

Title: Toluene Free Silica Supported Single-Site Metallocene Catalysts from *In-Situ* Supported MAO Formation in Aliphatic Solvents

Inventors: Lubin Luo, Anupriya Jain, and Charles J. Harlan

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PRIORITY CLAIM

[0001] This application claims priority to and the benefit of USSN 62/579,587, filed October 31, 2017 and EP 18152100.6, filed January 17, 2018 and are incorporated by reference in their entirety.

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FIELD

[0002] The present disclosure relates to catalyst systems for olefin polymerization, catalyst system precursors, methods of producing the precursors and catalyst systems and polyolefins formed from the catalyst systems.

BACKGROUND

15 [0003] Polyolefins are widely used commercially because of their robust physical properties. For example, various types of polyethylenes, including high density, low density, and linear low density polyethylenes, are some of the most commercially useful. Polyolefins are typically prepared with a catalyst (mixed with one or more other components to form a catalyst system) which promotes polymerization of olefin monomers in a reactor, such as a gas
20 phase reactor.

[0004] Methyalumoxane, or MAO, is the most popular activator supported on silica to activate a single site catalyst precursor, e.g., a metallocene, to form an active solid catalyst used in a commercial gas phase reactor to produce single-site polyolefin resins. Commercial MAO is commonly sold as a toluene solution because an aromatic solvent can dissolve MAO without
25 causing any issue observed with other solvents, e.g., a donor containing solvent (e.g., an ether or a THF) deactivates MAO, an active proton containing solvent (e.g., an alcohol) reacts and destroys MAO, and an aliphatic solvent (e.g., hexane) precipitates MAO. However, the MAO toluene solution is stored in a cold environment, e.g., at -20 to -30°C, to reduce the gelation process typically observed for this kinetic product. A homogeneous MAO solution is desired
30 for MAO molecules to be evenly distributed in the pores of the catalyst support material, e.g., silica, to obtain a catalyst with good performance including good productivity and good operability. However, polyolefin products are often used as plastic packaging for sensitive products, and the amount of non-polyolefin compounds, such as toluene, present in the polyolefin products should be minimized.

[0005] References of interest include: U.S. Patent Nos. 8,354,485; 9,090,720; 7,910,764; 8,575,284; 8,575,284; 5,006,500; 4,937,217; U.S. Patent Publication No. 2016/0355618; WO 2016/170017; Luo, Jain, and Harlan, ACS Annual Meeting, Conference Abstracts PMSE 126 and INOR 1169, April 2-6, 2017; and Sinn, et al, "Formation, Structure, and Mechanism of
5 Oligomeric Methylaluminoxane", in Kaminsky (ed.), *Metalorg. Cat. for Synth. & Polym.*, Springer-Verlag, 1999, pp 105.

[0006] Therefore, there is a need for catalyst systems free from a detectable amount of aromatic solvent, while maintaining good performance including good productivity and good operability. There is also a need for methods of forming such catalyst systems. There is also
10 a need for polyolefins that are free from a detectable amount of aromatic solvent.

[0007] In addition, commercially available MAO is provided in a toluene solution and is unstable, typically involving special handling and cold storage. The commercially available MAO has a short life, typically less than one week under ambient conditions and less than twelve months in cold storage, and undergoes compositional changes, e.g. gelation, even in
15 cold storage. Therefore, there is also a need for more stable and less expensive MAO compositions.

SUMMARY

[0008] This invention relates to a method for preparing supported alumoxane comprising contacting in an aliphatic solvent at a temperature of from 0°C to -60°C at least one support
20 material having absorbed water and at least one hydrocarbyl aluminum compound. The supported alumoxane is more stable and less expensive, relative to prior art alumoxanes, and is free of any detectable amount of aromatic solvent, such as toluene.

[0009] This invention also relates to a method for preparing a catalyst system comprising contacting in an aliphatic solvent at a temperature of from less than 0°C to -60°C at least one
25 support material having absorbed water and at least one hydrocarbyl aluminum compound to form a supported alumoxane and contacting the supported alumoxane with at least one catalyst compound having a Group 3 through Group 12 metal atom or lanthanide metal atom. The supported alumoxane may be heated prior to contact with the catalyst compound.

[0010] This invention also relates to a catalyst system including a catalyst compound
30 having a Group 3 through Group 12 metal atom or lanthanide metal atom. The catalyst system further includes supported alumoxane and has no detectable amount of aromatic solvent.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1a, FIG. 1b and FIG. 1c are H^1 -NMR (using Bruker 400MHz THF-d8) of methylalumoxane and trimethylaluminum regions of MAO extracted with THF-d8 from the supported methylalumoxane prepared according to the present disclosure compared with prior art supported methylalumoxane.

[0012] FIG. 2a and FIG. 2b are FT-IR spectra of supported methylalumoxane prepared according to the present disclosure compared with prior art supported methylalumoxane, both on ES70-875 silica.

[0013] FIG. 2c is an FT-IR spectra the supported methylalumoxane of FIG 2a after heating at 100°C for 3hrs.

DETAILED DESCRIPTION

[0014] The present disclosure relates to catalyst systems for olefin polymerization, methods of producing the catalyst systems, and polyolefins formed from the catalyst systems. Embodiments of the present disclosure include methods for preparing a supported alumoxane including contacting in an aliphatic solvent at a temperature of from less than 0°C to -60°C at least one support material having absorbed water and at least one hydrocarbyl aluminum compound. The supported alumoxane is formed *in-situ* when the hydrocarbyl aluminum compound reacts with the absorbed water on the silica. Furthermore, the supported alumoxane is formed *in-situ* when the hydrocarbyl aluminum compound reacts with the absorbed water on the silica in a ratio of water:Al of 1:0.95 to 1:100 (mol:mol). The present disclosure also includes methods for preparing catalyst systems including heating the supported alumoxane prior to contact with a catalyst compound. The catalyst compound has a Group 3 through Group 12 metal atom or lanthanide metal atom. The catalyst compound can be a metallocene catalyst compound comprising a Group 4 metal.

[0015] In at least one embodiment, the present disclosure relates to a continuous process for preparing supported alumoxane comprising contacting in an aliphatic solvent at a temperature of from less than 0°C to -60°C at least one support material having absorbed water and at least one hydrocarbyl aluminum compound to produce a silica supported alumoxane, separating the silica supported alumoxane from the aliphatic solvent and recycling the aliphatic solvent and any excess hydrocarbyl aluminum.

[0016] The present disclosure also relates to a method of polymerizing olefins to produce a polyolefin composition comprising contacting at least one olefin with a catalyst system

prepared as described herein and obtaining a polyolefin having no detectable aromatic hydrocarbon solvent.

[0017] The present disclosure also relates to a method for preparing a catalyst system comprising contacting in an aliphatic solvent at a temperature of from less than 0°C to -60°C at least one support material having absorbed water and at least one hydrocarbyl aluminum compound to form a supported alumoxane, heating the supported alumoxane to at least 60°C up to 140°C and contacting the heated supported alumoxane with at least one catalyst compound having a Group 3 through Group 12 metal atom or lanthanide metal atom.

[0018] The present disclosure also relates to a method for preparing a catalyst system comprising contacting in an aliphatic solvent at a temperature of from less than 0°C to -60°C at least one support material having absorbed water and at least one hydrocarbyl aluminum compound to form a supported alumoxane, contacting the supported alumoxane with at least one catalyst compound having a Group 3 through Group 12 metal atom or lanthanide metal atom to form a supported catalyst system and heating the supported catalyst system to at least 60°C up to 140°C.

[0019] The present disclosure also relates to a process of making a supported aluminoxane free of aromatic solvent comprising adding at least one support material having absorbed water as a solid form to a hydrocarbyl aluminum aliphatic solvent solution at a temperature of from less than 0°C to about -60°C.

[0020] The present disclosure also relates to a process of making a supported aluminoxane free of aromatic solvent comprising adding an aliphatic solution of at least one support material having absorbed water to hydrocarbyl aluminum aliphatic solvent solution at a temperature of from about less than 0°C to about -60°C.

[0021] The present disclosure also relates to any process described herein where the hydrocarbyl aluminum solution concentration is 0.1 to 40 wt%, preferably is 1.0 to 20 wt%.

[0022] The present disclosure also relates to processes where the process is continuous and comprises isolating the solid supported aluminoxane product and recycling any excess hydrocarbyl aluminum.

[0023] The present disclosure also relates to any process described herein where the supported alumoxane composition is further heat-treated at a temperature selected from 60°C to 200°C for 0.5 to 24 hours prior to contact with the catalyst compound.

[0024] Embodiments of the present disclosure also include catalyst systems including a Group 4 metal catalyst compound selected from a metallocene catalyst compound or a bis(phenolate) catalyst compound.

[0025] Use of an aliphatic solvent instead of toluene provides a catalyst system (and polyolefin products) with no detectable amount of aromatic hydrocarbon solvent content while maintaining activity similar to that of catalyst systems prepared with pre-formed MAO and or using toluene. Maintaining activity would not be expected since catalyst system components such as methylalumoxane, precipitate in the presence of saturated hydrocarbon. It has been discovered that neither drying nor the addition of saturated hydrocarbon to catalyst systems of the present disclosure significantly reduces the activity of the catalyst system for polymerization.

[0026] Eliminating aromatic hydrocarbon solvent in the catalyst system provides polyolefin products having no detectable aromatic hydrocarbon solvent (preferably no detectable toluene), as determined by gas phase chromatography as described in the Experimental section below. The polyolefin products may be used as plastic materials for use in toluene-free materials such as in packaging for food products. Furthermore, many saturated hydrocarbons have lower boiling points than aromatic hydrocarbons, such as toluene (110°C), which makes the saturated hydrocarbons easier to remove from the polyolefin products.

[0027] For purposes of the present disclosure, “detectable aromatic hydrocarbon solvent” means 0.1 mg/m² or more as determined by gas phase chromatography. For purposes of the present disclosure, “detectable toluene” means 0.1 mg/m² or more as determined by gas phase chromatography.

[0028] As used herein, the term “saturated hydrocarbon” includes hydrocarbons that contain zero carbon-carbon double bonds. The saturated hydrocarbon can be a linear or cyclic hydrocarbon. The saturated hydrocarbon can be a C₄-C₄₀ hydrocarbon, such as a C₄-C₇ hydrocarbon. In at least one embodiment, the C₄-C₄₀ hydrocarbon is isobutene, cyclohexane, isopentane, isohexane, hexane, heptane, or mixtures thereof.

[0029] In at least one embodiment, a method of polymerizing olefins to produce a polyolefin composition includes contacting at least one olefin with a catalyst system of the present disclosure and obtaining a polyolefin having no detectable aromatic hydrocarbon solvent. Polymerization can be conducted at a temperature of from about 0°C to about 300°C, at a pressure of from about 0.35 MPa to about 10 MPa, and at a time up to about 300 minutes. The at least one olefin can be C₂ to C₄₀ olefin, preferably C₂ to C₂₀ alpha-olefin preferably

ethylene, propylene, butene, pentene, hexene, heptene, octene, nonene, decene, undecene, dodecene, or mixtures thereof.

[0030] For purposes of the present disclosure, the numbering scheme for the Periodic Table Groups is used as described in CHEMICAL AND ENGINEERING NEWS, 63(5), pg. 27 (1985).

5 Therefore, a “Group 4 metal” is an element from group 4 of the Periodic Table, *e.g.*, Hf, Ti, or Zr.

[0031] “Catalyst productivity” is a measure of how many grams of polymer (P) are produced using a polymerization catalyst comprising W g of catalyst (cat), over a period of time of T hours; and may be expressed by the following formula: $P/(T \times W)$ and expressed in
10 units of $\text{gP/gcat} \cdot \text{hr}^{-1}$. Conversion is the amount of monomer that is converted to polymer product, and is reported as mol% and is calculated based on the polymer yield (weight) and the amount of monomer fed into the reactor. Catalyst activity is a measure of the level of activity of the catalyst and is reported as the mass of product polymer (P) produced per mass of supported catalyst (cat) ($\text{gP/g supported cat}$). In an at least one embodiment, the activity of the
15 catalyst is at least 800 $\text{gpolymer/gsupported catalyst/hour}$, such as about 1,000 or more $\text{gpolymer/gsupported catalyst/hour}$, such as about 2,000 or more $\text{gpolymer/gsupported catalyst/hour}$, such as about 3,000 or more $\text{gpolymer/gsupported catalyst/hour}$, such as about 4,000 or more $\text{gpolymer/gsupported catalyst/hour}$, such as about 5,000 or more $\text{gpolymer/gsupported catalyst/hour}$.

20 [0032] An “olefin,” alternatively referred to as “alkene,” is a linear, branched, or cyclic compound of carbon and hydrogen having at least one double bond. When a polymer or copolymer is referred to as comprising an olefin, the olefin present in such polymer or copolymer is the polymerized form of the olefin. For example, when a copolymer is said to have an ethylene content of 35 wt% to 55 wt%, it is understood that the monomer (“mer”) unit
25 in the copolymer is derived from ethylene in the polymerization reaction and the derived units are present at 35 wt% to 55 wt%, based upon the weight of the copolymer. A “polymer” has two or more of the same or different mer units. A “homopolymer” is a polymer having mer units that are the same. A “copolymer” is a polymer having two or more mer units that are different from each other. A “terpolymer” is a polymer having three mer units that are different
30 from each other. “Different” as used to refer to mer units indicates that the mer units differ from each other by at least one atom or are different isomerically. Accordingly, the definition of “copolymer,” as used herein, includes terpolymers and the like. An oligomer is typically a polymer having a low molecular weight, such as an M_n of less than 25,000 g/mol, or less than

2,500 g/mol, or a low number of mer units, such as 75 mer units or less or 50 mer units or less. An "ethylene polymer" or "ethylene copolymer" is a polymer or copolymer comprising at least 50 mole% ethylene derived units, a "propylene polymer" or "propylene copolymer" is a polymer or copolymer comprising at least 50 mole% propylene derived units, and so on.

5 [0033] A "catalyst system" is a combination of at least one catalyst compound and a support material. The catalyst system may have at least one activator and/or at least one co-activator. When catalyst systems are described as comprising neutral stable forms of the components, it is well understood that the ionic form of the component is the form that reacts with the monomers to produce polymers. For purposes of the present disclosure, "catalyst system"
10 includes both neutral and ionic forms of the components of a catalyst system.

[0034] As used herein, Mn is number average molecular weight, Mw is weight average molecular weight, and Mz is z average molecular weight, wt% is weight percent, and mol% is mole percent. Molecular weight distribution (MWD), also referred to as polydispersity index (PDI), is defined to be Mw divided by Mn. Unless otherwise noted, all molecular weight units
15 (e.g., Mw, Mn, Mz) are g/mol.

[0035] In the present disclosure, the catalyst may be described as a catalyst precursor, a pre-catalyst compound, catalyst compound or a transition metal compound, and these terms are used interchangeably. An "anionic ligand" is a negatively charged ligand which donates one or more pairs of electrons to a metal ion. A "neutral donor ligand" is a neutrally charged ligand
20 which donates one or more pairs of electrons to a metal ion.

[0036] For purposes of the present disclosure in relation to catalyst compounds, the term "substituted" means that a hydrogen group has been replaced with a hydrocarbyl group, a heteroatom, or a heteroatom containing group. For example, methylcyclopentadiene (MeCp) is a Cp group substituted with a methyl group.

25 [0037] For purposes of the present disclosure, "alkoxides" include those where the alkyl group is a C₁ to C₁₀ hydrocarbyl. The alkyl group may be straight chain, branched, or cyclic. The alkyl group may be saturated or unsaturated. In at least one embodiment, the alkyl group may comprise at least one aromatic group. The term "alkoxy" or "alkoxide" preferably means an alkyl ether or aryl ether radical wherein the term alkyl is a C₁ to C₁₀ alkyl. Examples of
30 suitable alkyl ether radicals include, but are not limited to, methoxy, ethoxy, n-propoxy, iso-propoxy, n-butoxy, iso-butoxy, sec-butoxy, tert-butoxy, phenoxy, and the like.

[0038] The present disclosure describes transition metal complexes. The term complex is used to describe molecules in which an ancillary ligand is coordinated to a central transition

metal atom. The ligand is stably bonded to the transition metal so as to maintain its influence during use of the catalyst, such as polymerization. The ligand may be coordinated to the transition metal by covalent bond and/or electron donation coordination or intermediate bonds. The transition metal complexes are generally subjected to activation to perform their polymerization function using an activator which is believed to create a cation as a result of the removal of an anionic group, often referred to as a leaving group, from the transition metal.

[0039] When used in the present disclosure, the following abbreviations mean: dme is 1,2-dimethoxyethane, Me is methyl, Ph is phenyl, Et is ethyl, Pr is propyl, iPr is isopropyl, n-Pr is normal propyl, cPr is cyclopropyl, Bu is butyl, iBu is isobutyl, tBu is tertiary butyl, p-tBu is para-tertiary butyl, nBu is normal butyl, sBu is sec-butyl, TMS is trimethylsilyl, TIBAL is triisobutylaluminum, TNOAL is tri(n-octyl)aluminum, MAO is methylalumoxane, sMAO is supported methylalumoxane, Bn is benzyl (i.e., CH₂Ph), THF (also referred to as thf) is tetrahydrofuran, RT is room temperature (and is 23°C unless otherwise indicated), tol is toluene, EtOAc is ethyl acetate, and Cy is cyclohexyl.

