

CATALYST COMPOUNDS AND USE THEREOF

INVENTORS: Garth R. Giesbrecht, Gregory A. Solan, Christopher J. Davies

5 **PRIORITY CLAIM**

[0001] This application claims priority to European Patent Application number EP 08154611.1-1214, filed April 16, 2008. This application also claims priority to and the benefit of USSN 11/962,822 filed December 21, 2007, which is a continuation-in-part of USSN 11/042,217, filed January 25, 2005, which claims the benefit of and priority to USSN
10 60/553,839, filed March 17, 2004.

FIELD OF THE INVENTION

[0002] This invention relates to catalyst compounds useful for polymerization and or oligomerization of unsaturated monomers, such as olefins.

BACKGROUND OF THE INVENTION

15 [0003] As is well known, various processes and catalysts exist for the homopolymerization or copolymerization of olefins. New polymerization catalysts are of interest in the industry because they offer many new opportunities for providing new processes and products to the markets in a cheaper and more efficient manner.

[0004] References of general interest related to the instant invention include: US
20 2006/142497; WO 2000/020427; WO 2001/010875; WO 2003/054038; Polymer International, (2002) 51 (12), 1301-1303; Collection of Czechoslovak Chemical Communications (1988), 63(3), 371-377; and Transition Metal Chemistry (London) (1988) 23 (5), 609-613.

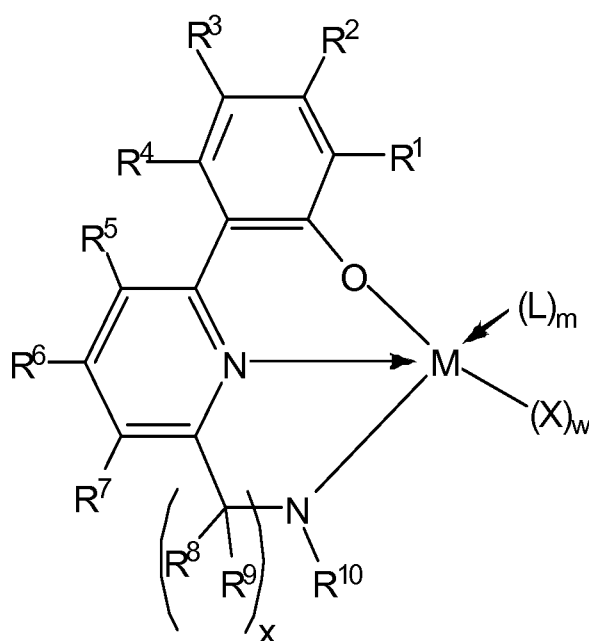
[0005] US 2005/0209420 discloses various Group 4, 5, 6, 7, 8, 9, 10 or 11 transition
25 metal compounds containing neutral, mono- or di-anionic tridentate nitrogen/oxygen based ligands and Group 4, 5, 6, 7, 8, 9, 10 or 11 transition metal compounds containing neutral, bidentate nitrogen/oxygen based ligands that are useful to polymerize olefins, however the activities and molecular weights produced are both low.

[0006] There is a need, therefore, for new polymerization technology, catalysts and
30 products produced therefrom that are based on new transition metal catalyst compounds that can preferably produce higher molecular weights at higher activities.

SUMMARY OF THE INVENTION

[0007] Group 4 catalyst compounds containing di-anionic tridentate nitrogen/oxygen based ligands are provided. The catalyst compounds are useful, with or without activators, to polymerize olefins, particularly α -olefins, or other unsaturated monomers. Systems and processes to oligomerize and/or polymerize one or more unsaturated monomers olefins using the catalyst compound, as well as the oligomers and/or polymers produced therefrom are also provided. For the purposes of this disclosure, " α -olefins" includes ethylene.

[0008] The catalyst compounds can be represented by the following structure:



each X is, independently, a hydride, a halogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl;

w is 2;

each R¹, R², R³, and R⁴ is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, preferably, a C₁ to C₃₀ hydrocarbyl, a C₁ to C₃₀ substituted hydrocarbyl, a C₁ to C₃₀ halocarbyl, or a C₁ to C₃₀ substituted halocarbyl, more preferably a C₁ to C₁₀ hydrocarbyl, a C₁ to C₁₀ substituted hydrocarbyl, a C₁ to C₁₀ halocarbyl, or a C₁ to C₁₀ substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group; or independently, may join together to form a C₄ to C₆₂ cyclic or polycyclic ring structure;

each R^5 , R^6 , and R^7 is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, preferably, a C_1 to C_{30} hydrocarbyl, a C_1 to C_{30} substituted hydrocarbyl, a C_1 to C_{30} halocarbyl, or a C_1 to C_{30} substituted halocarbyl, more preferably a C_1 to C_{10} hydrocarbyl, a C_1 to C_{10} substituted hydrocarbyl, a C_1 to C_{10} halocarbyl, or a C_1 to C_{10} substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group; or independently, may join together to form a C_4 to C_{62} cyclic or polycyclic ring structure;

each R^8 and R^9 , is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, preferably, a C_1 to C_{30} hydrocarbyl, a C_1 to C_{30} substituted hydrocarbyl, a C_1 to C_{30} halocarbyl, or a C_1 to C_{30} substituted halocarbyl, more preferably a C_1 to C_{10} hydrocarbyl, a C_1 to C_{10} substituted hydrocarbyl, a C_1 to C_{10} halocarbyl, or a C_1 to C_{10} substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group;

