as measured by ASTM-D6866-12.

[0226] Embodiment 70. The engine oil according to any preceding enumerated Embodiment wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from biobased esters and base oil blend has greater than 60% of biodegradability at 28 days as measured by OECD-301B, wherein the engine oil has renewable carbon content greater than 50% as measured by ASTM-D6866-12.

[0227] Embodiment 71. The engine oil of any preceding enumerated Embodiment, wherein the average molecular weight of the base oil is between about 300 and about 1500 g/mol.

[0228] Embodiment 72. The engine oil of any preceding enumerated Embodiment, wherein the base oil has a saturate content of at least 90% as determined by ASTM-D2007-11.

[0229] Embodiment 73. The engine oil of any preceding enumerated

[0230] Embodiment, wherein the engine oil has, when determined by ASTM-D7320-13,

[0231] (a) a kinematic viscosity increase, at 40° C., of no more than 150%,

[0232] (b) an average weighted piston deposit rating greater than 4.0, and

[0233] (c) an average cam plus lifter wear of less than 60 82 m.

[0234] Embodiment 74. The engine oil of any preceding enumerated

[0235] Embodiment, wherein the engine oil has average cam wear less than 90 µm as measured by ASTM-D6891-14

[0236] Embodiment 75. The engine oil of any preceding enumerated Embodiment, wherein the engine oil has, when determined by ASTM-D6593-14,

[0237] (a) an average engine sludge merit greater than 8.0

[0238] (b) an average engine rocker cover sludge merit greater than 8.3

[0239] (c) an average engine varnish merit greater than 8.9

[0240] (d) an average piston skirt varnish merit greater than 7.5

[0241] (e) an oil sludge screen sludge less than 15 area %.

[0242] Embodiment 76. The engine oil of any preceding enumerated Embodiment, wherein the engine oil has, when determined by ASTM-D7589-14, a total fuel economy index of at least 1.5% and a fuel economy index after 100 hrs aging of at least 0.6%.

[0243] Embodiment 77. The engine oil of Embodiment 76, wherein the engine oil has, when determined by ASTM-D7589-14,

[0244] (a) a kinematic viscosity, at 100° C., of at least 5.6cSt as measured by ASTM-D445-14e2,

[0245] (b) a kinematic viscosity, at 100° C., less than 9.3cSt as measured by ASTM-D445-14e2,

[0246] (c) a total fuel economy index of no less than 2.6%, and

[0247] (d) a fuel economy index after 100 hrs aging of no less than 1.2%.

[0248] Embodiment 78. The engine oil of Embodiment 76, wherein the engine oil has, when determined by ASTM-D7589-14,

[0249] (a) a kinematic viscosity, at 100° C., no less than 9.3cSt as measured by ASTM-D445-14e2

[0250] (b) a kinematic viscosity, at 100° C., less than 12.5cSt as measured by ASTM-D445-14e2

[0251] (c) a total fuel economy index no less than 1.9%, and

[0252] (d) a fuel economy index after 100 hrs aging of no less than 0.9%.

[0253] Embodiment 79. The engine oil of any preceding enumerated Embodiment, wherein the engine oil has a bearing weight loss value of no more than 26 mg of when measured by ASTM-D6709-14.

[0254] Embodiment 80. The engine oil of any preceding enumerated Embodiment, wherein the base oil has an aniline point greater than 115° C.

[0255] Embodiment 81. An engine oil comprising a biobased base oil with renewable carbon content greater than 25% as measured by ASTM-D6866-12, and having a pour point of less than -40° C. by ASTM-D97-12 in the absence of a pour point depressant.

[0256] Embodiment 82. The engine oil of any preceding enumerated Embodiment, wherein the engine oil meets the requirements of ILSAC GF-5.

[0257] Embodiment 83. The engine oil of any preceding enumerated Embodiment, wherein the engine oil meets the requirements of ILSAC GF-6

[0258] Embodiment 84. The engine oil of any preceding enumerated Embodiment, wherein the engine oil meets the requirements of API SN.

[0259] Embodiment 85. The engine oil of any preceding enumerated Embodiment, wherein the engine oil meets the requirements of dexos.

[0260] Embodiment 86. The engine oil of any preceding enumerated Embodiment, wherein the engine oil meets the requirements of ACEA-A1, ACEA-A2, ACEA-A3, ACEA-B1, ACEA-B2, ACEA-B3, and ACEA-B4.

[0261] Embodiment 87. The engine oil of any preceding enumerated Embodiment, wherein the engine oil meets the requirements of ACEA-E1, ACEA-E2, ACEA-E3, and ACEA-E4.

[0262] Embodiment 88. The engine oil of any preceding enumerated Embodiment, wherein the engine oil meets the requirements of PC-11.

[0263] Embodiment 89. The engine oil of any of Embodiments 81 to 88 wherein the engine oil does not contain a pour point depressant or a viscosity modifier and has less than 13% Noack volatility as measured by ASTM-D5800-10 method B.