[0040] The terms "hydrocarbyl radical," "hydrocarbyl," "hydrocarbyl group," "alkyl radical," and "alkyl" are used interchangeably throughout this disclosure. Likewise, the terms "group", "radical", and "substituent" are also used interchangeably in this disclosure. For purposes of this disclosure, "hydrocarbyl radical" is defined to be C₁-C₁₀₀ radicals, that may be linear, branched, or cyclic, and when cyclic, aromatic or non-aromatic. Examples of such radicals include, but are not limited to, methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl, tert-butyl, pentyl, iso-amyl, hexyl, octyl cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, cyclooctyl, and the like including their substituted analogues. Substituted hydrocarbyl radicals are radicals in which at least one hydrogen atom of the hydrocarbyl radical has been substituted with at least a non-hydrogen group, such as halogen (such as Br, Cl, F or I) or at least one functional group such as NR*₂, OR*, SeR*, TeR*, PR*₂, AsR*₂, SbR*₂, SR*, BR*₂, SiR*₃, GeR*₃, SnR*₃, PbR*₃, and the like, or where at least one heteroatom has been inserted within a hydrocarbyl ring.

[0041] The term "alkenyl" means a straight-chain, branched-chain, or cyclic hydrocarbon radical having one or more carbon-carbon double bonds. These alkenyl radicals may be substituted. Examples of suitable alkenyl radicals include, but are not limited to, ethenyl, propenyl, allyl, 1,4-butadienyl, cyclopropenyl, cyclobutenyl, cyclopentenyl, cyclohexenyl, cycloctenyl and the like including their substituted analogues.

[0042] The term "aryl" or "aryl group" means a carbon-containing aromatic ring and the substituted variants thereof, including but not limited to, phenyl, 2-methyl-phenyl, xylyl, 4-bromo-xylyl. Likewise, heteroaryl means an aryl group where a ring carbon atom (or two or three ring carbon atoms) has been replaced with a heteroatom, preferably N, O, or S. As used
5 herein, the term "aromatic" also refers to pseudoaromatic heterocycles which are heterocyclic substituents that have similar properties and structures (nearly planar) to aromatic heterocyclic ligands, but are not by definition aromatic.

[0043] "Aromatic" means a hydrocarbyl compound containing a planar unsaturated ring of atoms that is stabilized by interaction of the bonds forming the ring. Such compounds are often
10 six membered rings such as benzene and its derivatives. As used herein, the term "aromatic" also refers to pseudoaromatics which are compounds that have similar properties and structures (nearly planar) to aromatics, but are not by definition aromatic; likewise, the term aromatic also refers to substituted aromatics.

[0044] Where isomers of a named alkyl, alkenyl, alkoxide, or aryl group exist (*e.g.*, n-butyl, iso-butyl, sec-butyl, and tert-butyl) reference to one member of the group (*e.g.*, n-butyl) shall
15 expressly disclose the remaining isomers (*e.g.*, iso-butyl, sec-butyl, and tert-butyl) in the family. Likewise, reference to an alkyl, alkenyl, alkoxide, or aryl group without specifying a particular isomer (*e.g.*, butyl) expressly discloses all isomers (*e.g.*, n-butyl, iso-butyl, sec-butyl, and tert-butyl).

[0045] The term "ring atom" means an atom that is part of a cyclic ring structure. By this definition, a benzyl group has six ring atoms and tetrahydrofuran has 5 ring atoms. A heterocyclic ring is a ring having a heteroatom in the ring structure as opposed to a heteroatom substituted ring where a hydrogen on a ring atom is replaced with a heteroatom. For example, tetrahydrofuran is a heterocyclic ring and 4-N,N-dimethylamino-phenyl is a heteroatom
25 substituted ring.

[0046] "Complex" as used herein, is also often referred to as catalyst precursor, precatalyst, catalyst, catalyst compound, transition metal compound, or transition metal complex. These terms are used interchangeably. Activator and cocatalyst are also used interchangeably.

[0047] A scavenger is a compound that may be added to a catalyst system to facilitate
30 polymerization by scavenging impurities. Some scavengers may also act as activators and may be referred to as co-activators. A co-activator, that is not a scavenger, may also be used in conjunction with an activator in order to form an active catalyst system. In at least one

embodiment, a co-activator can be pre-mixed with the transition metal compound to form an alkylated transition metal compound.

[0048] In the present disclosure, a catalyst may be described as a catalyst precursor, a pre-catalyst compound, catalyst compound or a transition metal compound, and these terms are used interchangeably. A polymerization catalyst system is a catalyst system that can polymerize monomers into polymer.

[0049] The term "continuous" means a system that operates without interruption or cessation for a period of time. For example, a continuous process to produce a polymer would be one where the reactants are continually introduced into one or more reactors and polymer product is continually withdrawn.

[0050] A "bulk polymerization" means a polymerization process in which the monomers and/or comonomers being polymerized are used as a solvent or diluent using little or no inert solvent or diluent. A small fraction of inert solvent might be used as a carrier for catalyst and scavenger. A bulk polymerization system contains less than about 25 wt% of inert solvent or diluent, such as less than about 10 wt%, such as less than about 1 wt%, such as 0 wt%.

Support Materials

[0051] In at least one embodiment, a catalyst system comprises an inert support material capable of absorbing water in an amount of at least 0.5 mmol of water per gram of support material. The support material may be a porous support material, for example, talc, and inorganic oxides. Other support materials include zeolites, clays, organoclays, or any other organic or inorganic support material and the like, or mixtures thereof.

[0052] In at least one embodiment, the support material is an inorganic oxide in a finely divided form. Suitable inorganic oxide materials for use in catalyst systems herein include Groups 2, 4, 13, and 14 metal oxides, such as silica, alumina, and mixtures thereof. Other inorganic oxides that may be employed, either alone or in combination, with the silica, or alumina are magnesia, titania, zirconia, and the like. Other suitable support materials, however, can be employed, for example, finely divided functionalized polyolefins, such as finely divided polyethylene, polypropylene, and polystyrene with functional groups that are able to absorb water, e.g., oxygen or nitrogen containing groups such as -OH, -RC=O, -OR, and -NR₂. Particularly useful supports include magnesia, titania, zirconia, montmorillonite, phyllosilicate, zeolites, talc, clays, silica clay, silicon oxide clay, and the like. Also, combinations of these support materials may be used, for example, silica-chromium, silica-alumina, silica-titania, and the like. In at least one embodiment, the support material is selected from Al₂O₃, ZrO₂, SiO₂,

SiO₂/Al₂O₃, silica clay, silicon oxide/clay, or mixtures thereof. The support material may be fluorided.

[0053] As used herein, the phrases "fluorided support" and "fluorided support composition" mean a support, desirably particulate and porous, which has been treated with at least one inorganic fluorine containing compound. For example, the fluorided support composition can be a silicon dioxide support wherein a portion of the silica hydroxyl groups has been replaced with fluorine or fluorine containing compounds. Suitable fluorine containing compounds include, but are not limited to, inorganic fluorine containing compounds and/or organic fluorine containing compounds.

[0054] Fluorine compounds suitable for providing fluorine for the support may be organic or inorganic fluorine compounds and are desirably inorganic fluorine containing compounds. Such inorganic fluorine containing compounds may be any compound containing a fluorine atom as long as it does not contain a carbon atom. Particularly desirable are inorganic fluorine-containing compounds selected from NH₄BF₄, (NH₄)₂SiF₆, NH₄PF₆, NH₄F, (NH₄)₂TaF₇, NH₄NbF₄, (NH₄)₂GeF₆, (NH₄)₂SmF₆, (NH₄)₂TiF₆, (NH₄)₂ZrF₆, MoF₆, ReF₆, GaF₃, SO₂ClF, F₂, SiF₄, SF₆, ClF₃, ClF₅, BrF₅, IF₇, NF₃, HF, BF₃, NHF₂, NH₄HF₂, and combinations thereof. In at least one embodiment, ammonium hexafluorosilicate and ammonium tetrafluoroborate are used.

[0055] In at least one embodiment, the support material comprises a support material treated with an electron-withdrawing anion. The support material can be silica, alumina, silica-alumina, silica-zirconia, alumina-zirconia, aluminum phosphate, heteropolytungstates, titania, magnesia, boria, zinc oxide, mixed oxides thereof, or mixtures thereof; and the electron-withdrawing anion is selected from fluoride, chloride, bromide, phosphate, triflate, bisulfate, sulfate, or any combination thereof.

[0056] An electron-withdrawing component can be used to treat the support material. The electron-withdrawing component can be any component that increases the Lewis or Brønsted acidity of the support material upon treatment (as compared to the support material that is not treated with at least one electron-withdrawing anion). In at least one embodiment, the electron-withdrawing component is an electron-withdrawing anion derived from a salt, an acid, or other compound, such as a volatile organic compound, that serves as a source or precursor for that anion. Electron-withdrawing anions can be sulfate, bisulfate, fluoride, chloride, bromide, iodide, fluorosulfate, fluoroborate, phosphate, fluorophosphate, trifluoroacetate, triflate, fluorozirconate, fluorotitanate, phospho-tungstate, or mixtures thereof, or combinations

thereof. An electron-withdrawing anion can be fluoride, chloride, bromide, phosphate, triflate, bisulfate, or sulfate, and the like, or any combination thereof, at least one embodiment of this disclosure. In at least one embodiment, the electron-withdrawing anion is sulfate, bisulfate, fluoride, chloride, bromide, iodide, fluorosulfate, fluoroborate, phosphate, fluorophosphate, trifluoroacetate, triflate, fluoro-zirconate, fluorotitanate, or combinations thereof.

[0057] Thus, for example, the support material suitable for use in the catalyst systems of the present disclosure can be one or more of fluorided alumina, chlorided alumina, bromided alumina, sulfated alumina, fluorided silica-alumina, chlorided silica-alumina, bromided silica-alumina, sulfated silica-alumina, fluorided silica-zirconia, chlorided silica-zirconia, bromided silica-zirconia, sulfated silica-zirconia, fluorided silica-titania, fluorided silica-coated alumina, sulfated silica-coated alumina, phosphated silica-coated alumina, and the like, or combinations thereof. In at least one embodiment, the activator-support can be, or can comprise, fluorided alumina, sulfated alumina, fluorided silica-alumina, sulfated silica-alumina, fluorided silica-coated alumina, sulfated silica-coated alumina, phosphated silica-coated alumina, or combinations thereof. In another embodiment, the support material includes alumina treated with hexafluorotitanic acid, silica-coated alumina treated with hexafluorotitanic acid, silica-alumina treated with hexafluorozirconic acid, silica-alumina treated with trifluoroacetic acid, fluorided boria-alumina, silica treated with tetrafluoroboric acid, alumina treated with tetrafluoroboric acid, alumina treated with hexafluorophosphoric acid, or combinations thereof. Further, any of these activator-supports optionally can be treated with a metal ion.

[0058] Nonlimiting examples of cations suitable for use in the present disclosure in the salt of the electron-withdrawing anion include ammonium, trialkyl ammonium, tetraalkyl ammonium, tetraalkyl phosphonium, H^+ , $[H(OEt_2)_2]^+$, $[HNR_3]^+$ ($R = C_1-C_{20}$ hydrocarbyl group, which may be the same or different) or combinations thereof.

[0059] Further, combinations of one or more different electron-withdrawing anions, in varying proportions, can be used to tailor the specific acidity of the support material to a desired level. Combinations of electron-withdrawing components can be contacted with the support material simultaneously or individually, and in any order that provides a desired chemically-treated support material acidity. For example, in at least one embodiment, two or more electron-withdrawing anion source compounds in two or more separate contacting steps.

[0060] An example of a process by which a chemically-treated support material is prepared is as follows: a selected support material, or combination of support materials, can be contacted with a first electron-withdrawing anion source compound to form a first mixture; such first

mixture can be calcined and then contacted with a second electron-withdrawing anion source compound to form a second mixture; the second mixture can then be calcined to form a treated support material. In such a process, the first and second electron-withdrawing anion source compounds can be either the same or different compounds.

5 [0061] The method by which the oxide is contacted with the electron-withdrawing component, typically a salt or an acid of an electron-withdrawing anion, can include, but is not limited to, gelling, co-gelling, impregnation of one compound onto another, and the like, or combinations thereof. Following a contacting method, the contacted mixture of the support material, electron-withdrawing anion, and optional metal ion, can be calcined.

10 [0062] According to another embodiment of the present disclosure, the support material can be treated by a process comprising: (i) contacting a support material with a first electron-withdrawing anion source compound to form a first mixture; (ii) calcining the first mixture to produce a calcined first mixture; (iii) contacting the calcined first mixture with a second electron-withdrawing anion source compound to form a second mixture; and (iv) calcining the
15 second mixture to form the treated support material.

[0063] It is preferred that the support material, most preferably an inorganic oxide, has a surface area between about 10 m²/g and about 800 m²/g (optionally 700 m²/g), pore volume between about 0.1 cc/g and about 4.0 cc/g and average particle size between about 5 μm and about 500 μm. In at least one embodiment, the surface area of the support material is between
20 about 50 m²/g and about 500 m²/g, pore volume between about 0.5 cc/g and about 3.5 cc/g and average particle size between about 10 μm and about 200 μm. The surface area of the support material may be between about 100 m²/g and about 400 m²/g, pore volume between about 0.8 cc/g and about 3.0 cc/g and average particle size between about 5 μm and about 100 μm. The average pore size of the support material may be between about 10 Å and about 1000 Å, such
25 as between about 50 Å and about 500 Å, such as between about 75 Å and about 350 Å. In at least one embodiment, the support material is an amorphous silica with surface area of 300 to 400 m²/gm and a pore volume of 0.9 to 1.8 cm³/gm. In at least one embodiment, the supported material may optionally be a sub-particle containing silica with average sub-particle size of 0.05 to 5 micron, e.g., from the spray drying of average particle size of 0.05 to 5 micron small
30 particle to form average particle size of 5 to 200 micron large main particles. In at least one embodiment of the supported material, at least 20% of the total pore volume (as defined by BET method) has a pore diameter of 100 angstrom or more. Non-limiting example silicas include Grace Davison's 952, 955, and 948; PQ Corporation's ES70 series, PD 14024,

PD16042, and PD16043; Asahi Glass Chemical (AGC)'s D70-120A, DM-H302, DM-M302, DM-M402, DM-L302, and DM-L402; Fuji's P-10/20 or P-10/40; and the like.

Supported Materials Having Absorbed Water

[0064] In embodiments of the present disclosure, the support material will contain from
5 0.5 mmol absorbed water per gram of support material to 30 mmol absorbed water per gram of support material. The amount of absorbed water is determined by adding a known amount of water into the support hydrocarbon slurry in a close container and agitate to allow the water to distribute in the pore of the support and/or by a standard thermogravimetric analysis method, e.g., LOD (loss on drying) at the temperature 300°C for 4hr. Most commercial support
10 materials will contain some absorbed water and in some cases the amount of absorbed water may be sufficient. In other cases additional water can be added or the support material can be dried and then the support material can be contacted with an amount of water. This can be accomplished, for example, by slurrying the silica in an aliphatic solvent, for example hexane, containing an amount of water sufficient to provide water absorbance onto the silica. In at least
15 one embodiment, a support material is contacted with from about 0.5mmol water/g support material to about 30mmol water/g support material.

[0065] Preferably, the support material is silica, alumina, alumina-silica or a derivative thereof.

[0066] Preferably, the support material has an average particle size between 1 and 200
20 microns, an average pore volume of between 0.05 and 5 mL/g, and a surface area between 50 and 800 m²/g.

[0067] Preferably, the support material has been treated with one or more of a Bronsted acid, a Lewis acid, a salt and a Lewis base.

[0068] Preferably, the support material comprises a silylating agent.

25 [0069] Preferably, the support material comprises a hydrocarbyl aluminum compound.

[0070] Preferably, one or more of the support material comprises an electron withdrawing anion.

Aliphatic Solvents

[0071] Suitable aliphatic solvents are materials in which all of the reactants used herein,
30 e.g., the support and the hydrocarbyl aluminum, are at least partially soluble and which are liquid at reaction temperatures. Non-limiting example solvents are non-cyclic alkanes with formula C_nH_(n+2) where n = 4-30, such as isopentane, hexane, n-heptane, octane, nonane,

decane and the like, and cycloalkanes with formula C_nH_n where $n = 5-30$, such as cyclopentane, methylcyclopentane, cyclohexane, methylcyclohexane and the like.

Aliphatic Solvents

[0072] Suitable aliphatic solvents are materials in which all of the reactants used herein, e.g., the support and the hydrocarbyl aluminum, are at least partially soluble and which are liquid at reaction temperatures. Non-limiting example solvents are non-cyclic alkanes with formula $C_nH_{(n+2)}$ where $n = 4-30$, such as isopentane, hexane, n-heptane, octane, nonane, decane and the like, and cycloalkanes with formula C_nH_n where $n = 5-30$, such as cyclopentane, methylcyclopentane, cyclohexane, methylcyclohexane and the like.

10 Hydrocarbyl Aluminum Compounds

[0073] The hydrocarbyl aluminum compounds are preferably alkylaluminium compounds such as a trialkylaluminium compound wherein the alkyl substituents are alkyl groups of up to 10 carbon atoms, such as octyl, isobutyl, ethyl or methyl. Thus, suitable hydrocarbyl aluminum compounds include trimethylaluminum, triethylaluminum, tripropylaluminum, tri-n-butylaluminum, tri-isobutyl-aluminum, tri(2-methylpentyl)aluminum, trihexylaluminum, tri-n-octylaluminum, and tri-n-decylaluminum. Preferred hydrocarbyl aluminum compounds are trimethylaluminum and tri-n-octylaluminum.

[0074] In the process of the present disclosure, the ratio of water absorbed in the supported material to the amount of hydrocarbyl aluminum compound in one embodiment can be from 1:0.95 to 1:100. Preferably, the ratio is from 1:1.5 to 1: 20; more preferably, the ratio is from 1:1.5 to 10; and most preferably, the ratio is 1:1.5 to 1:3.