R^{10} is a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, preferably, a C_1 to C_{30} hydrocarbyl, a C_1 to C_{30} substituted hydrocarbyl, a C_1 to C_{30} halocarbyl, or a C_1 to C_{30} substituted halocarbyl, more preferably a C_1 to C_{10} hydrocarbyl, a C_1 to C_{10} substituted hydrocarbyl, a C_1 to C_{10} halocarbyl, or a C_1 to C_{10} substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group;

x is 1, 2, 3 or 4, preferably, x is 1;

L is a neutral ligand bonded to M that may include molecules such as but not limited to pyridine, acetonitrile, diethyl ether, tetrahydrofuran, dimethylaniline, trimethylamine, tributylamine, trimethylphosphine, triphenylphosphine, lithium chloride, ethylene, propylene, butene, octene, styrene, and the like;

M is a group 4 metal, preferably Hf, Zr or Ti; and

m is 0, 1 or 2 and indicates the absence or presence of L.

In a preferred embodiment, R^1 is not hydrogen, preferably R^1 is phenyl or substituted phenyl.

In a preferred embodiment, R^8 is phenyl or substituted phenyl. In a preferred embodiment,

R^1 is phenyl or substituted phenyl and R^8 is phenyl or substituted phenyl, and preferably M is

Zr.

BRIEF DESCRIPTION OF DRAWINGS

[0009] Figure 1 depicts an X-ray crystal structure of 6-(5'-methyl-2'-hydroxyphenyl)-2-(1'-(2,6-diisopropylanilido)ethyl)-pyridine.

[0010] Figure 2 depicts an X-ray crystal structure of 14c-ZrBz₂, or [6-(2'-hydroxy-3'-phenyl-5'-tert-butylphenyl)-2-(1'-(2,6-diisopropyl anilido) (2-isopropylbenzyl)pyridine]zirconium (IV)dibenzyl.

DEFINITIONS

5 [0011] In the structures depicted throughout this specification and the claims, a solid line indicates a bond, and an arrow indicates that the bond may be dative.

[0012] As used herein, the new notation for the Periodic Table Groups is used as described in CHEMICAL AND ENGINEERING NEWS, 63(5), 27 (1985).

[0013] Neutral ligands are defined as ligands that are neutral, with respect to charge, when formally removed from the metal in their closed shell electronic state. Neutral ligands contain at least one lone pair of electrons, pi-bond or sigma bond that are capable of binding to the transition metal. Neutral ligands may also be polydentate when more than one Neutral ligand is connected via a bond or a hydrocarbyl, substituted hydrocarbyl or a functional group tether. A Neutral ligand may be a substituent of another metal complex, either the same or
10 different, such that multiple complexes are bound together.

[0014] Anionic ligands are defined as ligands that are anionic, with respect to charge, when formally removed from the metal in their closed shell electronic state. Anionic ligands include hydride, halide, hydrocarbyl, substituted hydrocarbyl or functional group. Non-limiting examples of anionic ligands include hydride, fluoride, chloride, bromide, iodide, alkyl, aryl, alkenyl, alkynyl, allyl, benzyl, acyl, trimethylsilyl. Anionic ligands may also be polydentate when more than one anionic ligand is connected via a bond or a hydrocarbyl, substituted hydrocarbyl or a functional group tether. An anionic ligand may be a substituent of another metal complex, either the same or different, such that multiple complexes are bound together. A mono-anionic ligand is defined to be an anionic ligand that has a -1
20 charge. A di-anionic ligand is defined to be an anionic ligand that has a -2 charge.

[0015] The terms "hydrocarbyl radical," "hydrocarbyl" and hydrocarbyl group" are used interchangeably throughout this document. Likewise the terms "group" and "substituent" are also used interchangeably in this document. For purposes of this disclosure, "hydrocarbyl radical" is defined to be C₁-C₁₀₀ radicals, that may be linear, branched, or cyclic (aromatic or non-aromatic); and include substituted hydrocarbyl radicals, halocarbyl radicals, and substituted halocarbyl radicals, silylcarbyl radicals, and germylcarbyl radicals as these terms
30 are defined below.

[0016] Substituted hydrocarbyl radicals are radicals in which at least one hydrogen atom has been substituted with 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 non-hydrocarbon atom or group has been inserted within the hydrocarbyl radical, such as
 5 O, S, Se, Te, NR^* , PR^* , AsR^* , SbR^* , BR^* , SiR^*_2 , GeR^*_2 , SnR^*_2 , PbR^*_2 and the like, where R^* is independently a hydrocarbyl or halocarbyl radical.