[0264] Embodiment 90. An engine oil comprising a base oil, wherein

[0265] (a) greater than 25% of the base oil is biobased hydrocarbon base oil,

[0266] (b) greater than 40% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule,

- [0267] (c) the engine oil contains a dispersant, a detergent, a corrosion inhibitor, antioxidant, an antifoaming agent, an anti-wear agent, and a friction modifier, and
- [0268] (d) the engine oil has, when determined by ASTM-D7320-13, (i) a kinematic viscosity increase, at 40° C., of no more than 150%, (ii) an average weighted piston deposit rating greater than 4.0, and (iii) an average cam plus lifter wear of less than 60 μm .
- [0269] Embodiment91. The engine oil of Embodiment 90 wherein at least 50% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule.
- [0270] Embodiment92. The engine oil of Embodiment 90 wherein at least 60% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule.
- [0271] Embodiment93. The engine oil of Embodiment 90 wherein at least 70% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule.
- [0272] Embodiment94. The engine oil of Embodiment 90 wherein at least 80% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule.
- [0273] Embodiment95. The engine oil of any of Embodiments 90-94 wherein at least 50% of the base oil is biobased hydrocarbon base oil.
- [0274] Embodiment96. The engine oil of any of Embodiments 90-94 wherein at least 60% of the base oil is biobased hydrocarbon base oil.
- [0275] Embodiment97. The engine oil of any of Embodiments 90-94 wherein at least 70% of the base oil is biobased hydrocarbon base oil.
- [0276] Embodiment98. The engine oil of any of Embodiments 90-94 wherein at least 80% of the base oil is biobased hydrocarbon base oil.
- [0277] Embodiment99. The engine oil of any of Embodiments 90-94 wherein at least 90% of the base oil is biobased hydrocarbon base oil.
- [0278] Embodiment100. The engine oil of any of Embodiments 90-94 wherein at least 95% of the base oil is biobased hydrocarbon base oil.
- [0279] Embodiment101. The engine oil of any preceding enumerated Embodiment, wherein the engine oil is biodegradable.
- [0280] Embodiment102. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil has greater than 60% of biodegradation in 28 days according to OECD 301B test method.
- [0281] Embodiment103. The engine oil of any of the preceding enumerated Embodiments wherein the biobased base oil has greater than 70% of biodegradation in 28 days according to OECD 301B test method.
- [0282] Embodiment104. The engine oil of any preceding enumerated Embodiment, wherein the base oil comprises a biobased terpene selected from the group consisting of myrcene, ocimene, farnesene, and combinations thereof.
- [0283] Embodiment105. The engine oil of any preceding enumerated Embodiment, wherein the base oil comprises farnesene.
- [0284] Embodiment106. The engine oil of Embodiment 105 wherein the engine oil does not contain a pour point depressant or a viscosity modifier, and has less than 13% Noack volatility as measured by ASTM-D5800-10 method B.
- [0285] Embodiment107. The engine oil of any of preceding enumerated Embodiment, wherein the engine oil comprises about 50 wt % to about 99 wt % biobased hydrocarbon base oil and from about 0.2 to about 20 wt % of an additive package.
- [0286] Embodiment108. The engine oil of Embodiment 107 wherein the additive package comprises at least one additive selected from the group consisting of anti-foaming agents, anti-wear agents, anti-oxidants, demulsifiers, detergents, dispersants, extreme pressure agents, friction modifiers, metal deactivators, pour point depressants, rust and corrosion inhibitors, viscosity modifiers, and combinations thereof.
- [0287] Embodiment109. The engine oil of Embodiment 108 wherein the additive package comprises an anti-wear additive selected from the group consisting of ashless, zinc-free, and zinc-containing, anti-wear additives, and combinations thereof.
- [0288] Embodiment110. The engine oil of any preceding enumerated Embodiment, wherein the engine oil contains between about 0.1 wt % and about 1 wt % of a phenolic anti-oxidant.
- [0289] Embodiment111. The engine oil of any preceding enumerated Embodiment, wherein the engine oil contains up to about 5 wt % of an anti-wear additive.
- [0290] Embodiment112. The engine oil of any preceding enumerated Embodiment wherein the anti-wear additive contains an amine phosphate anti-wear additive and the engine oil further comprises up to about 1 wt % of the anti-wear additive(s).
- [0291] Embodiment113. The engine oil of any preceding enumerated Embodiment, wherein the engine oil contains a viscosity index improver.
- [0292] Embodiment114. The engine oil of any preceding enumerated
- [0293] Embodiment wherein the engine oil contains at least 1 wt % of the viscosity index improver, wherein viscosity index improver is selected from polyisobutylene, high molecular weight poly alpha olefin, olefin copolymer, functionalized olefin copolymer, polymethacrylate, polyalkylmethacrylate, copolymers of styrene/isoprene, copolymers of styrene/butadiene, copolymers of isoprene/butadiene, copolymers of isoprene/divinylbenzene, polyisoprene, and polybutadiene with stereoscopic structure of such polymer molecules are selected from star-shaped structure, asterisk shaped structure, linear chain structure, and branched chain structure.
- [0294] Embodiment 115. The engine oil of any preceding enumerated Embodiment wherein the biobased base oil is derived from farnesene.
- [0295] Embodiment 116. The engine oil of any preceding enumerated Embodiment wherein the biobased base oil is derived from sugar.
- [0296] Embodiment 117. In an apparatus comprising an internal combustion engine lubricated by an engine oil, the improvement comprising an engine oil according to any of the preceding enumerated Embodiments.
- [0297] Embodiment 118. A process for formulating an engine oil, the process comprising combining a biobased base oil with an additive mixture and a viscosity modifier to form a first combination that meets or exceeds the perfor-