[0075] The alkylaluminium in some embodiments of the process is present in an amount of about 1.5 to 30 wt% aluminium based on the weight of the isolated solid product. Preferably, the amount of aluminium is between 5 wt% and 25 wt%, more preferably 6 and 20 wt%, based on the total weight of the isolated solid product.

Supported Alumoxanes

[0076] The supported alumoxanes of the present disclosure are prepared *in-situ* by contacting the water saturated silica in an aliphatic solvent with the hydrocarbyl aluminum compound in an aliphatic solvent. The silica slurry is added slowly to the hydrocarbyl aluminum solution, at a temperature of from less than 0°C to -60°C, preferably at a temperature of from -10°C to -50°C, such as from -20°C up to -40°C, or less than -10°C, -20°C or -30°C, so that the internal temperature of the reactor is maintained in a desired range, e.g., within 1°C, -15°C, or -25°C.

[0077] In at least one embodiment of the present disclosure, a hydrocarbon solvent such as mineral oil is added to the silica solution in order to produce a viscous slurry to reduce or avoid fast silica settlement.

[0078] In at least one embodiment of the present disclosure, the mixture of hydrocarbyl aluminum and water saturated silica is agitated.

Optional Heat Treatment of the Supported Aluminoxanes

[0079] The supported aluminoxanes of the present disclosure, after being prepared *in-situ*, can be further treated at a higher temperature for a certain period of time either in the form of an aliphatic solvent slurry or a solid. The high temperature treatment can be in the range of 60-200°C, preferably 70-140°C, and more preferably 80-120°C. The reaction mixture after contacting the support material having absorbed water and the hydrocarbyl aluminum compound in an aliphatic solvent at a low temperature can also be spray dried in a spray drying reactor at a higher temperature to evaporate the solvents/volatiles and form the solid product with a desired average particle size and particle size distribution. The preferred temperature range is 60-200°C, more preferred is 80-190°C, and the most preferred is 90-160°C.

Catalyst Compounds

[0080] In at least one embodiment, the present disclosure provides a catalyst system comprising a catalyst compound having a metal atom. The catalyst compound can be a metallocene catalyst compound. The metal can be a Group 3 through Group 12 metal atom, such as Group 3 through Group 10 metal atoms, or lanthanide Group atoms. The catalyst compound having a Group 3 through Group 12 metal atom can be monodentate or multidentate, such as bidentate, tridentate, or tetradentate, where a heteroatom of the catalyst, such as phosphorous, oxygen, nitrogen, or sulfur is chelated to the metal atom of the catalyst. Non-limiting examples include bis(phenolate)s. In at least one embodiment, the Group 3 through Group 12 metal atom is selected from Group 5, Group 6, Group 8, or Group 10 metal atoms. In at least one embodiment, a Group 3 through Group 10 metal atom is selected from Cr, Sc, Ti, Zr, Hf, V, Nb, Ta, Mn, Re, Fe, Ru, Os, Co, Rh, Ir, and Ni. In at least one embodiment, a metal atom is selected from Groups 4, 5, and 6 metal atoms. In at least one embodiment, a metal atom is a Group 4 metal atom selected from Ti, Zr, or Hf. The oxidation state of the metal atom can range from 0 to +7, for example +1, +2, +3, +4, or +5, for example +2, +3 or +4.

[0081] A catalyst compound of the present disclosure can be a chromium or chromium-based catalyst. Chromium-based catalysts include chromium oxide (CrO₃) and silylchromate catalysts. Chromium catalysts have been the subject of much development in the area of

continuous fluidized-bed gas-phase polymerization for the production of polyethylene polymers. Such catalysts and polymerization processes have been described, for example, in U.S. Publication No. 2011/0010938 and U.S. Patent Nos. 7,915,357; 8,129,484; 7,202,313; 6,833,417; 6,841,630; 6,989,344; 7,504,463; 7,563,851; 8,420,754; and 8,101,691.

- 5 **[0082]** Metallocene catalyst compounds as used herein include metallocenes comprising Group 3 to Group 12 metal complexes, preferably, Group 4 to Group 6 metal complexes, for example, Group 4 metal complexes. The metallocene catalyst compound of catalyst systems of the present disclosure may be unbridged metallocene catalyst compounds represented by the formula: $Cp^A Cp^B M' X'_n$, wherein each Cp^A and Cp^B is independently selected from
- 10 cyclopentadienyl ligands and ligands isolobal to cyclopentadienyl, one or both Cp^A and Cp^B may contain heteroatoms, and one or both Cp^A and Cp^B may be substituted by one or more R'' groups. M' is selected from Groups 3 through 12 atoms and lanthanide Group atoms. X' is an anionic leaving group. n is 0 or an integer from 1 to 4. R'' is selected from alkyl, lower alkyl, substituted alkyl, heteroalkyl, alkenyl, lower alkenyl, substituted alkenyl, heteroalkenyl,
- 15 alkynyl, lower alkynyl, substituted alkynyl, heteroalkynyl, alkoxy, lower alkoxy, aryloxy, alkylthio, lower alkylthio, arylthio, aryl, substituted aryl, heteroaryl, aralkyl, aralkylene, alkaryl, alkarylene, haloalkyl, haloalkenyl, haloalkynyl, heteroalkyl, heterocycle, heteroaryl, a heteroatom-containing group, hydrocarbyl, lower hydrocarbyl, substituted hydrocarbyl, heterohydrocarbyl, silyl, boryl, phosphino, phosphine, amino, amine, ether, and thioether.
- 20 **[0083]** In at least one embodiment, each Cp^A and Cp^B is independently selected from cyclopentadienyl, indenyl, fluorenyl, cyclopentaphenanthrenyl, benzindenyl, fluorenyl, octahydrofluorenyl, cyclooctatetraenyl, cyclopentacyclododecene, phenanthrindenyl, 3,4-benzofluorenyl, 9-phenylfluorenyl, 8-H-cyclopent[a]acenaphthylenyl, 7-H-dibenzofluorenyl, indeno[1,2-9]anthrene, thiophenoindenyl, thiophenofluorenyl, and hydrogenated versions
- 25 thereof.

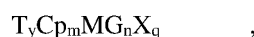
- [0084]** The metallocene catalyst compound may be a bridged metallocene catalyst compound represented by the formula: $Cp^A(A)Cp^B M' X'_n$, wherein each Cp^A and Cp^B is independently selected from cyclopentadienyl ligands and ligands isolobal to cyclopentadienyl. One or both Cp^A and Cp^B may contain heteroatoms, and one or both Cp^A and Cp^B may be
- 30 substituted by one or more R'' groups. M' is selected from Groups 3 through 12 atoms and lanthanide Group atoms. X' is an anionic leaving group. n is 0 or an integer from 1 to 4. (A) is selected from divalent alkyl, divalent lower alkyl, divalent substituted alkyl, divalent heteroalkyl, divalent alkenyl, divalent lower alkenyl, divalent substituted alkenyl, divalent

heteroalkenyl, divalent alkynyl, divalent lower alkynyl, divalent substituted alkynyl, divalent heteroalkynyl, divalent alkoxy, divalent lower alkoxy, divalent aryloxy, divalent alkylthio, divalent lower alkylthio, divalent arylthio, divalent aryl, divalent substituted aryl, divalent heteroaryl, divalent aralkyl, divalent aralkylene, divalent alkaryl, divalent alkarylene, divalent haloalkyl, divalent haloalkenyl, divalent haloalkynyl, divalent heteroalkyl, divalent heterocycle, divalent heteroaryl, a divalent heteroatom-containing group, divalent hydrocarbyl, divalent lower hydrocarbyl, divalent substituted hydrocarbyl, divalent heterohydrocarbyl, divalent silyl, divalent boryl, divalent phosphino, divalent phosphine, divalent amino, divalent amine, divalent ether, divalent thioether. R'' is selected from alkyl, lower alkyl, substituted alkyl, heteroalkyl, alkenyl, lower alkenyl, substituted alkenyl, heteroalkenyl, alkynyl, lower alkynyl, substituted alkynyl, heteroalkynyl, alkoxy, lower alkoxy, aryloxy, alkylthio, lower alkylthio, arylthio, aryl, substituted aryl, heteroaryl, aralkyl, aralkylene, alkaryl, alkarylene, haloalkyl, haloalkenyl, haloalkynyl, heteroalkyl, heterocycle, heteroaryl, a heteroatom-containing group, hydrocarbyl, lower hydrocarbyl, substituted hydrocarbyl, heterohydrocarbyl, silyl, boryl, phosphino, phosphine, amino, amine, germanium, ether, and thioether.

[0085] In at least one embodiment, each of Cp^A and Cp^B is independently selected from cyclopentadienyl, n-propylcyclopentadienyl, indenyl, pentamethylcyclopentadienyl, tetramethylcyclopentadienyl, and n-butylcyclopentadienyl.

[0086] (A) may be O, S, NR', or SiR'₂, where each R' is independently hydrogen or C₁-C₂₀ hydrocarbyl.

[0087] In another embodiment, the metallocene catalyst compound is represented by the formula:



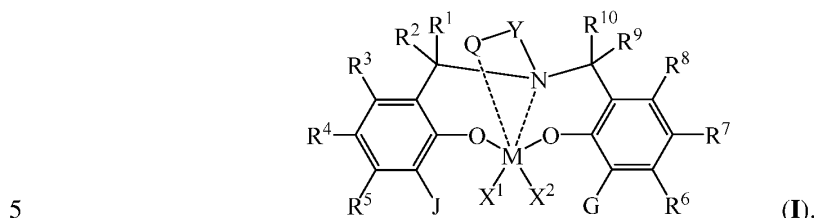
where Cp is independently a substituted or unsubstituted cyclopentadienyl ligand or substituted or unsubstituted ligand isolobal to cyclopentadienyl such as indenyl, fluorenyl and indacenyl. M is a Group 4 transition metal, such as Hf, Ti or Zr. G is a heteroatom group represented by the formula JR*_z where J is N, P, O or S, and R* is a linear, branched, or cyclic C₁-C₂₀ hydrocarbyl. z is 1 or 2. T is a bridging group. y is 0 or 1. X is a leaving group. m=1, n=1, 2 or 3, q=0, 1, 2, or 3, and the sum of m+n+q is equal to the oxidation state of the transition metal, preferably 2, 3, or 4, preferably 4.

[0088] In at least one embodiment, J is N, and R* is methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, cyclooctyl, cyclododecyl, decyl, undecyl, dodecyl, adamantyl or an isomer thereof. Preferred JR*_z groups include t-butyl amido and cyclododecylamido.

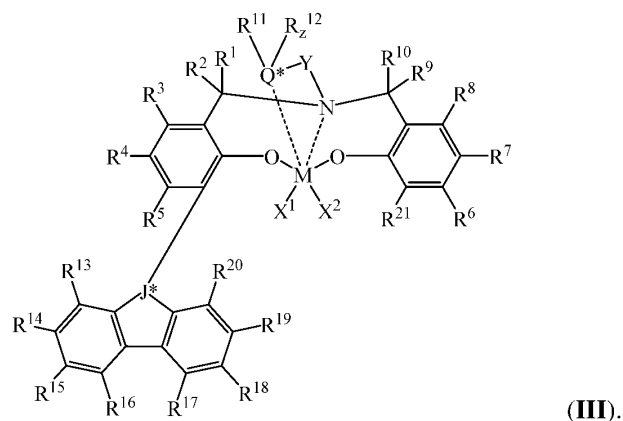
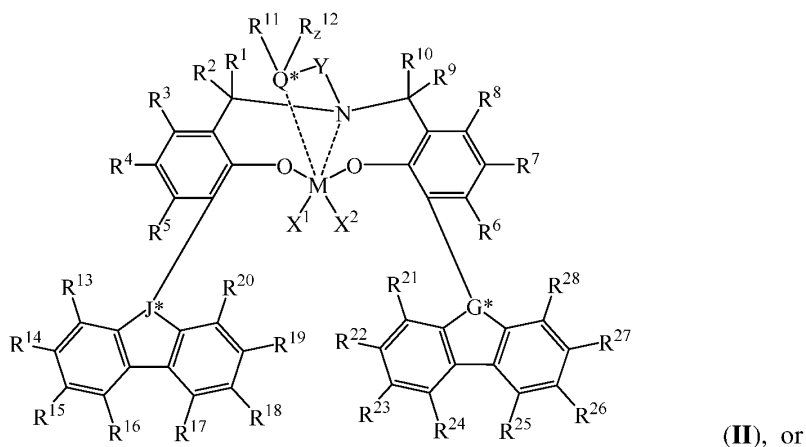
- [0089] Preferred examples for the bridging group T include CH₂, CH₂CH₂, SiMe₂, SiPh₂, SiMePh, Si(CH₂)₃, Si(CH₂)₄, O, S, NPh, PPh, NMe, PMe, NEt, NPr, NBu, PEt, PPr, Me₂SiOSiMe₂, and PBu. In a preferred embodiment of the invention in any embodiment of any formula described herein, T is represented by the formula ER^d₂ or (ER^d₂)₂, where E is C, Si, or Ge, and each R^d is, independently, hydrogen, halogen, C₁ to C₂₀ hydrocarbyl (such as methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, undecyl, or dodecyl) or a C₁ to C₂₀ substituted hydrocarbyl, and two R^d can form a cyclic structure including aromatic, partially saturated, or saturated cyclic or fused ring system.
- [0090] Each X is independently selected from the group consisting of hydrocarbyl radicals having from 1 to 20 carbon atoms, aryls, hydrides, amides, alkoxides, sulfides, phosphides, halides, dienes, amines, phosphines, ethers, and a combination thereof, (two Xs may form a part of a fused ring or a ring system), preferably each X is independently selected from halides, aryls and C₁ to C₅ alkyl groups, preferably each X is a phenyl, methyl, ethyl, propyl, butyl, pentyl, or chloro group.
- [0091] The metallocene catalyst compound may be selected from:
- bis(1-methyl, 3-n-butyl cyclopentadienyl) zirconium dichloride;
 - dimethylsilyl bis(tetrahydroindenyl) zirconium dichloride;
 - bis(n-propylcyclopentadienyl) hafnium dimethyl;
 - dimethylsilyl (tetramethylcyclopentadienyl)(cyclododecylamido)titanium dimethyl;
 - dimethylsilyl (tetramethylcyclopentadienyl)(cyclododecylamido)titanium dichloride;
 - dimethylsilyl (tetramethylcyclopentadienyl)(t-butylamido)titanium dimethyl;
 - dimethylsilyl (tetramethylcyclopentadienyl)(t-butylamido)titanium dichloride;
 - μ-(CH₃)₂Si(cyclopentadienyl)(1-adamantylamido)M(R)₂;
 - μ-(CH₃)₂Si(3-tertbutylcyclopentadienyl)(1-adamantylamido)M(R)₂;
 - μ-(CH₃)₂(tetramethylcyclopentadienyl)(1-adamantylamido)M(R)₂;
 - μ-(CH₃)₂Si(tetramethylcyclopentadienyl)(1-adamantylamido)M(R)₂;
 - μ-(CH₃)₂C(tetramethylcyclopentadienyl)(1-adamantylamido)M(R)₂;
 - μ-(CH₃)₂Si(tetramethylcyclopentadienyl)(1-tertbutylamido)M(R)₂;
 - μ-(CH₃)₂Si(fluorenyl)(1-tertbutylamido)M(R)₂;
 - μ-(CH₃)₂Si(tetramethylcyclopentadienyl)(1-cyclododecylamido)M(R)₂;
 - μ-(C₆H₅)₂C(tetramethylcyclopentadienyl)(1-cyclododecylamido)M(R)₂; and
 - μ-(CH₃)₂Si(η⁵-2,6,6-trimethyl-1,5,6,7-tetrahydro-s-indacen-1-yl)(tertbutylamido)M(R)₂;

where M is selected from Ti, Zr, and Hf; and each R is selected from halogen or C₁ to C₅ alkyl (preferably chloro, bromo, methyl, ethyl, propyl, butyl, pentyl or isomers thereof).