[0017] A substituted phenyl is a phenyl group where one or more hydrogens has been replaced by a hydrocarbyl group, a substituted hydrocarbyl group, a halogen, a halocarbyl group or a substituted halocarbyl group.

10 [0018] Halocarbyl radicals are radicals in which one or more hydrocarbyl hydrogen atoms have been substituted with at least one halogen (e.g. F, Cl, Br, I) or halogen-containing group (e.g. CF_3).

[0019] Substituted halocarbyl radicals are radicals in which at least one halocarbyl hydrogen or halogen atom has been substituted with at least one functional group such as
 15 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 non-carbon atom or group has been inserted within the halocarbyl radical such as O, S, Se, Te, NR^* , PR^* , AsR^* , SbR^* , BR^* , SiR^*_2 , GeR^*_2 , SnR^*_2 , PbR^*_2 and the like where R^* is independently a hydrocarbyl or halocarbyl radical provided that at least one halogen atom remains on the original halocarbyl radical.

20 [0020] Silylcarbyl radicals (also called silylcarbyls) are groups in which the silyl functionality is bonded directly to the indicated atom or atoms. Examples include SiH_3 , SiH_2R^* , SiHR^*_2 , SiR^*_3 , $\text{SiH}_2(\text{OR}^*)$, $\text{SiH}(\text{OR}^*)_2$, $\text{Si}(\text{OR}^*)_3$, $\text{SiH}_2(\text{NR}^*_2)$, $\text{SiH}(\text{NR}^*_2)_2$, $\text{Si}(\text{NR}^*_2)_3$, and the like where R^* is independently a hydrocarbyl or halocarbyl radical as defined above and two or more R^* may join together to form a substituted or unsubstituted
 25 saturated, partially unsaturated or aromatic cyclic or polycyclic ring structure.

[0021] Germylcarbyl radicals (also called germylcarbyls) are groups in which the germyl functionality is bonded directly to the indicated atom or atoms. Examples include GeH_3 , GeH_2R^* , GeHR^*_2 , GeR^*_3 , $\text{GeH}_2(\text{OR}^*)$, $\text{GeH}(\text{OR}^*)_2$, $\text{Ge}(\text{OR}^*)_3$, $\text{GeH}_2(\text{NR}^*_2)$, $\text{GeH}(\text{NR}^*_2)_2$, $\text{Ge}(\text{NR}^*_2)_3$, and the like where R^* is independently a hydrocarbyl or halocarbyl radical as
 30 defined above and two or more R^* may join together to form a substituted or unsubstituted saturated, partially unsaturated or aromatic cyclic or polycyclic ring structure.

[0022] Polar radicals or polar groups are groups in which the heteroatom functionality is bonded directly to the indicated atom or atoms. They include heteroatoms of groups 1-17 of

the periodic table either alone or connected to other elements by covalent or other interactions such as ionic, van der Waals forces, or hydrogen bonding. Examples of functional groups include carboxylic acid, acid halide, carboxylic ester, carboxylic salt, carboxylic anhydride, aldehyde and their chalcogen (Group 14) analogues, alcohol and phenol, ether, peroxide and hydroperoxide, carboxylic amide, hydrazide and imide, amidine and other nitrogen analogues of amides, nitrile, amine and imine, azo, nitro, other nitrogen compounds, sulfur acids, selenium acids, thiols, sulfides, sulfoxides, sulfones, phosphines, phosphates, other phosphorus compounds, silanes, boranes, borates, alanes, aluminates. Functional groups may also be taken broadly to include organic polymer supports or inorganic support material such as alumina, and silica. Preferred examples of polar groups include NR^*_2 , OR^* , SeR^* , TeR^* , PR^*_2 , AsR^*_2 , SbR^*_2 , SR^* , BR^*_2 , SnR^*_3 , PbR^*_3 and the like where R^* is independently a hydrocarbyl, substituted hydrocarbyl, halocarbyl or substituted halocarbyl radical as defined above and two R^* may join together to form a substituted or unsubstituted saturated, partially unsaturated or aromatic cyclic or polycyclic ring structure.