mance requirements of one or more of the following engine oil certification programs: ILSAC GF-5, ILSAC GF-6, API SN, dexos, CJ-4, ACEA-A1, ACEA-A2, ACEA-A3, ACEA-B1, ACEA-B2, ACEA-B3, ACEA-B4, ACEA-E1, ACEA-E2, ACEA-E3, ACEA-E4, and PC-11, wherein

[0298] (a) the additive mixture comprises two or more of additives selected from the group consisting of anti-foaming agents, anti-wear agents, anti-oxidants, demulsifiers, detergents, dispersants, extreme pressure agents, friction modifiers, metal deactivators, pour point depressants, rust and corrosion inhibitors, viscosity modifiers, and combinations thereof, and

[0299] (b) the additive mixture without variation of the combination of additives or the relative proportions thereof within the additive mixture may alternatively be combined with a non-biobased Group I, a Group II, a Group III or a Group IV base oil, or a combination thereof and a viscosity modifier to form a second combination that meets or exceeds the performance requirements of one or more of the following engine oil certification programs: ILSAC GF-5, ILSAC GF-6, API SN, dexos, CJ-4, ACEA-A1, ACEA-A2, ACEA-A3, ACEA-B1, ACEA-B2, ACEA-B3, ACEA-B4, ACEA-E1, ACEA-E2, ACEA-E3, ACEA-E4, and PC-11

[0300] Various embodiments have been described. However, the present disclosure is not intended to be limited to these embodiments and illustrations contained herein. The disclosure includes modified forms of the described embodiments, including portions of the embodiments and combinations of elements of different embodiments. These and other embodiments are within the scope of the following claims.

What is claimed is:

1. An engine oil comprising a biobased hydrocarbon base oil, wherein the engine oil meets the requirements of Engine Oil Viscosity Classification (J300) set by SAE and has a volatile loss of less than 13% when measured by ASTM D5800-10.

2. The engine oil of claim 1 wherein the biobased hydrocarbon base oil has a molecular weight (weight average) between 300 g/mol and 1500 g/mol.

3. The engine oil of claim 1 or 2 wherein at least about 25% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.

4. An engine oil comprising a biobased base oil, wherein the biobased base oil has greater than 90% saturates as measured by ASTM-D2007-11, less than 0.03% sulfur as measured by ASTM-D1552-08(2014)e1, ASTM D2622-10, ASTM D3120-08, ASTM D4294-10, ASTM D4927-10 or equivalent method, a viscosity index as measured by ASTM D2270-10e1 greater than 120, a renewable carbon content greater than 25% as measured by ASTM-D6866-12, contains a dispersant, a detergent, a corrosion inhibitor, an antioxidant, an antifoaming agent, an anti-wear agent, and a friction modifier, and wherein the engine oil has, when determined by ASTM-D7320-13, (a) a kinematic viscosity increase, at 40° C., of no more than 150%, (b) an average weighted piston deposit rating greater than 4.0, and (c) an average cam plus lifter wear of less than 60 μm.

5. An engine oil comprising a biobased Group III base oil, wherein the biobased Group III base oil has a renewable carbon content greater than 25% as measured by ASTM-D6866-12, contains a dispersant, a detergent, a corrosion inhibitor, antioxidant, an antifoaming agent, an anti-wear

agent, and a friction modifier, and wherein the engine oil has, when determined by ASTM-D7320-13, (a) a kinematic viscosity increase, at 40° C., of no more than 150%, (b) an average weighted piston deposit rating greater than 4.0, and (c) an average cam plus lifter wear of less than 60 μm.