[0092] In at least one embodiment, the catalyst compound is a bis(phenolate) catalyst compound represented by Formula (I):

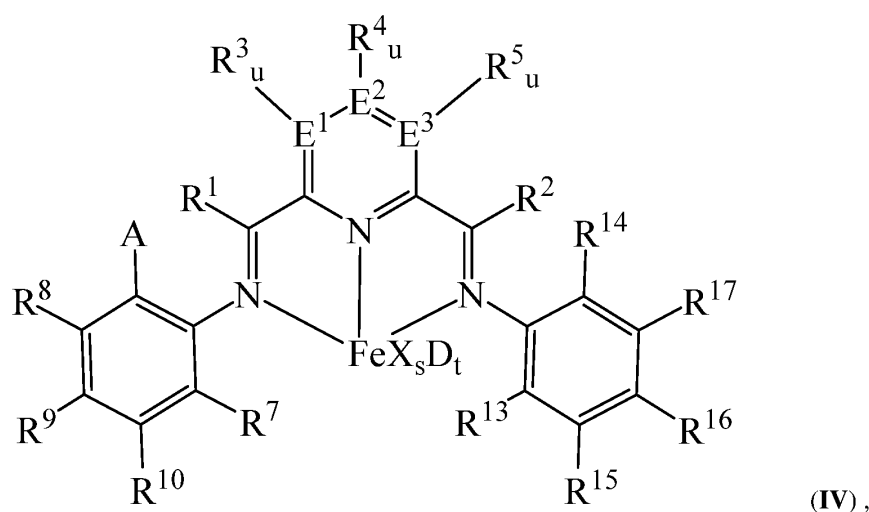


- M is a Group 4 metal, such as Hf or Zr. X¹ and X² are independently a univalent C₁-C₂₀ hydrocarbyl, C₁-C₂₀ substituted hydrocarbyl, a heteroatom or a heteroatom-containing group, or X¹ and X² join together to form a C₄-C₆₂ cyclic or polycyclic ring structure. R¹, R², R³, R⁴, R⁵, R⁶, R⁷, R⁸, R⁹, and R¹⁰ is independently hydrogen, C₁-C₄₀ hydrocarbyl, C₁-C₄₀ substituted hydrocarbyl, a heteroatom or a heteroatom-containing group, or two or more of R¹, R², R³, R⁴, R⁵, R⁶, R⁷, R⁸, R⁹, or R¹⁰ are joined together to form a C₄-C₆₂ cyclic or polycyclic ring structure, or a combination thereof; Q is a neutral donor group; J is heterocycle, a substituted or unsubstituted C₇-C₆₀ fused polycyclic group, where at least one ring is aromatic and where at least one ring, which may or may not be aromatic, has at least five ring atoms; G is as defined for J or may be hydrogen, C₂-C₆₀ hydrocarbyl, C₁-C₆₀ substituted hydrocarbyl, or may independently form a C₄-C₆₀ cyclic or polycyclic ring structure with R⁶, R⁷, or R⁸ or a combination thereof; Y is divalent C₁-C₂₀ hydrocarbyl or divalent C₁-C₂₀ substituted hydrocarbyl or (-Q*-Y-) together form a heterocycle; and heterocycle may be aromatic and/or may have multiple fused rings.
- 20 **[0093]** In at least one embodiment, the catalyst compound represented by Formula (I) is represented by Formula (II) or Formula (III):



- M is Hf, Zr, or Ti. X^1 , X^2 , R^1 , R^2 , R^3 , R^4 , R^5 , R^6 , R^7 , R^8 , R^9 , R^{10} , and Y are as defined for Formula (I). R^{11} , R^{12} , R^{13} , R^{14} , R^{15} , R^{16} , R^{17} , R^{18} , R^{19} , R^{20} , R^{21} , R^{22} , R^{23} , R^{24} , R^{25} , R^{26} , R^{27} , and R^{28} is independently a hydrogen, C_1 - C_{40} hydrocarbyl, C_1 - C_{40} substituted hydrocarbyl, a functional group comprising elements from Groups 13 to 17, or two or more of R^1 , R^2 , R^3 , R^4 , R^5 , R^6 , R^7 , R^8 , R^9 , R^{10} , R^{11} , R^{12} , R^{13} , R^{14} , R^{15} , R^{16} , R^{17} , R^{18} , R^{19} , R^{20} , R^{21} , R^{22} , R^{23} , R^{24} , R^{25} , R^{26} , R^{27} , and R^{28} may independently join together to form a C_4 - C_{62} cyclic or polycyclic ring structure, or a combination thereof; R^{11} and R^{12} may join together to form a five- to eight-membered heterocycle; Q^* is a group 15 or 16 atom; z is 0 or 1; J^* is CR'' or N, and G^* is CR'' or N, where R'' is C_1 - C_{20} hydrocarbyl or carbonyl-containing C_1 - C_{20} hydrocarbyl; and z = 0 if Q^* is a group 16 atom, and z = 1 if Q^* is a group 15 atom.

[0094] In at least one embodiment the catalyst is an iron complex represented by formula (IV):



wherein:

A is chlorine, bromine, iodine, -CF₃ or -OR¹¹;

each of R¹ and R² is independently hydrogen, C₁-C₂₂-alkyl, C₂-C₂₂-alkenyl, C₆-C₂₂-aryl, arylalkyl where alkyl has from 1 to 10 carbon atoms and aryl has from 6 to 20 carbon atoms, or five-, six- or seven-membered heterocyclyl comprising at least one atom selected from the group consisting of N, P, O and S;

wherein each of R¹ and R² is optionally substituted by halogen, -NR¹¹₂, -OR¹¹ or -SiR¹²₃;

wherein R¹ optionally bonds with R³, and R² optionally bonds with R⁵, in each case to independently form a five-, six- or seven-membered ring;

R⁷ is a C₁-C₂₀ alkyl;

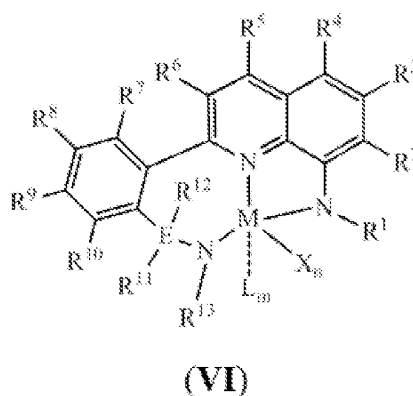
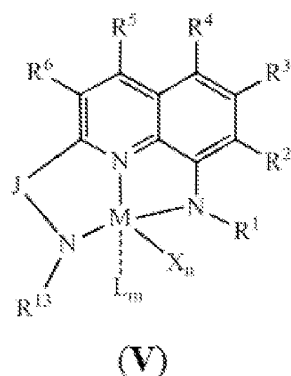
each of R³, R⁴, R⁵, R⁸, R⁹, R¹⁰, R¹⁵, R¹⁶, and R¹⁷ is independently hydrogen, C₁-C₂₂-alkyl, C₂-C₂₂-alkenyl, C₆-C₂₂-aryl, arylalkyl where alkyl has from 1 to 10 carbon atoms and aryl has from 6 to 20 carbon atoms, -NR¹¹₂, -OR¹¹, halogen, -SiR¹²₃ or five-, six- or seven-membered heterocyclyl comprising at least one atom selected from the group consisting of N, P, O, and S;

wherein R³, R⁴, R⁵, R⁷, R⁸, R⁹, R¹⁰, R¹⁵, R¹⁶, and R¹⁷ are optionally substituted by halogen, -NR¹¹₂, -OR¹¹ or -SiR¹²₃;

wherein R³ optionally bonds with R⁴, R⁴ optionally bonds with R⁵, R⁷ optionally bonds with R¹⁰, R¹⁰ optionally bonds with R⁹, R⁹ optionally bonds with R⁸, R¹⁷ optionally bonds with R¹⁶, and R¹⁶ optionally bonds with R¹⁵, in each case to independently form a five-, six- or seven-

- membered carbocyclic or heterocyclic ring, the heterocyclic ring comprising at least one atom from the group consisting of N, P, O and S;
- R^{13} is C_1 - C_{20} -alkyl bonded with the aryl ring via a primary or secondary carbon atom;
- R^{14} is chlorine, bromine, iodine, $-CF_3$ or $-OR^{11}$, or C_1 - C_{20} -alkyl bonded with the aryl ring;
- 5 each R^{11} is independently hydrogen, C_1 - C_{22} -alkyl, C_2 - C_{22} -alkenyl, C_6 - C_{22} -aryl, arylalkyl where alkyl has from 1 to 10 carbon atoms and aryl has from 6 to 20 carbon atoms, or $-SiR^{12}_3$, wherein R^{11} is optionally substituted by halogen, or two R^{11} radicals optionally bond to form a five- or six-membered ring;
- each R^{12} is independently hydrogen, C_1 - C_{22} -alkyl, C_2 - C_{22} -alkenyl, C_6 - C_{22} -aryl, arylalkyl where
- 10 alkyl has from 1 to 10 carbon atoms and aryl has from 6 to 20 carbon atoms, or two R^{12} radicals optionally bond to form a five- or six-membered ring;
- each of E^1 , E^2 , and E^3 is independently carbon, nitrogen or phosphorus;
- each u is independently 0 if E^1 , E^2 , and E^3 is nitrogen or phosphorus and is 1 if E^1 , E^2 , and E^3 is carbon;
- 15 each X is independently fluorine, chlorine, bromine, iodine, hydrogen, C_1 - C_{20} -alkyl, C_2 - C_{10} -alkenyl, C_6 - C_{20} -aryl, arylalkyl where alkyl has from 1 to 10 carbon atoms and aryl has from 6 to 20 carbon atoms, $-NR^{18}_2$, $-OR^{18}$, $-SR^{18}$, $-SO_3R^{18}$, $-OC(O)R^{18}$, $-CN$, $-SCN$, β -diketonate, $-CO$, $-BF_4^-$, $-PF_6^-$ or bulky non-coordinating anions, and the radicals X can be bonded with one another;
- 20 each R^{18} is independently hydrogen, C_1 - C_{20} -alkyl, C_2 - C_{20} -alkenyl, C_6 - C_{20} -aryl, arylalkyl where alkyl has from 1 to 10 carbon atoms and aryl has from 6 to 20 carbon atoms, or $-SiR^{19}_3$, wherein R^{18} can be substituted by halogen or nitrogen- or oxygen-containing groups and two R^{18} radicals optionally bond to form a five- or six-membered ring;
- each R^{19} is independently hydrogen, C_1 - C_{20} -alkyl, C_2 - C_{20} -alkenyl, C_6 - C_{20} -aryl or arylalkyl
- 25 where alkyl has from 1 to 10 carbon atoms and aryl has from 6 to 20 carbon atoms, wherein R^{19} can be substituted by halogen or nitrogen- or oxygen-containing groups or two R^{19} radicals optionally bond to form a five- or six-membered ring;
- s is 1, 2, or 3;
- D is a neutral donor; and
- 30 t is 0 to 2.

[0095] In at least one embodiment, the catalyst is a quinolinyldiamido transition metal complex represented by formulas (V) and (VI):



wherein:

M is a Group 3-12 metal;

J is a three-atom-length bridge between the quinoline and the amido nitrogen;

5 E is selected from carbon, silicon, or germanium;

X is an anionic leaving group;

L is a neutral Lewis base;

R¹ and R¹³ are independently selected from the group consisting of hydrocarbyls, substituted hydrocarbyls, and silyl groups;

10 R² through R¹² are independently selected from the group consisting of hydrogen, hydrocarbyls, alkoxy, silyl, amino, aryloxy, substituted hydrocarbyls, halogen, and phosphino;
n is 1 or 2;

m is 0, 1, or 2;

n+m is not greater than 4;

15 any two adjacent R groups (e.g., R¹ & R², R² & R³, etc.) may be joined to form a substituted or unsubstituted hydrocarbyl or heterocyclic ring, where the ring has 5, 6, 7, or 8 ring atoms and where substitutions on the ring can join to form additional rings;

any two X groups may be joined together to form a dianionic group;

any two L groups may be joined together to form a bidentate Lewis base; and

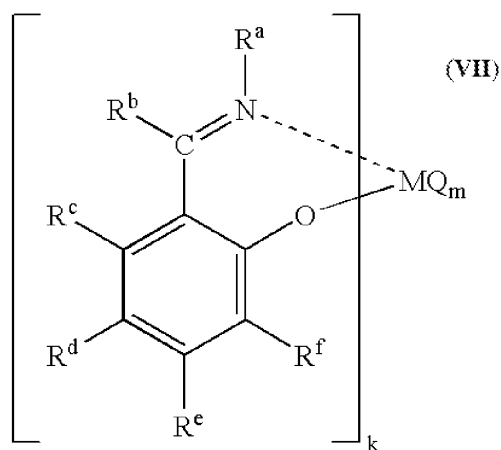
20 an X group may be joined to an L group to form a monoanionic bidentate group.

[0096] In a preferred embodiment M is a Group 4 metal, zirconium or hafnium.

[0097] In a preferred embodiment J is an arylmethyl, dihydro-1H-indenyl, or tetrahydronaphthalenyl group.

[0098] In a preferred embodiment E is carbon.

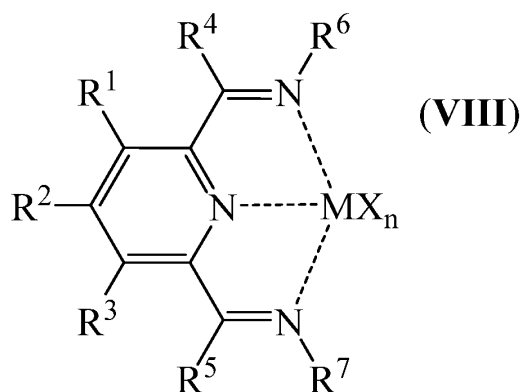
- [0099] In a preferred embodiment X is alkyl, aryl, hydride, alkylsilane, fluoride, chloride, bromide, iodide, triflate, carboxylate, or alkylsulfonate.
- [00100] In a preferred embodiment L is an ether, amine or thioether.
- [00101] In a preferred embodiment, R⁷ and R⁸ are joined to form a six membered aromatic ring with the joined R⁷ and R⁸ groups being -CH=CHCH=CH-.
- 5 [00102] In a preferred embodiment R¹⁰ and R¹¹ are joined to form a five membered ring with the joined R¹⁰ and R¹¹ groups being -CH₂CH₂-.
- [00103] In a preferred embodiment R¹⁰ and R¹¹ are joined to form a six membered ring with the joined R¹⁰ and R¹¹ groups being -CH₂CH₂CH₂-.
- 10 [00104] In a preferred embodiment, R¹ and R¹³ may be independently selected from phenyl groups that are variously substituted with between zero to five substituents that include F, Cl, Br, I, CF₃, NO₂, alkoxy, dialkylamino, aryl, and alkyl groups having 1 to 10 carbons, such as methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, and isomers thereof.
- [00105] In another embodiment, the catalyst is a phenoxyimine compound represented by
- 15 the formula (VII):



- wherein M represents a transition metal atom selected from the groups 3 to 11 metals in the periodic table; k is an integer of 1 to 6; m is an integer of 1 to 6; R^a to R^f may be the same or different from one another and each represent a hydrogen atom, a halogen atom, a hydrocarbon group, a heterocyclic compound residue, an oxygen-containing group, a nitrogen-containing group, a boron-containing group, a sulfur-containing group, a phosphorus-containing group, a silicon-containing group, a germanium-containing group or a tin-containing group, among
- 20 which 2 or more groups may be bound to each other to form a ring; when k is 2 or more, R^a

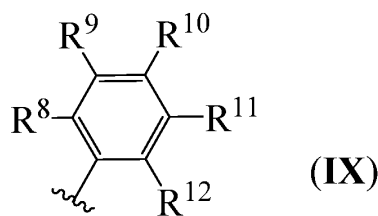
- groups, R^b groups, R^c groups, R^d groups, R^e groups, or R^f groups may be the same or different from one another, one group of R^a to R^f contained in one ligand and one group of R^a to R^f contained in another ligand may form a linking group or a single bond, and a heteroatom contained in R^a to R^f may coordinate with or bind to M; m is a number satisfying the valence of M; Q represents a hydrogen atom, a halogen atom, an oxygen atom, a hydrocarbon group, an oxygen-containing group, a sulfur-containing group, a nitrogen-containing group, a boron-containing group, an aluminum-containing group, a phosphorus-containing group, a halogen-containing group, a heterocyclic compound residue, a silicon-containing group, a germanium-containing group or a tin-containing group; when m is 2 or more, a plurality of groups represented by Q may be the same or different from one another, and a plurality of groups represented by Q may be mutually bound to form a ring.

[00106] In another embodiment, the catalyst is a bis(imino)pyridyl of the formula (VIII):



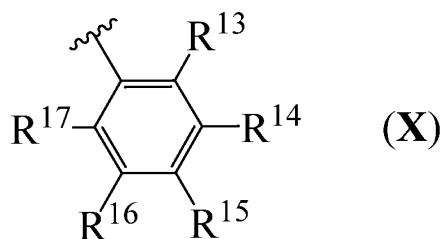
wherein:

- M is Co or Fe; each X is an anion; n is 1, 2 or 3, so that the total number of negative charges on said anion or anions is equal to the oxidation state of a Fe or Co atom present in (VIII); R^1 , R^2 and R^3 are each independently hydrogen, hydrocarbyl, substituted hydrocarbyl, or an inert functional group; R^4 and R^5 are each independently hydrogen, hydrocarbyl, an inert functional group or substituted hydrocarbyl;



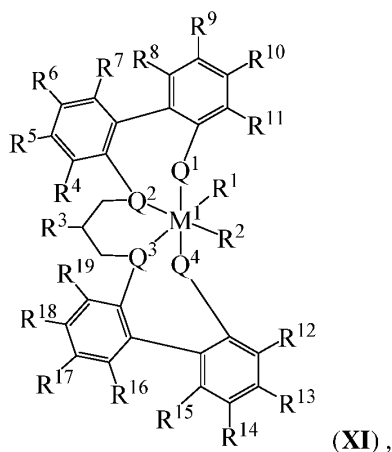
R^6 is formula IX:

and R⁷ is formula X:



- R⁸ and R¹³ are each independently hydrocarbyl, substituted hydrocarbyl or an inert functional group;
- 5 R⁹, R¹⁰, R¹¹, R¹⁴, R¹⁵ and R¹⁶ are each independently hydrogen, hydrocarbyl, substituted hydrocarbyl or an inert functional group;
- R¹² and R¹⁷ are each independently hydrogen, hydrocarbyl, substituted hydrocarbyl or an inert functional group;
- 10 and provided that any two of R⁸, R⁹, R¹⁰, R¹¹, R¹², R¹³, R¹⁴, R¹⁵, R¹⁶ and R¹⁷ that are adjacent to one another, together may form a ring.

[00107] In at least one embodiment, the catalyst compound is represented by the formula (XI):



- 15 M¹ is selected from the group consisting of titanium, zirconium, hafnium, vanadium, niobium, tantalum, chromium, molybdenum and tungsten. In at least one embodiment, M¹ is zirconium.
- [00108]** Each of Q¹, Q², Q³, and Q⁴ is independently oxygen or sulfur. In at least one embodiment, at least one of Q¹, Q², Q³, and Q⁴ is oxygen, alternately all of Q¹, Q², Q³, and Q⁴ are oxygen.