[0023] In some embodiments, the hydrocarbyl radical is independently selected from methyl, ethyl, ethenyl and isomers of propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, pentadecyl, hexadecyl, heptadecyl, octadecyl, nonadecyl, eicosyl, heneicosyl, docosyl, tricosyl, tetracosyl, pentacosyl, hexacosyl, heptacosyl, octacosyl, nonacosyl, triacontyl, propenyl, butenyl, pentenyl, hexenyl, heptenyl, octenyl, nonenyl, decenyl, undecenyl, dodecenyl, tridecenyl, tetradecenyl, pentadecenyl, hexadecenyl, heptadecenyl, octadecenyl, nonadecenyl, eicosenyl, heneicosenyl, docosenyl, tricosenyl, tetracosenyl, pentacosenyl, hexacosenyl, heptacosenyl, octacosenyl, nonacosenyl, triacontenyl, propynyl, butynyl, pentynyl, hexynyl, heptynyl, octynyl, nonynyl, decynyl, undecynyl, dodecynyl, tridecynyl, tetradecynyl, pentadecynyl, hexadecynyl, heptadecynyl, octadecynyl, nonadecynyl, eicosynyl, heneicosynyl, docosynyl, tricosynyl, tetracosynyl, pentacosynyl, hexacosynyl, heptacosynyl, octacosynyl, nonacosynyl, and triacontynyl. Also included are isomers of saturated, partially unsaturated and aromatic cyclic structures wherein the radical may additionally be subjected to the types of substitutions described above. Examples include phenyl, methylphenyl, benzyl, methylbenzyl, naphthyl, cyclohexyl, cyclohexenyl, methylcyclohexyl, and the like. For this disclosure, when a radical is listed, it indicates that radical type and all other radicals formed when that radical type is subjected to the substitutions defined above. Alkyl, alkenyl and alkynyl radicals listed include all isomers including where appropriate cyclic isomers, for example, butyl includes *n*-butyl, 2-

methylpropyl, 1-methylpropyl, *tert*-butyl, and cyclobutyl (and analogous substituted cyclopropyls); pentyl includes n-pentyl, cyclopentyl, 1-methylbutyl, 2-methylbutyl, 3-methylbutyl, 1-ethylpropyl, and neopentyl (and analogous substituted cyclobutyls and cyclopropyls); butenyl includes E and Z forms of 1-butenyl, 2-butenyl, 3-butenyl, 1-methyl-
 5 1-propenyl, 1-methyl-2-propenyl, 2-methyl-1-propenyl and 2-methyl-2-propenyl (and cyclobutenyls and cyclopropenyls). Cyclic compound having substitutions include all isomer forms, for example, methylphenyl would include ortho-methylphenyl, meta-methylphenyl and para-methylphenyl; dimethylphenyl would include 2,3-dimethylphenyl, 2,4-dimethylphenyl, 2,5-dimethylphenyl, 2,6-diphenylmethyl, 3,4-dimethylphenyl, and 3,5-
 10 dimethylphenyl.

[0024] In the context of this document, "homopolymerization" would produce a polymer made from one monomer. For example, homopolymerization of propylene would produce homopolypropylene. Homopolymerization of ethylene would produce homopolyethylene. It should be noted, however, that some of the catalysts of this invention homopolymerize
 15 ethylene or propylene to non-traditional "polyethylene" and "polypropylene" structures, respectively. Likewise, "copolymerization" would produce polymers with more than one monomer type. For example, ethylene copolymers include polymers of ethylene with α -olefins, cyclic olefins and diolefins, vinylaromatic olefins, α -olefinic diolefins, substituted α -olefins, and/or acetylenically unsaturated monomers. Non-limiting examples of α -olefins
 20 include propylene, 1-butene, 1-pentene, 1-hexene, 1-heptene, 1-octene, 1-nonene, 1-decene, 1-undecene 1-dodecene, 1-tridecene, 1-tetradecene, 1-pentadecene, 1-hexadecene, 1-heptadecene, 1-octadecene, 1-nonadecene, 1-eicosene, 1-heneicosene, 1-docosene, 1-tricosene, 1-tetracosene, 1-pentacosene, 1-hexacosene, 1-heptacosene, 1-octacosene, 1-nonacosene, 1-triacontene, 4-methyl-1-pentene, 3-methyl-1-pentene, 5-methyl-1-nonene,
 25 3,5,5-trimethyl-1-hexene, vinylcyclohexane, and vinylnorbornane. Non-limiting examples of cyclic olefins and diolefins include cyclobutene, cyclopentene, cyclohexene, cycloheptene, cyclooctene, cyclononene, cyclodecene, norbornene, 4-methylnorbornene, 2-methylcyclopentene, 4-methylcyclopentene, vinylcyclohexane, norbornadiene, dicyclopentadiene, 5-ethylidene-2-norbornene, vinylcyclohexene, 5-vinyl-2-norbornene, 1,3-
 30 divinylcyclopentane, 1,2-divinylcyclohexane, 1,3-divinylcyclohexane, 1,4-divinylcyclohexane, 1,5-divinylcyclooctane, 1-allyl-4-vinylcyclohexane, 1,4-diallylcyclohexane, 1-allyl-5-vinylcyclooctane, and 1,5-diallylcyclooctane. Non-limiting