6. An engine oil comprising a dispersant, a detergent, a corrosion inhibitor, antioxidant, an antifoaming agent, an antiwear agent, a friction modifier, and a biobased base oil, wherein the biobased base oil having the molecular structure:



wherein,

[B] is a biobased hydrocarbon repeating unit;

[P] is a non-biobased hydrocarbon repeating unit;

n is greater than 1, and m is less than 4;

the stereoscopic arrangement of [B] and [P] is linear, branched or cyclic;

the sequential arrangement of [B] and [P] is block, alternating or random;

the molecular weight of the biobased base oil is in range of 300 g/mol to 1500 g/mol; and

the biobased content of the engine oil is greater than 25%, as measured by ASTM D6866-12.

7. The engine oil of claim 6 wherein the molecular weight of the biobased base oil is in range of 300 g/mol to 800 g/mol.

8. The engine oil of claim 6 wherein the molecular weight of the biobased base oil is in range of 390 g/mol to 510 g/mol.

9. An engine oil comprising a group III base oil, wherein the engine oil does not contain pour point depressant but contains a dispersant, a detergent, a corrosion inhibitor, an antioxidant, an antifoaming agent, an anti-wear agent, and a friction modifier, and wherein the engine oil has, when determined by ASTM-D7320-13, (a) a kinematic viscosity increase, at 40° C., of no more than 150%, (b) an average weighted piston deposit rating greater than 4.0, and (c) an average cam plus lifter wear of less than 60 μm.

10. An engine oil comprising: (a) at least 50 wt % of a biobased base oil having a weight average molecular weight in the range of 300 to 1500 g/mol and a viscosity index greater than 120; and (b) wherein the engine oil has,

(i) a cold cranking viscosity less than 6200 cP at -35° C. by ASTM D 5293-14,

(ii) a low temperature pumping viscosity less than 60000 at -40° C. by ASTM D4684-14, and

(iii) a kinematic viscosity greater than 3.8cSt at 100° C. by ASTM D445-14E2.

11. The engine oil of claim 10 wherein the engine oil has (a) a kinematic viscosity at 100° C. that is greater than or equal to 9.3cSt by ASTM D445-14E2,

(b) a kinematic viscosity at 100° C. that is less than or equal to 12.5cSt by ASTM D445-14E2, and

a high shear rate viscosity at 150° C. that is greater than 2.9 cP by ASTM D4683-13.

12. The engine oil of claim 10 wherein the engine oil has, a kinematic viscosity at 100° C. that is greater than or equal to 6.9cSt by ASTM D445-14E2,

(b) a kinematic viscosity at 100° C. that is less than or equal to 9.3cSt by ASTM D445-14E2, and

(c) a high shear rate viscosity at 150° C. that is greater than 2.6 cP by ASTM D4683-13.

13. The engine oil of claim 10 wherein the engine oil has
(a) a kinematic viscosity at 100° C. that is greater than or equal to 6.1cSt by ASTM D445-14E2
(b) a kinematic viscosity at 100° C. that is less than or equal to 8.2cSt by ASTM D445-14E2, and
(c) a high shear rate viscosity at 150° C. that is greater than 2.3 cP by ASTM D4683-13.
14. The engine oil of claim 10 wherein the engine oil has
(a) a kinematic viscosity at 100° C. that is greater than or equal to 5.0cSt by ASTM D445-14E2,
(b) a kinematic viscosity at 100° C. that is less than or equal to 7.1cSt by ASTM D445-14E2, and
(c) a high shear rate viscosity at 150° C. that is greater than 2.0 cP by ASTM D4683-13.
15. The engine oil of claim 10 wherein the engine oil has
(a) a kinematic viscosity at 100° C. that is greater than or equal to 4.0cSt by ASTM D445-14E2,
(b) a kinematic viscosity at 100° C. that is less than or equal to 6.1cSt by ASTM D445-14E2, and
(c) a high shear rate viscosity at 150° C. that is greater than 1.7 cP by ASTM D4683-13.
16. The engine oil of claim 10 wherein the engine oil has
(a) a kinematic viscosity at 100° C. that is greater than or equal to 3.0cSt by ASTM D445-14E2,
(b) a kinematic viscosity at 100° C. that is less than or equal to 5.1cSt by ASTM D445-14E2, and
(c) a high shear rate viscosity at 150° C. that is greater than 1.4 cP by ASTM D4683-13.
17. The engine oil of any of claims 10-16, wherein the engine oil does not contain a pour point depressant.
18. The engine oil of any of claims 10-16, wherein the engine oil does not contain a viscosity index improver or a viscosity modifier.
19. The engine oil of any of claims 10-16, wherein the engine oil has less than 13% Noack volatility as measured by ASTM-D5800-10 method B.
20. The engine oil of any of the preceding claims wherein the biobased base oil comprises at least 95% non-cyclic isoparaffins having a molecular structure in which 25-34% of total carbon atoms are contained in the branches and less than half of the total isoparaffin branches contain two or more carbon atoms and the engine oil has a renewable hydrocarbon content greater than 25%, as measured by ASTM-D6866 method.
21. The engine oil of any of the preceding claims wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 7.
22. The engine oil of any of the preceding claims wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 8.
23. The engine oil of any of the preceding claims wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 9.
24. The engine oil of any of the preceding claims wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 10.
25. The engine oil of any of the preceding claims wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 11.
26. The engine oil of any of the preceding claims wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 15.
27. The engine oil of any of the preceding claims wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 20.
28. The engine oil of any of the preceding claims wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 22.
29. The engine oil of any of the preceding claims wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 24.
30. The engine oil of any of the preceding claims wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 26.
31. The engine oil of any of the preceding claims wherein the biobased base oil additionally has an average methyl branch index (methyl branches per 100 carbons) of at least 27.
32. The engine oil of any of the preceding claims wherein at least 95 wt % of the biobased base oil comprises acyclic isoparaffins and at least 25 wt % of the acyclic isoparaffins are hydrogenated sesquiterpenoid monomer units.
33. The engine oil of claim 32 wherein at least 30 wt % of the acyclic isoparaffins are hydrogenated sesquiterpenoid monomer units.
34. The engine oil of claim 32 wherein at least 35 wt % of the acyclic isoparaffins are hydrogenated sesquiterpenoid monomer units.
35. The engine oil of claim 32 wherein at least 45 wt % of the acyclic isoparaffins are hydrogenated sesquiterpenoid monomer units.
36. The engine oil of any of the preceding claims wherein at least about 40% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.
37. The engine oil of any of the preceding claims wherein at least about 50% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.
38. The engine oil of any of the preceding claims wherein at least about 60% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.
39. The engine oil of any of the preceding claims wherein at least about 70% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.
40. The engine oil of any of the preceding claims wherein at least about 80% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.
41. The engine oil of any of the preceding claims wherein at least about 90% of the carbon atoms in the biobased base oil originate from renewable carbon sources as measured by ASTM-D6866-12.
42. An engine oil comprising a biobased base oil, wherein the biobased base oil has greater than 50% of biodegradation in 28 days according to OECD 301B test method, the