[00109] R¹ and R² are independently hydrogen, halogen, hydroxyl, hydrocarbyl, or substituted hydrocarbyl (such as C₁-C₁₀ alkyl, C₁-C₁₀ alkoxy, C₆-C₂₀ aryl, C₆-C₁₀ aryloxy, C₂-C₁₀ alkenyl, C₂-C₄₀ alkenyl, C₇-C₄₀ arylalkyl, C₇-C₄₀ alkylaryl, C₈-C₄₀ arylalkenyl, or conjugated diene which is optionally substituted with one or more hydrocarbyl, tri(hydrocarbyl) silyl or tri(hydrocarbyl) silylhydrocarbyl, the diene having up to 30 atoms other than hydrogen). R¹ and R² can be a halogen selected from fluorine, chlorine, bromine, or iodine. Preferably, R¹ and R² are chlorine.

[00110] Alternatively, R¹ and R² may also be joined together to form an alkanediyl group or a conjugated C₄-C₄₀ diene ligand which is coordinated to M¹. R¹ and R² may also be identical or different conjugated dienes, optionally substituted with one or more hydrocarbyl, tri(hydrocarbyl) silyl or tri(hydrocarbyl) silylhydrocarbyl, the dienes having up to 30 atoms not counting hydrogen and/or forming a π -complex with M¹.

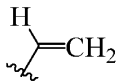
[00111] Exemplary groups suitable for R¹ and or R² can include 1,4-diphenyl, 1,3-butadiene, 1,3-pentadiene, 2-methyl 1,3-pentadiene, 2,4-hexadiene, 1-phenyl, 1,3-pentadiene, 1,4-dibenzyl, 1,3-butadiene, 1,4-ditolyl-1,3-butadiene, 1,4-bis (trimethylsilyl)-1,3-butadiene, and 1,4-dinaphthyl-1,3-butadiene. R¹ and R² can be identical and are C₁-C₃ alkyl or alkoxy, C₆-C₁₀ aryl or aryloxy, C₂-C₄ alkenyl, C₇-C₁₀ arylalkyl, C₇-C₁₂ alkylaryl, or halogen.

[00112] Each of R⁴, R⁵, R⁶, R⁷, R⁸, R⁹, R¹⁰, R¹¹, R¹², R¹³, R¹⁴, R¹⁵, R¹⁶, R¹⁷, R¹⁸, and R¹⁹ is independently hydrogen, halogen, C₁-C₄₀ hydrocarbyl or C₁-C₄₀ substituted hydrocarbyl (such as C₁-C₁₀ alkyl, C₁-C₁₀ alkoxy, C₆-C₂₀ aryl, C₆-C₁₀ aryloxy, C₂-C₁₀ alkenyl, C₂-C₄₀ alkenyl, C₇-C₄₀ arylalkyl, C₇-C₄₀ alkylaryl, C₈-C₄₀ arylalkenyl, or conjugated diene which is optionally substituted with one or more hydrocarbyl, tri(hydrocarbyl) silyl or tri(hydrocarbyl) silylhydrocarbyl, the diene having up to 30 atoms other than hydrogen), -NR'₂, -SR', -OR, -OSiR'₃, -PR'₂, where each R' is hydrogen, halogen, C₁-C₁₀ alkyl, or C₆-C₁₀ aryl, or one or more of R⁴ and R⁵, R⁵ and R⁶, R⁶ and R⁷, R⁸ and R⁹, R⁹ and R¹⁰, R¹⁰ and R¹¹, R¹² and R¹³, R¹³ and R¹⁴, R¹⁴ and R¹⁵, R¹⁶ and R¹⁷, R¹⁷ and R¹⁸, and R¹⁸ and R¹⁹ are joined to form a saturated ring, unsaturated ring, substituted saturated ring, or substituted unsaturated ring. In at least one embodiment, C₁-C₄₀ hydrocarbyl is selected from methyl, ethyl, propyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl, n-pentyl, isopentyl, sec-pentyl, n-hexyl, isohexyl, sec-hexyl, n-heptyl, isoheptyl, sec-heptyl, n-octyl, isooctyl, sec-octyl, n-nonyl, isononyl, sec-nonyl, n-decyl, isodecyl, and sec-decyl. Preferably, R¹¹ and R¹² are C₆-C₁₀ aryl such as phenyl or naphthyl optionally substituted with C₁-C₄₀ hydrocarbyl, such as C₁-C₁₀ hydrocarbyl. Preferably, R⁶ and R¹⁷ are C₁-40 alkyl, such as C₁-C₁₀ alkyl.

[00113] In at least one embodiment, each of R⁴, R⁵, R⁶, R⁷, R⁸, R⁹, R¹⁰, R¹³, R¹⁴, R¹⁵, R¹⁶, R¹⁷, R¹⁸, and R¹⁹ is independently hydrogen or C₁-C₄₀ hydrocarbyl. In at least one embodiment, C₁-C₄₀ hydrocarbyl is selected from methyl, ethyl, propyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl, n-pentyl, isopentyl, sec-pentyl, n-hexyl, isohexyl, sec-hexyl, n-heptyl, isoheptyl, sec-heptyl, n-octyl, isooctyl, sec-octyl, n-nonyl, isononyl, sec-nonyl, n-decyl, isodecyl, and sec-decyl. Preferably, each of R⁶ and R¹⁷ is C₁-C₄₀ hydrocarbyl and R⁴, R⁵, R⁷, R⁸, R⁹, R¹⁰, R¹³, R¹⁴, R¹⁵, R¹⁶, R¹⁸, and R¹⁹ is hydrogen. In at least one embodiment, C₁-C₄₀ hydrocarbyl is selected from methyl, ethyl, propyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl, n-pentyl, isopentyl, sec-pentyl, n-hexyl, isohexyl, sec-hexyl, n-heptyl, isoheptyl, sec-heptyl, n-octyl, isooctyl, sec-octyl, n-nonyl, isononyl, sec-nonyl, n-decyl, isodecyl, and sec-decyl.

[00114] R³ is a C₁-C₄₀ unsaturated alkyl or substituted C₁-C₄₀ unsaturated alkyl (such as C₁-C₁₀ alkyl, C₁-C₁₀ alkoxy, C₆-C₂₀ aryl, C₆-C₁₀ aryloxy, C₂-C₁₀ alkenyl, C₂-C₄₀ alkenyl, C₇-C₄₀ arylalkyl, C₇-C₄₀ alkylaryl, C₈-C₄₀ arylalkenyl, or conjugated diene which is optionally substituted with one or more hydrocarbyl, tri(hydrocarbyl) silyl or tri(hydrocarbyl) silylhydrocarbyl, the diene having up to 30 atoms other than hydrogen).

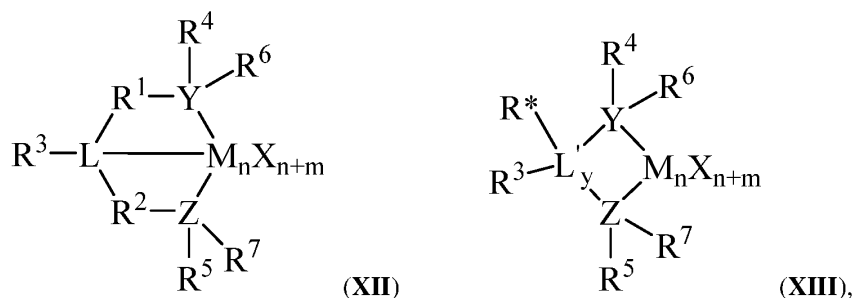
[00115] Preferably, R³ is a hydrocarbyl comprising a vinyl moiety. As used herein, “vinyl” and “vinyl moiety” are used interchangeably and include a terminal alkene, e.g., represented

by the structure . Hydrocarbyl of R³ may be further substituted (such as C₁-C₁₀ alkyl, C₁-C₁₀ alkoxy, C₆-C₂₀ aryl, C₆-C₁₀ aryloxy, C₂-C₁₀ alkenyl, C₂-C₄₀ alkenyl, C₇-C₄₀ arylalkyl, C₇-C₄₀ alkylaryl, C₈-C₄₀ arylalkenyl, or conjugated diene which is optionally substituted with one or more hydrocarbyl, tri(hydrocarbyl) silyl or tri(hydrocarbyl) silylhydrocarbyl, the diene having up to 30 atoms other than hydrogen). Preferably, R³ is C₁-C₄₀ unsaturated alkyl that is vinyl or substituted C₁-C₄₀ unsaturated alkyl that is vinyl. R³ can be represented by the structure -R'CH=CH₂ where R' is C₁-C₄₀ hydrocarbyl or C₁-C₄₀ substituted hydrocarbyl (such as C₁-C₁₀ alkyl, C₁-C₁₀ alkoxy, C₆-C₂₀ aryl, C₆-C₁₀ aryloxy, C₂-C₁₀ alkenyl, C₂-C₄₀ alkenyl, C₇-C₄₀ arylalkyl, C₇-C₄₀ alkylaryl, C₈-C₄₀ arylalkenyl, or conjugated diene which is optionally substituted with one or more hydrocarbyl, tri(hydrocarbyl) silyl or tri(hydrocarbyl) silylhydrocarbyl, the diene having up to 30 atoms other than hydrogen). In at least one embodiment, C₁-C₄₀ hydrocarbyl is selected from methyl, ethyl, propyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl, n-pentyl, isopentyl, sec-pentyl,

n-hexyl, isohexyl, sec-hexyl, n-heptyl, isoheptyl, sec-heptyl, n-octyl, isooctyl, sec-octyl, n-nonyl, isononyl, sec-nonyl, n-decyl, isodecyl, and sec-decyl.

[00116] In at least one embodiment, R^3 is 1-propenyl, 1-butenyl, 1-pentenyl, 1-hexenyl, 1-heptenyl, 1-octenyl, 1-nonenyl, or 1-decenyl.

- 5 [00117] In at least one embodiment, the catalyst is a Group 15-containing metal compound represented by Formulas (XII) or (XIII):

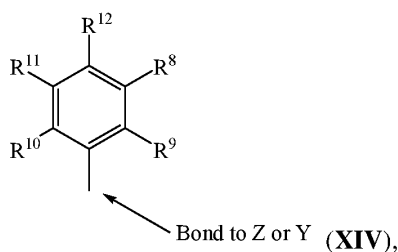


- wherein M is a Group 3 to 12 transition metal or a Group 13 or 14 main group metal, a Group 4, 5, or 6 metal. In many embodiments, M is a Group 4 metal, such as zirconium, titanium, hafnium. Each X is independently a leaving group, such as an anionic leaving group. The leaving group may include a hydrogen, a hydrocarbyl group, a heteroatom, a halogen, or an alkyl; y is 0 or 1 (when y is 0 group L' is absent). The term 'n' is the oxidation state of M. In various embodiments, n is +3, +4, or +5. In many embodiments, n is +4. The term 'm' represents the formal charge of the YZL or the YZL' ligand, and is 0, -1, -2 or -3 in various embodiments.
- 10 In many embodiments, m is -2. L is a Group 15 or 16 element, such as nitrogen or oxygen; L' is a Group 15 or 16 element or Group 14 containing group, such as carbon, silicon or germanium. Y is a Group 15 element, such as nitrogen or phosphorus. In many embodiments, Y is nitrogen. Z is a Group 15 element, such as nitrogen or phosphorus. In many embodiments, Z is nitrogen. R^1 and R^2 are, independently, a C_1 to C_{20} hydrocarbon group, a heteroatom containing group having up to twenty carbon atoms, silicon, germanium, tin, lead, or phosphorus. In many embodiments, R^1 and R^2 are a C_2 to C_{20} alkyl, aryl or aralkyl group, such as a C_2 to C_{20} linear, branched or cyclic alkyl group, or a C_2 to C_{20} hydrocarbon group. R^1 and R^2 may also be interconnected to each other. R^3 may be absent or may be a hydrocarbon group, a hydrogen, a halogen, a heteroatom containing group. In many embodiments, R^3 is absent, for example, if L is an oxygen, or a hydrogen, or a linear, cyclic, or branched alkyl group having 1 to 20 carbon atoms. R^4 and R^5 are independently an alkyl group, an aryl group, substituted aryl group, a cyclic alkyl group, a substituted cyclic alkyl group, a cyclic aralkyl group, a
- 25

substituted cyclic aralkyl group, or multiple ring system, often having up to 20 carbon atoms. In many embodiments, R⁴ and R⁵ have between 3 and 10 carbon atoms, or are a C₁ to C₂₀ hydrocarbon group, a C₁ to C₂₀ aryl group or a C₁ to C₂₀ aralkyl group, or a heteroatom containing group. R⁴ and R⁵ may be interconnected to each other. R⁶ and R⁷ are independently
 5 absent, hydrogen, an alkyl group, halogen, heteroatom, or a hydrocarbyl group, such as a linear, cyclic or branched alkyl group having 1 to 20 carbon atoms. In many embodiments, R⁶ and R⁷ are absent. R* may be absent, or may be a hydrogen, a Group 14 atom containing group, a halogen, or a heteroatom containing group.

[00118] By "formal charge of the YZL or YZL' ligand," it is meant the charge of the entire
 10 ligand absent the metal and the leaving groups X. By "R¹ and R² may also be interconnected" it is meant that R¹ and R² may be directly bound to each other or may be bound to each other through other groups. By "R⁴ and R⁵ may also be interconnected" it is meant that R⁴ and R⁵ may be directly bound to each other or may be bound to each other through other groups. An
 15 alkyl group may be linear, branched alkyl radicals, alkenyl radicals, alkynyl radicals, cycloalkyl radicals, aryl radicals, acyl radicals, aroyl radicals, alkoxy radicals, aryloxy radicals, alkylthio radicals, dialkylamino radicals, alkoxycarbonyl radicals, aryloxy carbonyl radicals, carbomoyl radicals, alkyl- or dialkyl- carbamoyl radicals, acyloxy radicals, acylamino radicals, aroylamino radicals, straight, branched or cyclic, alkylene radicals, or combination thereof. An aralkyl group is defined to be a substituted aryl group.

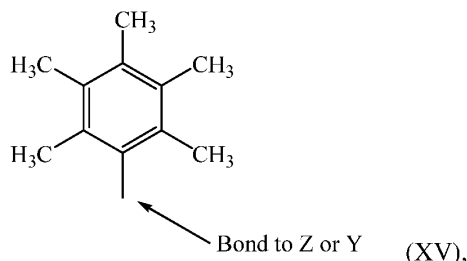
20 **[00119]** In one or more embodiments, R⁴ and R⁵ are independently a group represented by structure (XIV):



wherein R⁸ to R¹² are each independently hydrogen, a C₁ to C₄₀ alkyl group, a halide, a heteroatom, a heteroatom containing group containing up to 40 carbon atoms. In many
 25 embodiments, R⁸ to R¹² are a C₁ to C₂₀ linear or branched alkyl group, such as a methyl, ethyl, propyl, or butyl group. Any two of the R groups may form a cyclic group and/or a heterocyclic group. The cyclic groups may be aromatic. In one embodiment R⁹, R¹⁰ and R¹² are

independently a methyl, ethyl, propyl, or butyl group (including all isomers). In another embodiment, R^9 , R^{10} and R^{12} are methyl groups, and R^8 and R^{11} are hydrogen.

[00120] In one or more embodiments, R^4 and R^5 are both a group represented by structure (XV):



wherein M is a Group 4 metal, such as zirconium, titanium, or hafnium. In at least one embodiment, M is zirconium. Each of L, Y, and Z may be a nitrogen. Each of R^1 and R^2 may be $-\text{CH}_2-\text{CH}_2-$. R^3 may be hydrogen, and R^6 and R^7 may be absent.

[00121] In at least one embodiment, the maximum amount of alumoxane is up to a 5000-fold molar excess Al/M over the catalyst compound (per metal catalytic site). The minimum alumoxane-to-catalyst-compound is a 1:1 molar ratio. Alternate preferred ranges include from 1:1 to 500:1, alternately from 1:1 to 200:1, alternately from 1:1 to 100:1, or alternately from 1:1 to 50:1.

Catalyst System Formation:

[00122] Embodiments of the present disclosure include methods for preparing a catalyst system including contacting in an aliphatic solvent the supported alumoxane with at least one catalyst compound having a Group 3 through Group 12 metal atom or lanthanide metal atom. The catalyst compound having a Group 3 through Group 12 metal atom or lanthanide metal atom can be a metallocene catalyst compound comprising a Group 4 metal.

[00123] In at least one embodiment, the supported alumoxane is heated prior to contact with the catalyst compound.

[00124] The supported alumoxane can be slurried in an aliphatic solvent and the resulting slurry is contacted with a solution of at least one catalyst compound. The catalyst compound can also be added as a solid to the slurry of the aliphatic solvent and the supported alumoxane.

In at least one embodiment, the slurry of the supported alumoxane is contacted with the catalyst compound for a period of time between about 0.02 hours and about 24 hours, such as between about 0.1 hours and 1 hour, 0.2 hours and 0.6 hours, 2 hours and about 16 hours, or between about 4 hours and about 8 hours.

[00125] The mixture of the catalyst compound and the supported alumoxane may be heated to between about 0°C and about 70°C, such as between about 23°C and about 60°C, for example room temperature. Contact times may be between about 0.02 hours and about 24 hours, such as between about 0.1 hours and 1 hour, 0.2 hours and 0.6 hours, 2 hours and about 16 hours, or between about 4 hours and about 8 hours.

[00126] Useful aliphatic solvents are materials in which all or part of the reactants used herein, *e.g.*, the supported alumoxane and the catalyst compound, are at least partially soluble (or in the case of the solid support, suspended) and which are liquid at reaction temperatures. Non-limiting example solvents are non-cyclic alkanes with formula $C_nH_{(n+2)}$ where *n* is 4 to 30, such as isobutane, butane, isopentane, hexane, *n*-heptane, octane, nonane, decane and the like, and cycloalkanes with formula C_nH_n where *n* is 5 to 30, such as cyclopentane, methylcyclopentane, cyclohexane, methylcyclohexane and the like. Suitable aliphatic solvents also include mixtures of any of the above.