examples of vinylaromatic olefins include styrene, *para*-methylstyrene, *para*-*t*-butylstyrene, vinylnaphthylene, vinyltoluene, and divinylbenzene. Non-limiting examples of α -olefinic dienes include 1,4-hexadiene, 1,5-hexadiene, 1,5-heptadiene, 1,6-heptadiene, 6-methyl-1,6-heptadiene, 1,7-octadiene, 7-methyl-1,7-octadiene, 1,9-decadiene, 1,11-dodecene, 1,13-tetradecene and 9-methyl-1,9-decadiene. Substituted α -olefins (also called functional group containing α -olefins) include those containing at least one non-carbon Group 13 to 17 atom bound to a carbon atom of the substituted α -olefin where such substitution if silicon may be adjacent to the double bond or terminal to the double bond, or anywhere in between, and where inclusion of non-carbon and –silicon atoms such as for example B, O, S, Se, Te, N, P, Ge, Sn, Pb, As, F, Cl, Br, or I, are contemplated, where such non-carbon or –silicon moieties are sufficiently far removed from the double bond so as not to interfere with the coordination polymerization reaction with the catalyst and so to retain the generally hydrocarbyl characteristic. By being sufficiently far removed from the double bond we intend that the number of carbon atoms, or the number of carbon and silicon atoms, separating the double bond and the non-carbon or –silicon moiety may be 6 or greater, e.g. 7, or 8, or 9, or 10, or 11, or 12, or 13, or 14 or more. The number of such carbon atoms, or carbon and silicon atoms, is counted from immediately adjacent to the double bond to immediately adjacent to the non-carbon or –silicon moiety. Examples include allyltrimethylsilane, divinylsilane, 8,8,8-trifluoro-1-octene, 8-methoxyoct-1-ene, 8-methylsulfanyloct-1-ene, 8-dimethylaminoct-1-ene, or combinations thereof. The use of functional group-containing α -olefins where the functional group is closer to the double bond is also within the scope of embodiments of the invention when such olefins may be incorporated in the same manner as are their α -olefin analogs. See, “Metallocene Catalysts and Borane Reagents in The Block/Graft Reactions of Polyolefins”, T.C. Chung, *et al*, *Polym. Mater. Sci. Eng.*, v. 73, p. 463 (1995), and the masked α -olefin monomers of US 5,153,282. Such monomers permit the preparation of both functional-group containing copolymers capable of subsequent derivatization, and of functional macromers which may be used as graft and block type polymeric segments. All documents cited herein are incorporated by reference for purposes of all jurisdictions where such practice is allowed. Copolymerization can also incorporate α -olefinic macromonomers of up to 2000 mer units.

[0025] For purposes of this disclosure, the term oligomer refers to compositions having 2-75 mer units and the term polymer refers to compositions having 76 or more mer units. A

mer is defined as a unit of an oligomer or polymer that originally corresponded to the monomer(s) used in the oligomerization or polymerization reaction. For example, the mer of polyethylene would be ethylene.

[0026] The terms "catalyst" and "catalyst compound" are defined to mean a compound
5 capable of initiating catalysis. A catalyst compound may be used by itself to initiate catalysis or may be used in combination with an activator to initiate catalysis. When the catalyst compound is combined with an activator to initiate catalysis, the catalyst compound is often referred to as a pre-catalyst or catalyst precursor. The term "catalyst system" is defined to mean: 1) a catalyst precursor/activator pair, and or 2) a catalyst compound capable of
10 initiating catalysis without an activator. When "catalyst system" is used to describe such a pair before activation, it means the unactivated catalyst (pre-catalyst) together with an activator and, optionally, a co-activator. When it is used to describe such a pair after activation, it means the activated catalyst and the activator or other charge-balancing moiety.

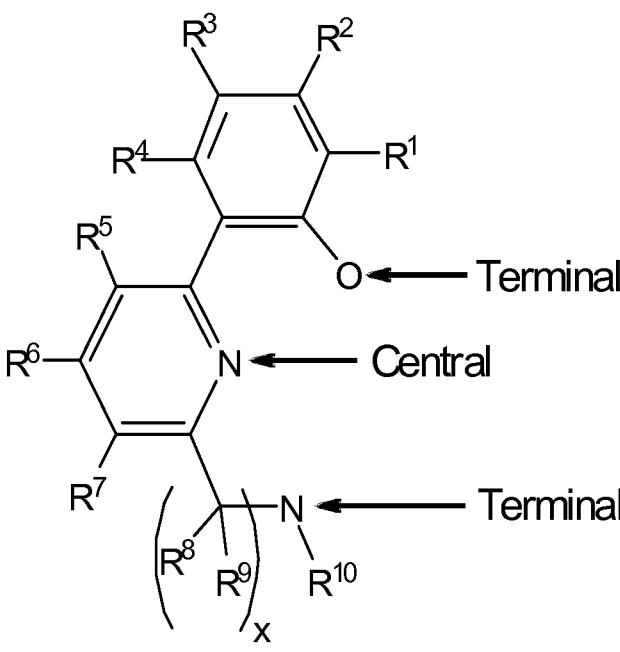
[0027] The catalyst compound may be neutral as in a pre-catalyst or a catalyst system not
15 requiring an activator, or may be a charged species with a counter ion as in an activated catalyst system.