biobased base oil constitutes at least 50 wt % of the engine oil, and wherein the engine oil has, when determined by ASTM-D7320-13, (a) a kinematic viscosity increase, at 40° C., of no more than 150%, (b) an average weighted piston deposit rating greater than 4.0, and (c) an average cam plus lifter wear of less than 60 μ m.

43. The engine oil of any of the preceding claims wherein the biobased base oil has greater than 50% of biodegradation in 28 days according to OECD 301B test method.

44. The engine oil of any of the preceding claims wherein the biobased base oil has greater than 60% of biodegradation in 28 days according to OECD 301B test method.

45. The engine oil of any of the preceding claims wherein the biobased base oil has greater than 70% of biodegradation in 28 days according to OECD 301B test method.

46. An engine oil comprising a biobased base oil and an additive package wherein (i) the engine oil and an otherwise identical engine oil comprising the additive package and a Group I, Group II or Group III base oil but no biobased base oil each satisfy the requirements of Engine Oil Viscosity Classification (J300) set by SAE and has a volatile loss of less than 13% when measured by ASTM D5800-10 and (ii) the engine oil even in the absence of additional solubilizer, co-base oil or co-solvent outperforms the otherwise identical engine oil in the Engine Oil Viscosity Classification (J300) and ASTM D5800-10 tests.

47. An engine oil comprising a biobased base oil and at least 0.1 wt % of an additive package comprising a dispersant, a detergent, a corrosion inhibitor, an antioxidant, an antifoaming agent, an antiwear agent, and a friction modifier, wherein the engine oil is compatible with engine oils formulated using Group I, Group II, or Group III base oil, meets requirements of Engine Oil Viscosity Classification (J300) set by SAE and has a volatile loss of less than 13% when measured by ASTM D5800-10.

48. An engine oil meeting performance requirements by SAE J300 specification, the engine oil comprising:

- (a) 1 to 95 wt % of a biobased hydrocarbon base oil;
- (b) up to 80 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from Group I, Group II, Group III, Group IV, and Group V base oils and combinations thereof, and
- (c) up to 30 wt % of one or more additives selected from the group consisting of anti-foaming agents, anti-wear agents, anti-oxidants, demulsifiers, detergents, dispersants, extreme pressure agents, friction modifiers, metal deactivators, pour point depressants, rust and corrosion inhibitors, viscosity modifiers, and combinations thereof.

49. An engine oil according to any preceding claim, wherein the biobased base oil is characterized by a viscosity index (VI) greater than 120, as measured in accordance with ASTM D2270-10e1, and has a branch ratio of less than 0.41.

50. An engine oil according to any preceding claim, wherein the biobased base oil is characterized by a viscosity index (VI) greater than 120, as measured in accordance with ASTM D2270-10e1, and greater than 40% of the biobased base oil molecules have more than 3 methyl branch per molecule.

51. The engine oil of claim 50 wherein at least 50% of the biobased base oil molecules have more than 3 methyl branch per molecule.