[00127] The solvent can be charged into a reactor, followed by a supported alumoxane. Catalyst can then be charged into the reactor, such as a solution of catalyst in an aliphatic solvent or as a solid. The mixture can be stirred at a temperature, such as room temperature. Additional solvent may be added to the mixture to form a slurry having a desired consistency, such as from about 2 cc/g of silica to about 20 cc/g silica, such as about 4 cc/g. The solvent is then removed. Removing solvent dries the mixture and may be performed under a vacuum atmosphere, purged with inert atmosphere, heating of the mixture, or combinations thereof. For heating of the mixture, any suitable temperature can be used that evaporates the aliphatic solvent. It is to be understood that reduced pressure under vacuum will lower the boiling point of the aliphatic solvent depending on the pressure of the reactor. Solvent removal temperatures can be from about 10°C to about 200°C, such as from about 60°C to about 140°C, such as from about 60°C to about 120°C, for example about 80°C or less, such as about 70°C or less. In at least one embodiment, removing solvent includes applying heat, applying vacuum, and applying nitrogen purged from bottom of the vessel by bubbling nitrogen through the mixture. The mixture is dried.

Polymerization Processes

[00128] In at least one embodiment of the present disclosure, a method includes polymerizing olefins to produce a polyolefin composition by contacting at least one olefin with a catalyst system of the present disclosure and obtaining the polyolefin composition.

Polymerization may be conducted at a temperature of from about 0°C to about 300°C, at a pressure of from about 0.35 MPa to about 10 MPa, and/or at a time up to about 400 minutes.

[00129] Embodiments of the present disclosure include polymerization processes where monomer (such as ethylene or propylene), and optionally comonomer, are contacted with a catalyst system comprising at least one catalyst compound and an activator, as described above. The at least one catalyst compound and activator may be combined in any order, and are combined typically prior to contact with the monomer.

[00130] Slurry and gas phase polymerizations may be conducted in the presence of an aliphatic hydrocarbon solvent/diluent/condensing agent (such as isobutane, butane, pentane, isopentane, hexanes, isohexane, heptane, octane, dodecane, and mixtures thereof; cyclic and alicyclic hydrocarbons, such as cyclohexane, cycloheptane, methylcyclohexane, methylcycloheptane, and mixtures thereof; preferably aromatics are present in the solvent/diluent/condensing agent at less than 1 wt%, preferably less than 0.5 wt%, preferably at 0 wt% based upon the weight of the solvents/diluent/condensing agent).

[00131] In preferred embodiments, solvents/diluents used in the polymerizations are not aromatic, preferably aromatics are present in the solvent/diluent at less than 1 wt%, preferably less than 0.5 wt%, preferably less than 0 wt% based upon the weight of the solvents/diluents.

[00132] Monomers useful herein include substituted or unsubstituted C₂ to C₄₀ alpha olefins, preferably C₂ to C₂₀ alpha olefins, preferably C₂ to C₁₂ alpha olefins, preferably ethylene, propylene, butene, pentene, hexene, heptene, octene, nonene, decene, undecene, dodecene and isomers thereof. In a preferred embodiment, olefins include a monomer that is propylene and one or more optional comonomers comprising one or more ethylene or C₄ to C₄₀ olefin, preferably C₄ to C₂₀ olefin, or preferably C₆ to C₁₂ olefin. The C₄ to C₄₀ olefin monomers may be linear, branched, or cyclic. The C₄ to C₄₀ cyclic olefin may be strained or unstrained, monocyclic or polycyclic, and may include one or more heteroatoms and/or one or more functional groups. In another preferred embodiment, olefins include a monomer that is ethylene and an optional comonomer comprising one or more of C₃ to C₄₀ olefin, preferably C₄ to C₂₀ olefin, or preferably C₆ to C₁₂ olefin. The C₃ to C₄₀ olefin monomers may be linear, branched, or cyclic. The C₃ to C₄₀ cyclic olefins may be strained or unstrained, monocyclic or polycyclic, and may include heteroatoms and/or one or more functional groups.

[00133] Exemplary C₂ to C₄₀ olefin monomers and optional comonomers include ethylene, propylene, butene, pentene, hexene, heptene, octene, nonene, decene, undecene, dodecene, norbornene, norbornadiene, dicyclopentadiene, cyclopentene, cycloheptene, cyclooctene,

cyclooctadiene, cyclododecene, 7-oxanorbornene, 7-oxanorbornadiene, substituted derivatives thereof, and isomers thereof, preferably hexene, heptene, octene, nonene, decene, dodecene, cyclooctene, 1,5-cyclooctadiene, 1-hydroxy-4-cyclooctene, 1-acetoxy-4-cyclooctene, 5-methylcyclopentene, cyclopentene, dicyclopentadiene, norbornene, norbornadiene, and substituted derivatives thereof, preferably norbornene, norbornadiene, and dicyclopentadiene.

5 **[00134]** In at least one embodiment, one or more dienes are present in a polymer produced herein at up to about 10 wt%, such as from about 0.00001 to about 1.0 wt%, such as from about 0.002 to about 0.5 wt%, such as from about 0.003 to about 0.2 wt%, based upon the total weight of the composition. In at least one embodiment, about 500 ppm or less of diene is added to the
10 polymerization, such as about 400 ppm or less, such as about 300 ppm or less. In at least one embodiment, at least about 50 ppm of diene is added to the polymerization, or about 100 ppm or more, or 150 ppm or more.

[00135] Diolefin monomers include any hydrocarbon structure, preferably C₄ to C₃₀, having at least two unsaturated bonds, wherein at least two of the unsaturated bonds are readily
15 incorporated into a polymer by either a stereospecific or a non-stereospecific catalyst(s). It is further preferred that the diolefin monomers be selected from alpha, omega-diene monomers (i.e., di-vinyl monomers). In at least one embodiment, the diolefin monomers are linear di-vinyl monomers, such as those containing from 4 to 30 carbon atoms. Non-limiting examples of dienes include butadiene, pentadiene, hexadiene, heptadiene, octadiene,
20 nonadiene, decadiene, undecadiene, dodecadiene, tridecadiene, tetradecadiene, pentadecadiene, hexadecadiene, heptadecadiene, octadecadiene, nonadecadiene, icosadiene, heneicosadiene, docosadiene, tricosadiene, tetracosadiene, pentacosadiene, hexacosadiene, heptacosadiene, octacosadiene, nonacosadiene, triacontadiene, particularly preferred dienes include 1,6-heptadiene, 1,7-octadiene, 1,8-nonadiene, 1,9-decadiene, 1,10-undecadiene,
25 1,11-dodecadiene, 1,12-tridecadiene, 1,13-tetradecadiene, and low molecular weight polybutadienes (Mw less than 1000 g/mol). Non-limiting example cyclic dienes include cyclopentadiene, vinylnorbornene, norbornadiene, ethylidene norbornene, divinylbenzene, dicyclopentadiene or higher ring containing diolefins with or without substituents at various ring positions.

30 **[00136]** In at least one embodiment, where butene is the comonomer, the butene source may be a mixed butene stream comprising various isomers of butene. The 1-butene monomers are expected to be preferentially consumed by the polymerization process as compared to other butene monomers. Use of such mixed butene streams will provide an economic benefit, as

these mixed streams are often waste streams from refining processes, for example, C₄ raffinate streams, and can therefore be substantially less expensive than pure 1-butene.

[00137] Polymerization processes of the present disclosure can be carried out in any suitable manner. Any suitable slurry or gas phase polymerization process can be used. Such processes
5 can be run in a batch, semi-batch, or continuous mode.

[00138] Preferred polymerizations can be run at any temperature and/or pressure suitable to obtain the desired polyolefins. Typical temperatures and/or pressures include a temperature from about 0°C to about 300°C, such as from about 20°C to about 200°C, such as from about 35°C to about 150°C, such as from about 40°C to about 120°C, such as from about 65°C to
10 about 95°C; and at a pressure from about 0.35 MPa to about 10 MPa, such as from about 0.45 MPa to about 6 MPa, or preferably from about 0.5 MPa to about 4 MPa.

[00139] In a typical polymerization, the run time of the reaction is up to about 400 minutes, such as from about 5 to about 250 minutes, such as from about 10 to about 120 minutes.

[00140] Hydrogen, may be added to a reactor for molecular weight control of polyolefins.
15 In at least one embodiment, hydrogen is present in the polymerization reactor at a partial pressure of from about 0.001 and 50 psig (0.007 to 345 kPa), such as from about 0.01 to about 25 psig (0.07 to 172 kPa), such as from about 0.1 and 10 psig (0.7 to 70 kPa). In one embodiment, 600 ppm or less of hydrogen is added, or 500 ppm or less of hydrogen is added, or 400 ppm or less or 300 ppm or less. In other embodiments, at least 50 ppm of hydrogen is
20 added, or 100 ppm or more, or 150 ppm or more.

[00141] In an alternative embodiment, the activity of the catalyst is at least about 50 g/mmol/hour, such as about 500 or more g/mmol/hour, such as about 5,000 or more g/mmol/hr, such as about 750,000 or more g/mmol/hr where the amount of metallocene catalyst is in the denominator. In an alternative embodiment, the conversion of olefin monomer is at least about
25 10%, based upon polymer yield (weight) and the weight of the monomer entering the reaction zone, such as about 20% or more, such as about 30% or more, such as about 50% or more, such as about 80% or more.

[00142] Preferably, alumoxane is present at a molar ratio of aluminum to transition metal of a catalyst compound of less than about 500:1, such as less than about 300:1, such as less
30 than about 100:1, such as less than about 1:1.

[00143] In a preferred embodiment, little or no scavenger is used in the process to produce the polyolefin composition. Preferably, scavenger (such as tri alkyl aluminum) is present at zero mol%. Alternatively, the scavenger is present at a molar ratio of scavenger metal to

transition metal of the catalyst of less than about 100:1, such as less than about 50:1, such as less than about 15:1, such as less than about 10:1.

[00144] In a preferred embodiment, the polymerization: 1) is conducted at temperatures of 0 to 300°C (preferably 25 to 150°C, preferably 40 to 120°C, preferably 45 to 80°C); 2) is conducted at a pressure of atmospheric pressure to 10 MPa (preferably 0.35 to 10 MPa, preferably from 0.45 to 6 MPa, preferably from 0.5 to 4 MPa); 3) wherein the catalyst system used in the polymerization comprises alumoxane at a molar ratio of aluminum to transition metal of a catalyst compound of less than 200:1, preferably 75:1 to 160:1, preferably 90:1 to 150:1, such as 95:1 to 125:1; 4) the polymerization preferably occurs in one reaction zone; 5) the productivity of the catalyst compound is at least 80,000 g/mmol/hr (preferably at least 150,000 g/mmol/hr, preferably at least 200,000 g/mmol/hr, preferably at least 250,000 g/mmol/hr, preferably at least 300,000 g/mmol/hr); 6) optionally scavengers (such as trialkyl aluminum compounds) are absent (e.g., present at zero mol%). Alternatively, the scavenger is present at a molar ratio of scavenger metal to transition metal of less than 100:1, preferably less than 50:1, preferably less than 15:1, preferably less than 10:1; and 8) optionally hydrogen is present in the polymerization reactor at a partial pressure of 0.001 to 50 psig (0.007 to 345 kPa) (preferably from 0.01 to 25 psig (0.07 to 172 kPa), more preferably 0.1 to 10 psig (0.7 to 70 kPa)). In a preferred embodiment, the catalyst system used in the polymerization comprises no more than one catalyst compound. A "reaction zone", also referred to as a "polymerization zone", is a vessel where polymerization takes place, for example a batch reactor. When multiple reactors are used in either series or parallel configuration, each reactor is considered as a separate polymerization zone. For a multi-stage polymerization in both a batch reactor and a continuous reactor, each polymerization stage is considered as a separate polymerization zone. The polymerization can occur in one or more reaction zones.

[00145] Other additives may also be used in the polymerization, as desired, such as one or more scavengers, promoters, modifiers, chain transfer agents (such as diethyl zinc), reducing agents, oxidizing agents, hydrogen, aluminum alkyls, or silanes.

[00146] Chain transfer agents may be alkylalumoxanes, a compound represented by the formula AlR_3 , ZnR_2 (where each R is, independently, a C_1 - C_8 aliphatic radical, preferably methyl, ethyl, propyl, butyl, penyl, hexyl, heptyl, octyl or an isomer thereof) or a combination thereof, such as diethyl zinc, methylalumoxane, trimethylaluminum, triisobutylaluminum, trioctylaluminum, or a combination thereof.

[00147] Gas phase polymerization: Gas phase polymerization processes may be used herein. Generally, in a fluidized gas bed process used for producing polymers, a gaseous stream containing one or more monomers is continuously cycled through a fluidized bed in the presence of a catalyst under reactive conditions. The gaseous stream is withdrawn from the fluidized bed and recycled back into the reactor. Simultaneously, polymer product is withdrawn from the reactor and fresh monomer is added to replace the polymerized monomer. (See, for example, U.S. Patent Nos. 4,543,399; 4,588,790; 5,028,670; 5,317,036; 5,352,749; 5,405,922; 5,436,304; 5,453,471; 5,462,999; 5,616,661; and 5,668,228; all of which are fully incorporated herein by reference.)

10 [00148] Slurry phase polymerization: Slurry phase polymerization processes may be used herein. A slurry polymerization process generally operates between 1 to about 50 atmosphere pressure range (15 psi to 735 psi, 103 kPa to 5068 kPa) or even greater and temperatures of 0°C to about 120°C. In a slurry polymerization, a suspension of solid, particulate polymer is formed in a liquid polymerization diluent medium to which monomer and comonomers, along with catalysts, are added. The suspension including diluent is intermittently or continuously removed from the reactor where the volatile components are separated from the polymer and recycled, optionally after a distillation, to the reactor. The liquid diluent employed in the polymerization medium is typically an alkane having from 3 to 7 carbon atoms, preferably a branched alkane. The medium employed should be liquid under the conditions of polymerization and relatively inert. When a propane medium is used, the process should be operated above the reaction diluent critical temperature and pressure. Preferably, a hexane or an isobutane medium is employed. In another embodiment, the diluent is not aromatic, preferably aromatics are present in the diluent at less than 1 wt%, preferably less than 0.5 wt%, preferably less than 0 wt% based upon the weight of the diluents employed.

25 Polyolefin Products

[00149] The present disclosure also relates to polyolefin compositions, such as resins, produced by the catalyst systems of the present disclosure. Polyolefins of the present disclosure can have no detectable aromatic solvent.

30 [00150] In at least one embodiment, a process includes utilizing a catalyst system of the present disclosure to produce propylene homopolymers or propylene copolymers, such as propylene-ethylene and/or propylene-alphaolefin (preferably C₃ to C₂₀) copolymers (such as propylene-hexene copolymers or propylene-octene copolymers) having an Mw/Mn of greater

than about 1, such as greater than about 2, such as greater than about 3, such as greater than about 4.

[00151] In at least one embodiment, a process includes utilizing a catalyst system of the present disclosure to produce olefin polymers, preferably polyethylene and polypropylene
5 homopolymers and copolymers. In at least one embodiment, the polymers produced herein are homopolymers of ethylene or copolymers of ethylene preferably having from about 0 and 25 mol% of one or more C₃ to C₂₀ olefin comonomer (such as from about 0.5 and 20 mol%, such as from about 1 to about 15 mol%, such as from about 3 to about 10 mol%). Olefin comonomers may be C₃ to C₁₂ alpha-olefins, such as one or more of propylene, butene, hexene,
10 octene, decene, or dodecene, preferably propylene, butene, hexene, or octene. Olefin monomers may be one or more of ethylene or C₄ to C₁₂ alpha-olefin, preferably ethylene, butene, hexene, octene, decene, or dodecene, preferably ethylene, butene, hexene, or octene.

[00152] Polymers produced herein may have an Mw of from about 5,000 to about 1,000,000 g/mol (such as from about 25,000 to about 750,000 g/mol, such as from about 50,000 to about
15 500,000 g/mol), and/or an Mw/Mn of from about 1 to about 40 (such as from about 1.2 to about 20, such as from about 1.3 to about 10, such as from about 1.4 to about 5, such as from about 1.5 to about 4, such as from about 1.5 to about 3) as determined by GPC-4D as described in the Experimental section below.

[00153] The polyolefins produced herein contain 0 ppm of aromatic hydrocarbon.
20 Preferably, the polyolefins produced herein contain 0 ppm of toluene.

Blends

[00154] In at least one embodiment, the polymer (such as polyethylene or polypropylene) produced herein and having no detectable aromatic solvent is combined with one or more additional polymers prior to being formed into a film, molded part or other article. Other useful
25 polymers, which may or may not contain a detectable amount of aromatic solvent, include polyethylene, isotactic polypropylene, highly isotactic polypropylene, syndiotactic polypropylene, random copolymer of propylene and ethylene, and/or butene, and/or hexene, polybutene, ethylene vinyl acetate, LDPE, LLDPE, HDPE, ethylene vinyl acetate, ethylene methyl acrylate, copolymers of acrylic acid, polymethylmethacrylate or any other polymers
30 polymerizable by a high-pressure free radical process, polyvinylchloride, polybutene-1, isotactic polybutene, ABS resins, ethylene-propylene rubber (EPR), vulcanized EPR, EPDM, block copolymer, styrenic block copolymers, polyamides, polycarbonates, PET resins, cross linked polyethylene, copolymers of ethylene and vinyl alcohol (EVOH), polymers of aromatic

monomers such as polystyrene, poly-1 esters, polyacetal, polyvinylidene fluoride, polyethylene glycols, and/or polyisobutylene.