[0028] The terms "activator" and "cocatalyst" are used interchangeably herein. A scavenger is a compound that is typically added to facilitate oligomerization or polymerization by scavenging impurities. Some scavengers may also act as activators and
20 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. In some embodiments a co-activator can be pre-mixed with the catalyst compound to form an alkylated catalyst compound, also referred to as an alkylated invention compound.

[0029] Noncoordinating anion (NCA) is defined to mean an anion either that does not
25 coordinate to the catalyst metal cation or that does coordinate to the metal cation, but only weakly. An NCA coordinates weakly enough that a neutral Lewis base, such as an olefinically or acetylenically unsaturated monomer can displace it from the catalyst center. Any metal or metalloid that can form a compatible, weakly coordinating complex may be used or contained in the noncoordinating anion. Suitable metals include, but are not limited
30 to, aluminum, gold, and platinum. Suitable metalloids include, but are not limited to, boron, aluminum, phosphorus, and silicon.

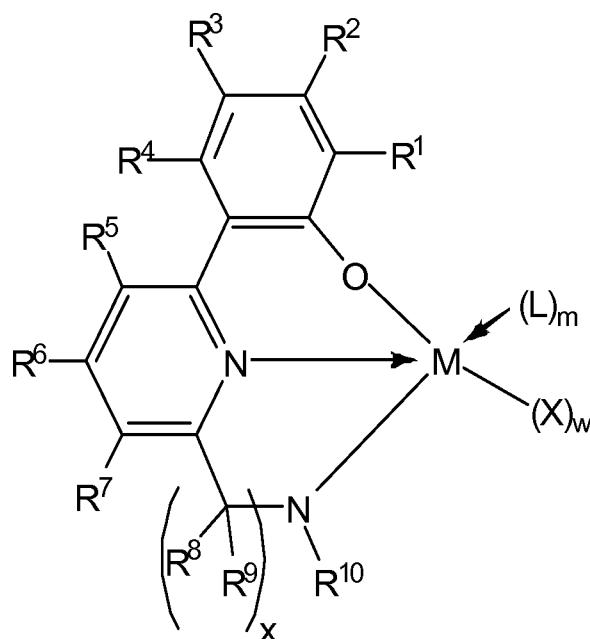
[0030] A stoichiometric activator can be either neutral or ionic. The terms ionic activator, and stoichiometric ionic activator can be used interchangeably. Likewise, the terms neutral stoichiometric activator, and Lewis acid activator can be used interchangeably.

[0031] For purposes of this invention and the claims thereto, in describing a ligand, a terminal nitrogen atom, is a nitrogen atom that is indirectly bonded to only one other nitrogen atom. A central nitrogen atom is a nitrogen atom that is indirectly bonded to at least one other nitrogen atom and at least one oxygen atom. A terminal oxygen atom is an oxygen atom that is indirectly bonded to only the central nitrogen atom. An example is illustrated below:



DETAILED DESCRIPTION OF THE INVENTION

[0032] This invention relates to Group 4 dialkyl compounds supported by a phenoxy-pyridyl-amido ("PPA") tridentate ligand. Such compounds exhibit high activities for the polymerization of high molecular weight polyethylene. The catalyst compound can be represented by the following structure:



each X is, independently, a hydride, a halogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl (alternately X may be independently selected from halogen, alkoxide, aryloxy, amide, phosphide, or other anionic ligand when Lewis-acid activators (such as methylalumoxane, aluminum alkyls, alkylaluminum alkoxides) or alkylaluminum halides (capable of donating a hydride, hydrocarbyl, substituted hydrocarbyl, halocarbyl or substituted halocarbyl X ligand to the transition metal component) are used, or when an ionic activator is capable of extracting X, provided that the resulting activated catalyst contains at least one M-H or M-C bond into which an olefin can insert);

w is 2;

each R¹, R², R³, and R⁴ is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, preferably, a C₁ to C₃₀ hydrocarbyl, a C₁ to C₃₀ substituted hydrocarbyl, a C₁ to C₃₀ halocarbyl, or a C₁ to C₃₀ substituted halocarbyl, more preferably a C₁ to C₁₀ hydrocarbyl, a C₁ to C₁₀ substituted hydrocarbyl, a C₁ to C₁₀ halocarbyl, or a C₁ to C₁₀ substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group; or independently, may join together to form a C₄ to C₆₂ cyclic or polycyclic ring structure;

each R⁵, R⁶, and R⁷ is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, preferably, a C₁ to C₃₀ hydrocarbyl, a C₁ to C₃₀ substituted hydrocarbyl, a C₁ to C₃₀ halocarbyl, or a C₁ to C₃₀ substituted

halocarbyl, more preferably a C₁ to C₁₀ hydrocarbyl, a C₁ to C₁₀ substituted hydrocarbyl, a C₁ to C₁₀ halocarbyl, or a C₁ to C₁₀ substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group; or independently, may join together to form a C₄ to C₆₂ cyclic or polycyclic ring structure;