52. The engine oil of claim 50 wherein at least 60% of the biobased base oil molecules have more than 3 methyl branch per molecule.

53. An engine oil according to any preceding claim, wherein the biobased base oil is characterized by a viscosity index (VI) greater than 120, as measured in accordance with ASTM D2270-10e1, and greater than 25% of the biobased base oil molecules have more than 6 methyl branch per molecule.

54. The engine oil of claim 53 wherein at least 30% of the biobased base oil molecules have more than 3 methyl branch per molecule.

55. The engine oil of claim 53 wherein at least 40% of the biobased base oil molecules have more than 3 methyl branch per molecule.

56. The engine oil of claim 53 wherein at least 50% of the biobased base oil molecules have more than 3 methyl branch per molecule.

57. The engine oil of claim 53 wherein at least 60% of the biobased base oil molecules have more than 3 methyl branch per molecule.

58. The engine oil according to any preceding claim wherein the engine oil contains about 2 to 50 wt % of one or more co-base oils selected from Group I, Group II, Group III, Group IV, Group V, and re-refined base oils, and combinations thereof.

59. The engine oil according to any preceding claim wherein the engine oil contains a Group V co-base oil selected from alkylated aromatics, polyalkylene glycols, esters, estolides, and mixtures thereof.

60. The engine oil according to any preceding claim wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from Group I, Group II, Group III, Group IV, and Group V base oils and combinations thereof.

61. The engine oil according to any preceding claim wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from non biobased Group III base oils and base oil blend has cranking viscosity less than 3000 cP at -35° C. as measured by ASTM-D5293-14 and Noack volatility less than 13% as measured by ASTM-D5800-10.

62. The engine oil according to any preceding claim wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from non biobased Group IV base oils and base oil blend has cranking viscosity less than 3000 cP at -35° C. as measured by ASTM-D5293-14 and kinematic viscosity greater than 4cSt at 100° C. as measured by ASTM-D445-14E2, and the engine oil has low temperature pumping viscosity less than 11,000 cP at -40° C. as measured by ASTM-D4684-14.

63. The engine oil according to any preceding claim wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from biobased Group IV base oils and base oil blend has cranking viscosity less than 3000 cP at -35° C. as measured by ASTM-D5293-14, and kinematic viscosity greater than 4cSt at 100° C. as measured by ASTM-D445-14E2, wherein the engine oil has low temperature pumping viscosity less than

11,000 cP at -40° C. as measured by ASTM-D4684-14 and has renewable carbon content greater than 50% as measured by ASTM-D6866-12.

64. The engine oil according to any preceding claim wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from biobased Group V base oils and base oil blend has cranking viscosity less than 3000 cP at -35° C. as measured by ASTM-D5293-14, and kinematic viscosity greater than 4cSt at 100° C. as measured by ASTM-D445-14E2, wherein the engine oil has low temperature pumping viscosity less than 60,000 cP at -40° C. as measured by ASTM-D4684-14 and has renewable carbon content greater than 50% as measured by ASTM-D6866-12.

65. The engine oil according to any preceding claim wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from estolide base oils and base oil blend has cranking viscosity less than 3000 cP at -35° C. as measured by ASTM-D5293-14, and kinematic viscosity greater than 4cSt at 100° C. as measured by ASTM-D445-14E2, wherein the engine oil has less than 11,000 cP at -40° C. as measured by ASTM-D4684-14 and has renewable carbon content greater than 50% as measured by ASTM-D6866-12.

66. The engine oil according to claim **63**, **64** or **65** wherein the engine oil has a renewable carbon content greater than 60% as measured by ASTM-D6866-12.

67. The engine oil according to claim **63**, **64** or **65** wherein the engine oil has renewable carbon content greater than 70% as measured by ASTM-D6866-12.

68. The engine oil according to claim **63**, **64** or **65** wherein the engine oil has renewable carbon content greater than 80% as measured by ASTM-D6866-12.

69. The engine oil according to claim **63**, **64** or **65** wherein the engine oil has renewable carbon content greater than 90% as measured by ASTM-D6866-12.

70. The engine oil according to any preceding claim wherein the engine oil comprises 5 to 50 wt % of a biobased hydrocarbon base oil and 1 to 50 wt % of one or more co-base oils, wherein the co-base oil(s) are selected from biobased esters and base oil blend has greater than 60% of biodegradability at 28 days as measured by OECD-301B, wherein the engine oil has renewable carbon content greater than 50% as measured by ASTM-D6866-12.

71. The engine oil of any preceding claim, wherein the average molecular weight of the base oil is between about 300 and about 1500 g/mol.

72. The engine oil of any preceding claim, wherein the base oil has a saturate content of at least 90% as determined by ASTM-D2007-11.