[00155] In at least one embodiment, the polymer (such as polyethylene or polypropylene) is present in the above blends, at from about 10 to about 99 wt%, based upon the weight of total
5 polymers in the blend, such as from about 20 to about 95 wt%, such as from about 30 to about 90 wt%, such as from about 40 to about 90 wt%, such as from about 50 to about 90 wt%, such as from about 60 to about 90 wt%, such as from about 70 to about 90 wt%.

[00156] Blends of the present disclosure may be produced by mixing the polymers of the present disclosure with one or more polymers (as described above), by connecting reactors
10 together in series to make reactor blends or by using more than one catalyst in the same reactor to produce multiple species of polymer. The polymers can be mixed together prior to being put into the extruder or may be mixed in an extruder.

[00157] Blends of the present disclosure may be formed using conventional equipment and methods, such as by dry blending the individual components, such as polymers, and
15 subsequently melt mixing in a mixer, or by mixing the components together directly in a mixer, such as, for example, a Banbury mixer, a Haake mixer, a Brabender internal mixer, or a single or twin-screw extruder, which may include a compounding extruder and a side-arm extruder used directly downstream of a polymerization process, which may include blending powders or pellets of the resins at the hopper of the film extruder. Additionally, additives may be
20 included in the blend, in one or more components of the blend, and/or in a product formed from the blend, such as a film, as desired. Such additives can include, for example: fillers; antioxidants (e.g., hindered phenolics such as IRGANOX™ 1010 or IRGANOX™ 1076 available from Ciba-Geigy); phosphites (e.g., IRGAFOS™ 168 available from Ciba-Geigy); anti-cling additives; tackifiers, such as polybutenes, terpene resins, aliphatic and aromatic
25 hydrocarbon resins, alkali metal and glycerol stearates, and hydrogenated rosins; UV stabilizers; heat stabilizers; anti-blocking agents; release agents; anti-static agents; pigments; colorants; dyes; waxes; silica; fillers; talc; mixtures thereof, and the like.

[00158] In at least one embodiment, a polyolefin composition, such as a resin, that is a multi-modal polyolefin composition comprises a low molecular weight fraction and/or a high
30 molecular weight fraction. In at least one embodiment, the polyolefin composition produced by a catalyst system of the present disclosure has a comonomer content from about 3 wt% to about 15 wt%, such as from about 4 wt% and about 10 wt%, such as from about 5 wt% to about 8 wt%. In at least one embodiment, the polyolefin composition produced by a catalyst system

of the present disclosure has a polydispersity index of from about 2 to about 6, such as from about 2 to about 5.

Films

- [00159]** Any of the foregoing polymers, such as the foregoing polyethylenes or blends thereof, may be used in a variety of end-use applications. Such applications include, for example, mono- or multi-layer blown, extruded, and/or shrink films. These films may be formed by any suitable extrusion or coextrusion techniques, such as a blown bubble film processing technique, where the composition can be extruded in a molten state through an annular die and then expanded to form a uni-axial or biaxial orientation melt prior to being cooled to form a tubular, blown film, which can then be axially slit and unfolded to form a flat film. Films may be subsequently unoriented, uniaxially oriented, or biaxially oriented to the same or different extents. One or more of the layers of the film may be oriented in the transverse and/or longitudinal directions to the same or different extents. The uniaxially orientation can be accomplished using typical cold drawing or hot drawing methods. Biaxial orientation can be accomplished using tenter frame equipment or a double bubble process and may occur before or after the individual layers are brought together. For example, a polyethylene layer can be extrusion coated or laminated onto an oriented polypropylene layer or the polyethylene and polypropylene can be coextruded together into a film then oriented. Likewise, oriented polypropylene could be laminated to oriented polyethylene or oriented polyethylene could be coated onto polypropylene then optionally the combination could be oriented even further. Typically the films are oriented in the Machine Direction (MD) at a ratio of up to 15, preferably between 5 and 7, and in the Transverse Direction (TD) at a ratio of up to 15, preferably 7 to 9. However, in another embodiment, the film is oriented to the same extent in both the MD and TD directions.
- [00160]** The films may vary in thickness depending on the intended application; however, films of a thickness from 1 μm to 50 μm may be suitable. Films intended for packaging are usually from 10 μm to 50 μm thick. The thickness of the sealing layer is typically 0.2 μm to 50 μm . There may be a sealing layer on both the inner and outer surfaces of the film or the sealing layer may be present on only the inner or the outer surface.
- [00161]** In another embodiment, one or more layers may be modified by corona treatment, electron beam irradiation, gamma irradiation, flame treatment, or microwave. In a preferred embodiment, one or both of the surface layers is modified by corona treatment.

ExperimentalTest MethodsGPC-4D Procedure: Molecular Weight and Comonomer Composition Determination by GPC-IR Hyphenated with Multiple Detectors

- 5 **[00162]** Unless otherwise indicated, the distribution and the moments of molecular weight (Mw, Mn, Mw/Mn, etc.), the comonomer content (C₂, C₃, C₆, etc.) are determined by using a high temperature Gel Permeation Chromatography (Polymer Char GPC-IR) equipped with a multiple-channel band-filter based Infrared detector IR5, an 18-angle light scattering detector and a viscometer. Three Agilent PLgel 10-μm Mixed-B LS columns are used to provide
- 10 polymer separation. Aldrich reagent grade 1,2,4-trichlorobenzene (TCB) with 300 ppm antioxidant butylated hydroxytoluene (BHT) is used as the mobile phase. The TCB mixture is filtered through a 0.1-μm Teflon filter and degassed with an online degasser before entering the GPC instrument. The nominal flow rate is 1.0 ml/min and the nominal injection volume is 200 μL. The whole system including transfer lines, columns, and detectors are contained in an
- 15 oven maintained at 145°C. The polymer sample is weighed and sealed in a standard vial with 80-μL flow marker (Heptane) added to it. After loading the vial in the autosampler, polymer is automatically dissolved in the instrument with 8 ml added TCB solvent. The polymer is dissolved at 160°C with continuous shaking for about 1 hour for most PE samples or 2 hour for PP samples. The TCB densities used in concentration calculation are 1.463 g/ml at room
- 20 temperature and 1.284 g/ml at 145°C. The sample solution concentration is from 0.2 to 2.0 mg/ml, with lower concentrations being used for higher molecular weight samples. The concentration (*c*), at each point in the chromatogram is calculated from the baseline-subtracted IR5 broadband signal intensity (*I*), using the following equation: $c = \beta I$, where β is the mass constant. The mass recovery is calculated from the ratio of the integrated area of the
- 25 concentration chromatography over elution volume and the injection mass which is equal to the pre-determined concentration multiplied by injection loop volume. The conventional molecular weight (IR MW) is determined by combining universal calibration relationship with the column calibration which is performed with a series of monodispersed polystyrene (PS) standards ranging from 700 to 10M gm/mole. The MW at each elution volume is calculated
- 30 with following equation:

$$\log M = \frac{\log(K_{PS} / K)}{a+1} + \frac{a_{PS} + 1}{a+1} \log M_{PS},$$

where the variables with subscript “PS” stand for polystyrene while those without a subscript are for the test samples. In this method, $\alpha_{PS} = 0.67$ and $K_{PS} = 0.000175$ while α and K are for other materials as calculated and published in literature (Sun, T. et al. *Macromolecules* 2001, 34, 6812), except that for purposes of the present disclosure, $\alpha = 0.695$ and $K = 0.000579$ for linear ethylene polymers, $\alpha = 0.705$ and $K = 0.0002288$ for linear propylene polymers, $\alpha = 0.695$ and $K = 0.000181$ for linear butene polymers, α is 0.695 and K is $0.000579 \cdot (1 - 0.0087 \cdot w_{2b} + 0.000018 \cdot (w_{2b})^2)$ for ethylene-butene copolymer where w_{2b} is a bulk weight percent of butene comonomer, α is 0.695 and K is $0.000579 \cdot (1 - 0.0075 \cdot w_{2b})$ for ethylene-hexene copolymer where w_{2b} is a bulk weight percent of hexene comonomer, and α is 0.695 and K is $0.000579 \cdot (1 - 0.0077 \cdot w_{2b})$ for ethylene-octene copolymer where w_{2b} is a bulk weight percent of octene comonomer. Concentrations are expressed in g/cm^3 , molecular weight is expressed in $g/mole$, and intrinsic viscosity (hence K in the Mark-Houwink equation) is expressed in dL/g unless otherwise noted.

[00163] The comonomer composition is determined by the ratio of the IR5 detector intensity corresponding to CH_2 and CH_3 channel calibrated with a series of PE and PP homo/copolymer standards whose nominal value are predetermined by NMR or FTIR. In particular, this provides the methyls per 1000 total carbons ($CH_3/1000TC$) as a function of molecular weight. The short-chain branch (SCB) content per 1000TC ($SCB/1000TC$) is then computed as a function of molecular weight by applying a chain-end correction to the $CH_3/1000TC$ function, assuming each chain to be linear and terminated by a methyl group at each end. The weight % comonomer is then obtained from the following expression in which f is 0.3, 0.4, 0.6, 0.8, and so on for C_3 , C_4 , C_6 , C_8 , and so on co-monomers, respectively:

$$w_2 = f * SCB/1000TC.$$

[00164] The bulk composition of the polymer from the GPC-IR and GPC-4D analyses is obtained by considering the entire signals of the CH_3 and CH_2 channels between the integration limits of the concentration chromatogram. First, the following ratio is obtained

$$\text{Bulk IR ratio} = \frac{\text{Area of } CH_3 \text{ signal within integration limits}}{\text{Area of } CH_2 \text{ signal within integration limits}}$$

[00165] Then the same calibration of the CH_3 and CH_2 signal ratio, as mentioned previously in obtaining the $CH_3/1000TC$ as a function of molecular weight, is applied to obtain the bulk $CH_3/1000TC$. A bulk methyl chain ends per 1000TC (bulk $CH_{3end}/1000TC$) is obtained by weight-averaging the chain-end correction over the molecular-weight range. Then

$$w_{2b} = f * \text{bulk } CH_3/1000TC$$

$$\text{bulk SCB/1000TC} = \text{bulk CH3/1000TC} - \text{bulk CH3end/1000TC}$$

and bulk SCB/1000TC is converted to bulk w2 in the same manner as described above.

[00166] The LS detector is the 18-angle Wyatt Technology High Temperature DAWN HELEOSII. The LS molecular weight (M) at each point in the chromatogram is determined by
 5 analyzing the LS output using the Zimm model for static light scattering (*Light Scattering from Polymer Solutions*; Huglin, M. B., Ed.; Academic Press, 1972.):

$$\frac{K_o c}{\Delta R(\theta)} = \frac{1}{MP(\theta)} + 2A_2 c.$$

Here, $\Delta R(\theta)$ is the measured excess Rayleigh scattering intensity at scattering angle θ , c is the polymer concentration determined from the IR5 analysis, A_2 is the second virial coefficient,
 10 $P(\theta)$ is the form factor for a monodisperse random coil, and K_o is the optical constant for the system:

$$K_o = \frac{4\pi^2 n^2 (dn/dc)^2}{\lambda^4 N_A},$$

where N_A is Avogadro's number, and (dn/dc) is the refractive index increment for the system. The refractive index, $n=1.500$ for TCB at 145°C and $\lambda=665$ nm. For analyzing polyethylene
 15 homopolymers, ethylene-hexene copolymers, and ethylene-octene copolymers, $dn/dc=0.1048$ ml/mg and $A_2=0.0015$; for analyzing ethylene-butene copolymers, $dn/dc=0.1048*(1-0.00126*w2)$ ml/mg and $A_2=0.0015$ where $w2$ is weight percent butene comonomer.

MW reported in the Tables below is weight average molecular weight.

20 Density is determined according to ASTM 1505.

Aromatic content is determined by Gas Phase Chromatography as follows:

Scope:

The following multiple headspace GC-MS (SIM) method is addressed to the quantification of trace level of aromatics such as toluene in polymer (such as
 25 polyethylene) samples.

A polymer (such as polyethylene) sample is heated in the headspace autosampler for a time in order to establish the equilibrium between the polymer and its headspace. A fraction of the gas phase is then automatically injected into the capillary GC column. The sample is thermostatted and sampled in two more identical cycles to complete a
 30 multiple headspace extraction (MHE) of the polymer.

The peak areas obtained during the three MHE steps are extrapolated to infinity in order to calculate the polymer's total aromatic (such as toluene) content. Pure standard solutions of the aromatic of interest (such as toluene) at different concentration level were injected, and run under exactly the same conditions.

5 Test LOQ value: ~ 4 ppb

Test duration: 3 hours

Experimental Conditions

Sample preparation:

10 **Sample:** One gram of polymer sample is placed in a vial (Perkin Elmer part number B0104236), and sealed tightly with a headspace crimp cap containing a spring and a PTFE/silicone liner (Perkin Elmer part number B0104242).

15 **External References of toluene:** Four reference solutions of toluene at a final concentration of 1000 ppb, 200 ppb, 20 ppb and 10 ppb are prepared, diluted in the high boiling vacuum pump fluid Inland 45 (100% synthetic aliphatic hydrocarbon). One gram of each reference solution is placed in a headspace vial and run under exactly the same conditions as the sample. Each solution is injected in triplicate.

20 **Blank:** A blank prepared from one gram of the high boiling vacuum pump fluid is injected in the GC-MS under the same conditions. In case of impurity the area of the target toluene is corrected for the corresponding areas of the blank. Injection is performed in triplicate.

Instrument and Test Conditions:

25 All the applications were performed on a system consisting of a headspace autosampler Perkin Elmer Turbomatrix 4 couple with a gas chromatography 7890A Agilent coupled with a single quadrupole mass spectrometer inert MSD 5975C Triple Axis.

Headspace conditions:

Method:	mhe pp 200	
Temp:	oven:	175 °C
	needle:	185 °C
	transfer:	200 °C
Timing:	thermo:	30 min
	pressurize:	3 min
	inject:	0.06 min
	withdraw:	0.5 min
	cycle time:	30.0 min
PPC:	22 psi	
Operation Mode:	MHE # 3*	

*meaning: 3 headspace cycle per sample

GC-conditions:

5 Column: Agilent HP-Ultra 2 P.N. 19091B-115 (Phenyl methyl siloxane stationary phase) 50m x 0.32mm x 0.52 µm + a fragment of 0.17m x 0.1mm uncoated column directed to the MS transfer line.

Operational mode constant flow: 1.8 ml/min

Oven program: from 50°C (5 min) to 120°C at 10°C/min, than to 300 °C at 50°C/min (5 min).

Inlet temperature:	250°C
pressure:	15.5 psi
injection mode:	split/splitless
split ratio:	1:10

10

MS conditions: Electron ionization, in selected ion monitoring mode (SIM) 92 m/z.

Transfer line temperature 260 °C and Ion source 230 °C.

Calculations:

Data to be entered for the reference are:

15

The weight of the reference in grams (gr)

The concentration of the reference component in wtppb

The areas of the toluene peak (areas A_1 , A_2 and A_3 for the first, the second and the third cycle run, respectively)

k , the total area A_{tot} and the response factor, RF , are calculated:

$$k = \frac{\ln A_1 - \ln A_3}{3 - 1} \quad A_{tot} = \frac{A_1}{1 - e^{-k}} \quad RF_{ref} =$$

$$5 \quad \frac{A_{tot}}{\text{weight reference} \cdot \text{conc.ref.comp. (in wtppb)}}$$

Data to be entered for the sample are:

Weight of polymer sample in grams (gr)

The areas of the different volatile component (areas A_1 , A_2 and A_3 for the first, second and the third cycle run, respectively)

10 The concentration of the volatile component in the sample is then calculated as:

$$Wtppb \text{ volatile} = \frac{A_{tot}}{RF_{ref} * \text{weight sample (in gr)}}$$

While the above example is for toluene, the same procedure is applied for other aromatics.

Materials

15 **[00167]** Chemicals: Trimethylaluminum was purchased from Sigma Aldrich (St. Louis, MO) or AkzoNobel and used as obtained, unless stated otherwise. ES70™ silica was purchased from PQ Corporation. ES70-875 is ES70™ silica that has been calcined at 880°C for four hours after being ramped to 880°C according to the following ramp rates.

°C	°C/h	°C
ambient	100	200
200	50	300
300	133	400
400	200	800
800	50	880

20 **[00168]** D100-100 silica support and D70-120A silica were purchased from AGC Chemicals Americas, Inc.

[00169] All solvents were sparged with dry N_2 prior to use. All solvents, except Isopar E, also purchased from Sigma Aldrich, were anhydrous grade and were further treated with activated 3 Angstrom molecular sieves by storing the solvent in a container with 5-10 wt% molecular sieves at least for overnight before use. Isopar E, a high boiling point aliphatic solvent mixture (115°C-140°C boiling range) available from ExxonMobil Chemical Company (Baytown, Texas), was degassed overnight at 110°C under nitrogen flow and stored with

activated 3 angstrom molecular sieves before use. Water used is a lab deionized water. All reactions were performed under an inert nitrogen atmosphere, unless otherwise stated. All deuterated solvents were obtained from Cambridge Isotopes (Cambridge, MA) and dried over 3 Angstrom molecular sieves before use.

- 5 [00170] Equipment: Ace Glass 4L jacketed filter reactor with a Lauda chiller capable of controlling temperature range from -35°C to 165°C.