5 each R⁸ and R⁹, is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, preferably, a C₁ to C₃₀ hydrocarbyl, a C₁ to C₃₀ substituted hydrocarbyl, a C₁ to C₃₀ halocarbyl, or a C₁ to C₃₀ substituted halocarbyl, more preferably a C₁ to C₁₀ hydrocarbyl, a C₁ to C₁₀ substituted hydrocarbyl, a C₁ to C₁₀ halocarbyl, or a C₁ to C₁₀ substituted halocarbyl, a halogen, an alkoxide, a sulfide,
10 an amide, a phosphide, a silyl or another anionic heteroatom-containing group;

 R¹⁰ is a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, preferably, a C₁ to C₃₀ hydrocarbyl, a C₁ to C₃₀ substituted hydrocarbyl, a C₁ to C₃₀ halocarbyl, or a C₁ to C₃₀ substituted halocarbyl, more preferably a C₁ to C₁₀ hydrocarbyl, a C₁ to C₁₀ substituted hydrocarbyl, a C₁ to C₁₀ halocarbyl, or a C₁ to
15 C₁₀ substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group;

 x is 1, 2, 3 or 4, preferably, x is 1;

 L is a neutral ligand bonded to M that may include molecules such as but not limited to pyridine, acetonitrile, diethyl ether, tetrahydrofuran, dimethylaniline, trimethylamine,
20 tributylamine, trimethylphosphine, triphenylphosphine, lithium chloride, ethylene, propylene, butene, octene, styrene, and the like;

 M is a group 4 metal, preferably Ti, Zr or Hf; and

 m is 0, 1 or 2 and indicates the absence or presence of L.

[0033] Specific embodiments of the catalyst compound can include any combination of
25 the ligands listed in Table 1 below.

Table 1: Specific ligand combinations

R ¹ , R ² , R ³ , R ⁴	R ⁵ , R ⁶ , R ⁷	R ⁸ , R ⁹	R ¹⁰	X	M	L
hydrogen	hydrogen	hydrogen	hydrogen	chloride	titanium	acetonitrile
methyl	methyl	methyl	methyl	bromide	hafnium	diethyl ether
ethyl	ethyl	ethyl	ethyl	iodide	zirconium	tetrahydrofuran
propyl	propyl	propyl	propyl	methyl		furan
butyl	butyl	butyl	butyl	ethyl		thiofuran
pentyl	pentyl	pentyl	pentyl	propyl		chromane
hexyl	hexyl	hexyl	hexyl	butyl		isochromane
heptyl	heptyl	heptyl	heptyl	pentyl		thiochromane
octyl	octyl	octyl	octyl	hexyl		thioisochromane
nonyl	nonyl	nonyl	nonyl	heptyl		quinuclidine
decyl	decyl	decyl	decyl	octyl		benzofuran

undecyl dodecyl tridecyl tetradecyl octacosyl nonacosyl triacontyl cyclohexyl cyclopentyl cycloheptyl cyclooctyl cyclodecyl cyclododecyl naphthyl phenyl tolyl benzyl phenethyl dimethylphenyl diethylphenyl anthracenyl adamantyl norbornyl CF ₃ NO ₂ <i>t</i> -butyl <i>i</i> -propyl naphthyl fluoride trimethylphenyl methylphenyl ethylphenyl diethylphenyl triethylphenyl propylphenyl dipropylphenyl diisopropyl phenyl tripropylphenyl isopropylphenyl methylethyl phenyl dibutylphenyl butylphenyl	undecyl dodecyl tridecyl tetradecyl octacosyl nonacosyl triacontyl cyclohexyl cyclopentyl cycloheptyl cyclooctyl cyclodecyl cyclododecyl naphthyl phenyl tolyl benzyl phenethyl dimethylphenyl diethylphenyl anthracenyl adamantyl norbornyl CF ₃ NO ₂ <i>t</i> -butyl <i>i</i> -propyl naphthyl fluoride trimethylphenyl methylphenyl ethylphenyl diethylphenyl triethylphenyl propylphenyl dipropylphenyl diisopropyl phenyl tripropylphenyl isopropylphenyl methylethyl phenyl dibutylphenyl butylphenyl	undecyl dodecyl tridecyl tetradecyl octacosyl nonacosyl triacontyl cyclohexyl cyclopentyl cycloheptyl cyclooctyl cyclodecyl cyclododecyl naphthyl phenyl tolyl benzyl phenethyl dimethylphenyl diethylphenyl anthracenyl adamantyl norbornyl CF ₃ NO ₂ <i>t</i> -butyl <i>i</i> -propyl naphthyl fluoride trimethylphenyl methylphenyl ethylphenyl diethylphenyl triethylphenyl propylphenyl dipropylphenyl diisopropyl phenyl tripropylphenyl isopropylphenyl methylethyl phenyl dibutylphenyl butylphenyl	undecyl dodecyl tridecyl tetradecyl octacosyl nonacosyl triacontyl cyclohexyl cyclopentyl cycloheptyl cyclooctyl cyclodecyl cyclododecyl naphthyl phenyl tolyl benzyl phenethyl dimethylphenyl diethylphenyl anthracenyl adamantyl norbornyl CF ₃ NO ₂ <i>t</i> -butyl <i>i</i> -propyl naphthyl fluoride trimethylphenyl methylphenyl ethylphenyl diethylphenyl triethylphenyl propylphenyl dipropylphenyl diisopropyl phenyl tripropylphenyl isopropylphenyl methylethyl phenyl dibutylphenyl butylphenyl	nonyl decyl undecyl dodecyl tridecyl tetradecyl pentadecyl hexadecyl heptadecyl octadecyl nonadecyl eicosyl heneicosyl docosyl tricosyl tetracosyl pentacosyl hexacosyl heptacosyl octacosyl nonacosyl triacontyl hydride phenyl benzyl phenethyl tolyl methoxy ethoxy propoxy butoxy dimethylamido diethylamido methylethyl amido phenoxy benzoxo allyl trimethyl silylmethyl bis(trimethyl silyl)methyl	chromene isobenzofuran isoquinoline oxazole phenanthridine pyran pyridine quinoline selenophene thiophene trimethylamine triethylamine tributylamine dimethylaniline trimethyl phosphine triphenyl phosphine ethylene propylene butene hexene octene cyclohexene vinylcyclo hexene benzene styrene methylstyrene
--	--	--	--	--	--