73. The engine oil of any preceding claim, wherein the engine oil has, when determined by ASTM-D7320-13,

- (a) a kinematic viscosity increase, at 40° C., of no more than 150%,
- (b) an average weighted piston deposit rating greater than 4.0, and
- (c) an average cam plus lifter wear of less than 60 μ m.

74. The engine oil of any preceding claim, wherein the engine oil has average cam wear less than 90 pm as measured by ASTM-D6891-14

75. The engine oil of any preceding claim, wherein the engine oil has, when determined by ASTM-D6593-14,

- (a) an average engine sludge merit greater than 8.0
- (b) an average engine rocker cover sludge merit greater than 8.3
- (c) an average engine varnish merit greater than 8.9
- (d) an average piston skirt varnish merit greater than 7.5
- (e) an oil sludge screen sludge less than 15 area %.

76. The engine oil of any preceding claim, wherein the engine oil has, when determined by ASTM-D7589-14, a total fuel economy index of at least 1.5% and a fuel economy index after 100 hrs aging of at least 0.6%.

77. The engine oil of claim **76**, wherein the engine oil has, when determined by ASTM-D7589-14,

- (a) a kinematic viscosity, at 100° C., of at least 5.6cSt as measured by ASTM-D445-14e2,
- (b) a kinematic viscosity, at 100° C., less than 9.3cSt as measured by ASTM-D445-14e2,
- (c) a total fuel economy index of no less than 2.6%, and
- (d) a fuel economy index after 100 hrs aging of no less than 1.2%.

78. The engine oil of claim **76**, wherein the engine oil has, when determined by ASTM-D7589-14,

- (a) a kinematic viscosity, at 100° C., no less than 9.3cSt as measured by ASTM-D445-14e2
- (b) a kinematic viscosity, at 100° C., less than 12.5cSt as measured by ASTM-D445-14e2
- (c) a total fuel economy index no less than 1.9%, and
- (d) a fuel economy index after 100 hrs aging of no less than 0.9%.

79. The engine oil of any preceding claim, wherein the engine oil has a bearing weight loss value of no more than 26 mg of when measured by ASTM-D6709-14.

80. The engine oil of any preceding claim, wherein the base oil has an aniline point greater than 115° C.

81. An engine oil comprising a biobased base oil with renewable carbon content greater than 25% as measured by ASTM-D6866-12, and having a pour point of less than -40° C. by ASTM-D97-12 in the absence of a pour point depressant.

82. The engine oil of any preceding claim, wherein the engine oil meets the requirements of ILSAC GF-5.

83. The engine oil of any preceding claim, wherein the engine oil meets the requirements of ILSAC GF-6

84. The engine oil of any preceding claim, wherein the engine oil meets the requirements of API SN.

85. The engine oil of any preceding claim, wherein the engine oil meets the requirements of dexos.

86. The engine oil of any preceding claim, wherein the engine oil meets the requirements of ACEA-A1, ACEA-A2, ACEA-A3, ACEA-B1, ACEA-B2, ACEA-B3, and ACEA-B4.

87. The engine oil of any preceding claim, wherein the engine oil meets the requirements of ACEA-E1, ACEA-E2, ACEA-E3, and ACEA-E4.

88. The engine oil of any preceding claim, wherein the engine oil meets the requirements of PC-11.

89. The engine oil of any of claims **81** to **88** wherein the engine oil does not contain a pour point depressant or a viscosity modifier and has less than 13% Noack volatility as measured by ASTM-D5800-10 method B.