- [00171] Chemistry: a formula $(Al_4O_3Me_6)_4$ with 1-2 eq additional trimethylaluminum (TMA) served as coordinated TMA and free TMA was the targeted MAO composition. The coordinated TMA and the free TMA in the commercial MAO toluene solution, e.g., Albemarle
10 30% MAO in toluene, are experimentally detected and the experimental evidence strongly suggests that the coordinated TMA and free TMA serve as the major active site and the alkylation agent, respectively (see Luo, Jain, and Harlan, ACS Annual Meeting, Conference Abstracts PMSE 126 and INOR 1169, April 2-6, 2017; Luo, Wu, & Diefenbach, US Patent 9,090,720 (2015); and Sinn, et al, "Formation, Structure, and Mechanism of Oligomeric
15 Methylaluminoxane", in Kaminsky (ed.), *Metalorg. Cat. for Synth. & Polym.*, Springer-Verlag, 1999, pp105). To increase the heat removal efficiency just for the demonstration of this process, this experiment used approx. 3 wt% TMA solution.

- [00172] Supported MAO from 50g silica with about 16 wt% Al (5.9 mmol Al/g sMAO, or 9.1mmol Al/g silica) as the MAO loading target requires 8.2 g (0.456mol) of water and 50g of
20 TMA (0.69mol), an Al:O ratio of 1.5:1 based on the formula $(Al_4O_3Me_6)_4(AlMe_3)_2$. The silica was saturated with the calculated amount (8.2 g) of water by slurring in 500g hexane and stirring with the water overnight in a 1L Celstir reactor. To increase the viscosity of the silica slurry (to prevent fast precipitation during the silica addition), 300 g hexane was removed and replaced with 400 g mineral oil. The reactor jacket temperature was set to -30°C.

25 Example 1 In-Situ Silica Supported MAO Preparation Procedure

1. 1500g of dry hexane (3A molecular sieves overnight) was charged into a 4 L reactor and cooled to -32°C (jacket fluid) with the temperature controller set at -30°C and the hexane temperature stable at about -21°C, at an agitation rate of from 100 rpm to 900 rpm, preferably about 150 rpm, using a 76mm paddle stirrer (Ace Glass PTFE multi-blade 8089-08).
- 30 2. After the filtration cap at the reactor bottom was checked to ensure no leaking, 50.0g of neat TMA was added to the reactor.
3. 8.2 g water saturated silica (ES70-875) 50.0 g in 500 g dry hexane in a 1 L Celstir reactor, after agitating overnight in the dry box, was decanted to allow only 200 g hexane with the silica

and 400 g N₂ purge mineral oil was added to make a viscous slurry to avoid fast silica settlement.

4. The silica slurry was transferred to an addition funnel connected to the 4 L reactor, and the material was added slowly to the TMA solution under 250 rpm, with control of the addition rate slow enough to maintain the reactor internal temperature < -17°C, ~ 1.5 hr (80% reaction time at -19°C to -21°C).

5. After the addition of silica slurry, the agitation was adjusted to 150 rpm, the jacket temperature was increased to 1°C for 30 min, and then adjusted to 40°C for 1 hr.

6. The agitation was stopped and the solvent was removed through the filter under the bottom under vacuum. An ¹H-NMR spectrum was acquired for the filtrate in THF-d₈ (deuterated tetrahydrofuran) and showed no significant MAO but did show TMA.

7. The solid was washed 2 times with 300 g hexane and the wet solid was dried under vacuum overnight. Yield 77 g with solvent residue 1.7 wt% (hexane and mineral oil from THF extraction) or 75.7 g after solvent exclusion. The MAO loading is therefore about 25.7 g, corresponding to an amount of Al of 15.3 wt% (5.6mmol Al/g sMAO or 8.6 mmolAl/g silica based on MAO formula weight of 60g/mol).

Silica Supported MAO Identification

[00173] NMR identification of species extracted with THF for the *in-situ* sMAO formed above is compared with non-*in-situ* supported MAO (sMAO) from the same silica with similar MAO loading (Al = 4.3mmol/g sMAO or about 5.8mmol Al/g silica) and D100-100 silica calcined at 200°C for 3 hours with a higher MAO loading (Al = 7.3mmol/g sMAO).

[00174] FIG. 1a shows that similar to sMAO (FIG. 1b and FIG. 1c, respectively), the *in-situ* supported MAO spectrum (FIG. 1a) also shows AlMe₂⁺(THF)₂ at -0.6ppm (see U.S. Patent No. 8,575,284 for the identification method). The high temperature calcined silica ES70-875 shows significantly higher THF extractable MAO than low temperature calcined silica D100-100 (200°C), i.e., 8.0 wt% vs. 1.3 wt%, respectively, even with a lower MAO loading, due to less -OH groups remaining on the higher temperature calcined silica surface that form less chemically bonded MAO, which becomes THF unextractable. The *in-situ* supported MAO, although with the ES70-875, shows a THF extractable MAO amount of 5.2 wt%, in between the 200°C and 875°C calcined silica derived THF extractables, likely indicating that the high temperature calcined silica, after being saturated with water, has recovered some of the surface -OH groups able to form more chemically bonded MAO from THF extraction and behave like a 400°C-600°C calcined silica. IR spectroscopy did show that the *in-situ* supported MAO

contains more unreacted OH than the regular supported MAO from the same support ES70 after 875°C calcination, as shown in FIG. 2a and FIG. 2b.

Example 2 Heating of In-situ sMAO:

- [00175] Because the IR spectrum of the in-situ supported MAO shows more unreacted OH content than the regular supported MAO, the in-situ supported MAO solid was slurried in Isopar E (higher boiling point aliphatic solvent (ExxonMobil Chemical Company product, boiling point range 113-139°C) and then was heated at 100°C for 3hr. For example, in a 20ml vial took 2.0g of *in-situ* supported MAO from Example 1 and 10.0g Isopar E. The slurry was heated to 100°C for 3hrs and then washed with hexane and dried under vacuum for 2hrs. The solid was analyzed with IR spectroscopy (Fig. 2c) and compared to the in-situ supported MAO without heating (Example 1, FIG. 2a) and showed significantly less IR detectable OH groups.

Example 3 Catalyst Preparation

Example 3-1 Catalyst Preparation Solvent Effects: Toluene vs. Hexane:

Example 3-1-1 Toluene as the solvent:

- [00176] In a 20ml vial, 1.0gm *in-situ* supported MAO ES70-875 from Example 1, 5.0g toluene and 0.014g bispropylcyclopentadienyl hafnium dimethyl (0.6 wt% Hf, Mw: 422.82) were combined. The vial was shaken on a shaker for 1hr, then filtered through a frit, washed with 2x5g toluene and 5g hexane then dried under vacuum for 2hr. Yield: 0.98g

Example 3-1-2 Hexane as the solvent:

- [00177] In a 20ml vial, 1.0g *in-situ* supported MAO ES70-875 from Example 1, 5.0g hexane and 0.014gm bispropylcyclopentadienyl hafnium dimethyl (0.6 wt% Hf, Mw: 422.82) were combined. The vial was shaken on a shaker for 1hr. The slurry was then filtered through a frit, washed with 5g hexane, and dried under vacuum for 2hr. Yield: 0.95g

Example 3-2 Catalyst preparation from heated *in-situ* supported MAO:

- [00178] In a 20ml vial, 1.0g *in-situ* supported MAO ES70-875 heat-treated at 100°C 3hr from Example 2, 5.0g hexane and 0.015gm bispropylcyclopentadienyl hafnium dimethyl (0.6 wt% Hf, Mw: 422.82) were combined. The vial was shaken on a shaker for 1hr. The slurry was then filtered through a frit, washed with 5x2g hexane, and dried under vacuum for 2hr. Yield: 0.96g

- [00179] Example 3-3 Comparative-catalyst preparation from regular supported MAO:

The general preparation includes two different procedures: 1) mixing the metallocene with MAO 30% solution in a 1:100 mol:mol ratio, with MAO loading based on 12-14 wt% Al, for 1-2 hr at ambient temperature. The activated metallocene solution was then

- added to the silica (calcined at 875°C) toluene slurry, e.g., 1g silica with 3g toluene, then the mixture was agitated at ambient temperature for 1-2hr, and the volatiles removed under vacuum with or without heating, e.g., at 40-60°C; and 2) based on the same MAO:metallocene ratio and Al loading on silica, MAO was added to a silica slurry and heated at 80-100°C for 3-4hr
- 5 to form the sMAO, then the metallocene, either in solid form or in toluene slurry form, was added to the sMAO at ambient temperature. The volatiles were removed under vacuum with or without heating, e.g., at 40-60°C. Optionally, the mixture is passed through a frit to remove the toluene solvent and wash with a low boiling point aliphatic solvent before placing under vacuum to improve drying efficiency.
- 10 **[00180]** An example of preparation is as follows: in a 20ml vial, 30% MAO toluene solution (Al = 13.5 wt%, Albemarle product) having 1.28g (6.4mmol Al) was slowly added through a pipette to 1.0g ES-70™ silica (calcined at 875°C) in 4g toluene with constant hand-shake agitation. The mixture was then heat-treated at 100°C for 3hr. After the temperature of the hot mixture was reduced to ambient temperature, 0.019g bispropylcyclopentadienyl hafnium
- 15 dimethyl (0.6 wt% Hf, Mw: 422.82) was added. The vial was shaken on a shaker for 1hr. The slurry was then filtered through a frit, washed with 5x2g hexane, and dried under vacuum for 2hr. Yield: 1.41g

Example 3-4 iPP Metallocene on in-situ sMAO vs. on regular sMAO:

- [00181]** Example 3-4-1 *Rac*-dimethylsilyl(4-(3',5'-di-tert-butyl-4'-methoxy-phenyl)-2-methyl indenyl)(4-*o*-biphenyl 2-hexyl-indenyl)zirconium dichloride on *in-situ* supported MAO from Example 1.
- 20

- [00182]** A 20ml vial was charged with 1.0g supported MAO ES70-875 from Example 1, 5.0g hexane, and 0.073g neat TIBAL (triisobutylaluminum, Aldrich). The vial was shaken for 15 mins. Then the metallocene 0.016g (based on 0.16 wt% Zr) was added to the vial and shaken again for 1hr. The mixture was filtered through a frit, washed with 5g hexane, and dried under vacuum for 2hr. Yield: 0.98gm
- 25

Example 3-4-2 *Rac*-dimethylsilyl(4-(3',5'-di-tert-butyl-4'-methoxy-phenyl)-2-methyl indenyl)(4-*o*-biphenyl 2-hexyl-indenyl)zirconium dichloride on regular supported MAO on D70-120A silica:

- 30 **[00183]** In a 150ml Celstir reactor, 30% MAO toluene solution (Al = 13.5 wt%, Albemarle product) 24.64g (123mmol Al) was slowly added through a pipette to 10.0g D70-120A (600°C) silica in 80g toluene with agitation. The mixture was then heat-treated at 100°C for 3hr. After the temperature of the hot mixture was reduced to ambient temperature, the mixture was filtered

through a frit, washed with 1x30g toluene and 2x30g hexane, and dried under vacuum for overnight. Yield: 18.06g (Al = 20 wt% using MAO formula weight = 60g/mol).

- [00184] To a 150mL Celstir reactor was added 5.0g of supported MAO obtained above and 25g toluene. Then 0.365g neat TIBAL was added and the mixture was stirred for 15 min.
- 5 0.0827g *Rac*-dimethylsilyl(4-(3',5'-di-tert-butyl-4'-methoxy-phenyl)-2-methyl indenyl)(4-*o*-biphenyl 2-hexyl-indenyl)zirconium dichloride was added as a solid. The mixture was stirred for 1hr and the slurry was then filtered through a frit, washed with 50g toluene and 50x2g hexane, and dried under vacuum for overnight. Yield: 5.05g

Example 4 Polymerization tests:

- 10 Example 4-1 1-Hexene polymerization test with ethylenebisindenyl zirconium dichloride:

[00185] A 1-hexene polymerization test was carried out in a 4 mL vial to compare the bispropylcyclopentadienyl hafnium dimethyl derived catalyst activities based on *in-situ* supported MAO vs. supported MAO from a commercial like preparation, respectively.

- [00186] *In-situ* supported MAO :0.10 g; ethylenebisindenyl zirconium dichloride: 0.013 g;
- 15 toluene: 0.50 g.

[00187] Comparative supported MAO: 0.10 g; ethylenebisindenyl zirconium dichloride: 0.013 g; toluene: 0.50 g.

- [00188] The materials above mixed in two vials, respectively, were charged with 1/2 pipette 1-hexene (marked pipette to assure the same volume). The polymerization occurred vigorously
- 20 in both the vials, causing the liquid boiling.

Example 4-2 2L Salt-bed Reactor Gas-Phase Ethylene Polymerization:

- [00189] Catalyst Example 3-1-1, bispropylcyclopentadienyl hafnium dimethyl with *in-situ* supported MAO from Example 1 for standard polyethylene (PE) test in a salt-bed reactor: The catalyst based on 0.6 wt% Hf charge was tested in a 2 L salt-bed reactor for ethylene
- 25 polymerization under the conditions of: 21 mg catalyst, 120 mL H₂ and 2.5 mL hexene charges, H₂:C₂ = 0.5 and C₆:C₂ = 0.1, 60 min, 85°C; Yield: 69.2g; 3249g/g cat/hr activity. Catalysts Example 3-1-2, Example 3-2, and Example 3-3 were run under similar conditions and the results are collected in Table 1 and 2, including repeated catalyst preparation of Example 3-1-1 and Example 3-1-2 (labeled as Example 3-1-1r and Example 3-1-2r).

- 30 Example 4-3 2L Reactor Slurry Phase Propylene Polymerization:

[00190] *Rac*-dimethylsilyl(4-(3',5'-di-tert-butyl-4'-methoxy-phenyl)-2-methyl indenyl)(4-*o*-biphenyl 2-hexyl-indenyl)zirconium dichloride on *in-situ* supported MAO (Example 3-4-1) for isotactic polypropylene (iPP) test: The supported catalyst was prepared based on 0.16 wt%

Zr. iPP polymerization was carried out in a 2 L autoclave reactor. 1250 mL propylene, tri-n-octyl aluminum (TNOAL) as scavenger, dry catalyst 50 mg (intentionally overcharged, which may cause mass transfer limit, but for making sure that enough polymer is made), 20 pounds per square inch (150 mL) H₂, 10min, 70°C, yield: 51 g (activity = (51/0.050)*60/10 = 6,120g/g cat/hr).

[00191] Comparatively, *rac*-dimethylsilyl(4-(3',5'-di-tert-butyl-4'-methoxy-phenyl)-2-methyl indenyl)(4-*o*-biphenyl 2-hexyl-indenyl)zirconium dichloride supported on D70-120A silica with MAO loading of 12 mmol Al/g silica (Example 3-4-2) provided 46g polymer under the same conditions but with a catalyst charge of 0.51 g in a 5 wt% mineral oil slurry, which contains 0.0255 g catalyst. The activity was: (46/0.0255)*(60/10) = 10,823g/g cat/hr. Taking into consideration that a mineral oil slurry of catalyst has higher activity than a dry catalyst and the D70-120A version has significantly higher MAO loading, this experiment indicates that the performance of this *in-situ* supported MAO is reasonably close to a regular supported MAO.

[00192] The polymerization results for the two runs are collected in Table 2.

Table 1. In-Situ sMAO Preparation Reproducibility

Cat ID (r=repeat)	Solvent	Supported MAO Formation	Supported MAO Treatment	Activity (g/g cat/hr)	Silica (g)	Water (g) /AlMe ₃ (g)	Yield (g)
Example 3-1-2	Hexane	-18 to -20 °C	RT 3hr/ no heating	3,009	50.0	8.2/50	75.5
Example 3-2			100°C 3hr in isoPar E	5,560 5,647			
Example 3-1-2r	Hexane	-20 to -21°C	RT 3hr/ no heating	4,408	50.0	8.2/50	73.6
Example 3-2r			100°C 3hr in isoPar E	5,691 5,591			

Table 2. Comparisons of In-situ supported MAO Derived Catalysts vs. Regular MAO

Derived Catalysts

Cat ID	Supported MAO/heating	Cat Prep Solvent	PE/PP	Al (wt%)/ Hf or Zr (wt) ^a	Activity (g/g cat/hr)	Mw (g/mol)	Mw/Mn
Example 3-1-1	In-situ/no	Toluene	PE	15/0.6 (Hf)	3,249	NA	NA
Example 3-1-2	In-situ/no	Hexane	PE	15/0.6 (Hf)	3,009	95,755	3.25
Example 3-2	In-situ/yes	Hexane	PE	15/0.6 (Hf)	5,604 ^b	104,700 ^b	3.38 ^b
Example 3-3	Regular/NA	Toluene	PE	13/0.6 (Hf)	7,694	96,046	3.11
Example 3-4-1	In-situ/no	Hexane	PP	15/0.16 (Zr)	6,100	10,566	3.11
Example 3-4-2	Regular/NA	Toluene	PP	20/0.16 (Zr)	11,040	8,629	3.37

^a: Al wt% is calculated based on the product yield as shown in Example 1 step 7; Hf or Zr wt% is based on the charge ^b: average of two runs

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[00193] Overall, it has been discovered that the presence of saturated hydrocarbons (such as isopentane or hexane) in a catalyst system in combination with elimination of toluene does not interfere with catalyst activity. It has been discovered that neither drying nor the addition of saturated hydrocarbon to catalyst systems of the present disclosure reduces the activity of the catalyst system for polymerization.

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[00194] All documents described herein are incorporated by reference herein, including any priority documents and/or testing procedures to the extent they are not inconsistent with this text. As is apparent from the foregoing general description and the specific embodiments, while some embodiments have been illustrated and described, various modifications can be made without departing from the spirit and scope of the disclosure. Accordingly, it is not intended that the disclosure be limited thereby. Likewise, the term "comprising" is considered synonymous with the term "including." Likewise whenever a composition, an element or a group of elements is preceded with the transitional phrase "comprising", it is understood that we also contemplate the same composition or group of elements with transitional phrases "consisting essentially of," "consisting of", "selected from the group of consisting of," or "is" preceding the recitation of the composition, element, or elements and vice versa.

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