90. An engine oil comprising a base oil, wherein

- (a) greater than 25% of the base oil is biobased hydrocarbon base oil,

- (b) greater than 40% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule,
 - (c) the engine oil contains a dispersant, a detergent, a corrosion inhibitor, antioxidant, an antifoaming agent, an anti-wear agent, and a friction modifier, and
 - (d) the engine oil has, when determined by ASTM-D7320-13, (i) a kinematic viscosity increase, at 40° C., of no more than 150%, (ii) an average weighted piston deposit rating greater than 4.0, and (iii) an average cam plus lifter wear of less than 60 pm.
- 91.** The engine oil of claim **90** wherein at least 50% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule.
- 92.** The engine oil of claim **90** wherein at least 60% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule.
- 93.** The engine oil of claim **90** wherein at least 70% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule.
- 94.** The engine oil of claim **90** wherein at least 80% of hydrocarbon molecules comprised by the base oil comprise an odd number of carbon atoms per molecule.
- 95.** The engine oil of any of claims **90-94** wherein at least 50% of the base oil is biobased hydrocarbon base oil.
- 96.** The engine oil of any of claims **90-94** wherein at least 60% of the base oil is biobased hydrocarbon base oil.
- 97.** The engine oil of any of claims **90-94** wherein at least 70% of the base oil is biobased hydrocarbon base oil.
- 98.** The engine oil of any of claims **90-94** wherein at least 80% of the base oil is biobased hydrocarbon base oil.
- 99.** The engine oil of any of claims **90-94** wherein at least 90% of the base oil is biobased hydrocarbon base oil.
- 100.** The engine oil of any of claims **90-94** wherein at least 95% of the base oil is biobased hydrocarbon base oil.
- 101.** The engine oil of any preceding claim, wherein the engine oil is biodegradable.
- 102.** The engine oil of any of the preceding claims wherein the biobased base oil has greater than 60% of biodegradation in 28 days according to OECD 301B test method.
- 103.** The engine oil of any of the preceding claims wherein the biobased base oil has greater than 70% of biodegradation in 28 days according to OECD 301B test method.
- 104.** The engine oil of any preceding claim, wherein the base oil comprises a biobased terpene selected from the group consisting of myrcene, ocimene, farnesene, and combinations thereof.
- 105.** The engine oil of any preceding claim, wherein the base oil comprises farnesene.
- 106.** The engine oil of claim **105** wherein the engine oil does not contain a pour point depressant or a viscosity modifier, and has less than 13% Noack volatility as measured by ASTM-D5800-10 method B.
- 107.** The engine oil of any of preceding claim, wherein the engine oil comprises about 50 wt % to about 99 wt % biobased hydrocarbon base oil and from about 0.2 to about 20 wt % of an additive package.
- 108.** The engine oil of claim **107** wherein the additive package comprises at least one additive selected from the group consisting of anti-foaming agents, anti-wear agents, anti-oxidants, demulsifiers, detergents, dispersants, extreme pressure agents, friction modifiers, metal deactivators, pour point depressants, rust and corrosion inhibitors, viscosity modifiers, and combinations thereof.
- 109.** The engine oil of claim **108** wherein the additive package comprises an anti-wear additive selected from the group consisting of ashless, zinc-free, and zinc-containing, anti-wear additives, and combinations thereof.
- 110.** The engine oil of any preceding claim, wherein the engine oil contains between about 0.1 wt % and about 1 wt % of a phenolic anti-oxidant.
- 111.** The engine oil of any preceding claim, wherein the engine oil contains up to about 5 wt % of anti-wear additive.
- 112.** The engine oil of any preceding claim wherein the anti-wear additive contains an amine phosphate anti-wear additive and the engine oil further comprises up to about 1 wt % of the anti-wear additive(s).
- 113.** The engine oil of any preceding claim, wherein the engine oil contains a viscosity index improver.
- 114.** The engine oil of any preceding claim wherein the engine oil contains at least 1 wt % of the viscosity index improver, wherein viscosity index improver is selected from polyisobutylene, high molecular weight poly alpha olefin, olefin copolymer, functionalized olefin copolymer, polymethacrylate, polyalkylmethacrylate, copolymers of styrene/isoprene, copolymers of styrene/butadiene, copolymers of isoprene/butadiene, copolymers of isoprene/divinylbenzene, polyisoprene, and polybutadiene with stereoscopic structure of such polymer molecules are selected from star-shaped structure, asterisk shaped structure, linear chain structure, and branched chain structure.
- 115.** The engine oil of any preceding claim wherein the biobased base oil is derived from farnesene.
- 116.** The engine oil of any preceding claim wherein the biobased base oil is derived from sugar.
- 117.** In an apparatus comprising an internal combustion engine lubricated by an engine oil, the improvement comprising an engine oil according to any of the preceding claims.
- 118.** A process for formulating an engine oil, the process comprising combining a biobased base oil with an additive mixture and a viscosity modifier to form a first combination that meets or exceeds the performance requirements of one or more of the following engine oil certification programs: ILSAC GF-5, ILSAC GF-6, API SN, dexos, CJ-4, ACEA-A1, ACEA-A2, ACEA-A3, ACEA-B1, ACEA-B2, ACEA-B3, ACEA-B4, ACEA-E1, ACEA-E2, ACEA-E3, ACEA-E4, and PC-11, wherein
- (a) the additive mixture comprises two or more of additives selected from the group consisting of anti-foaming agents, anti-wear agents, anti-oxidants, demulsifiers, detergents, dispersants, extreme pressure agents, friction modifiers, metal deactivators, pour point depressants, rust and corrosion inhibitors, viscosity modifiers, and combinations thereof, and
 - (b) the additive mixture without variation of the combination of additives or the relative proportions thereof within the additive mixture may alternatively be combined with a non-biobased Group I, a Group II, a Group III or a Group IV base oil, or a combination thereof and a viscosity modifier to form a second combination that meets or exceeds the performance requirements of one or more of the following engine oil certification programs: ILSAC GF-5, ILSAC GF-6, API SN, dexos, CJ-4, ACEA-A1, ACEA-A2, ACEA-A3, ACEA-B1, ACEA-B2, ACEA-B3, ACEA-B4, ACEA-E1, ACEA-E2, ACEA-E3, ACEA-E4, and PC-11.
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