[0034] In a preferred embodiment, R¹ is not hydrogen, preferably R¹ is phenyl or substituted phenyl. In a preferred embodiment, R⁸ is phenyl or substituted phenyl. In a preferred embodiment, R¹ is phenyl or substituted phenyl and R⁸ is phenyl or substituted phenyl, and preferably M is Zr. Preferred substituents for the substituted phenyl are C₁ to C₂₀ hydrocarbyl groups (including linear, branched and cyclic hydrocarbyl groups) including

methyl, ethyl, propyl, butyl, pentyl, hexyl octyl, nonyl, decyl, dodecyl, phenyl and isomers thereof.

[0035] In another preferred embodiment, the catalyst system used herein has an activity of at least 1000 g/mmol h bar, preferably at least 1400 g/mmol h bar, preferably at least 2000 g/mmol h bar, preferably at least 4000 g/mmol h bar, preferably at least 5000 g/mmol h bar, preferably at least 6000 g/mmol h bar, preferably at least 8000 g/mmol h bar, preferably at least 10,000 g/mmol h bar, preferably at least 11,000 g/mmol h bar.

[0036] In a preferred embodiment the polyethylene produced herein using the catalyst compounds described herein has at least one of the following properties:

- 10 a) a weight average molecular weight (as measured by GPC) of 500,000 g/mol or more, preferably 600,000 g/mol or more, preferably 700,000 g/mol or more, preferably 800,000 g/mol or more, preferably 900,000 g/mol or more, preferably 1,000,000 g/mol or more, preferably 1,250,000 g/mol or more, preferably 1,500,000 g/mol or more, preferably 1,75,000 g/mol or more, preferably 2,000,000 g/mol or more; and or
- 15 b) a melting point (T_m) of 125 °C or more, preferably 130 °C or more, preferably 135 °C or more, preferably 140 °C or more (as measured by DSC); and or
- c) M_w/M_n of less than 5, preferably from greater than 1 to 4.5, preferably from 1.2 to 4.0.

[0037] Molecular weight and molecular weight distribution (M_w/M_n) were characterized using a High Temperature Size Exclusion Chromatograph (Waters Alliance 2000) equipped with a differential refractive index detector (DRI). Three Polymer Laboratories PLgel 10mm Mixed-B columns were used. The nominal flow rate was 1.0 mL/min, and the nominal injection volume was 300 μ L. The various transfer lines, columns and differential refractometer (the DRI detector) were contained in an oven maintained at 145 °C. Polymer solutions were prepared by dissolving the desired amount of dry polymer in the appropriate volume of 1,2,4-trichlorobenzene to yield concentrations ranging from 0.25 to 1.5 mg/mL. The sample mixtures were heated at 160 °C with continuous agitation for ~2 hours. The solution was filtered through a 2 micron stainless steel filter (Polymer Labs) into scintillation vials using a Polymer Labs SP260 Sample Prep Station. The separation efficiency of the column set was calibrated using a series of narrow MWD polystyrene standards (Polymer Laboratories), which reflects the expected MW range for samples and the exclusion limits of the column set. Seventeen individual polystyrene standards, ranging from M_p ~580 to 10,000,000, were used to generate the calibration curve.

[0038] Differential Scanning Calorimetry (DSC) measurements were performed on a Perkin Elmer Pyris 1 instrument to determine the melting point of the polymers. Samples were heated to 200 °C for 10 minutes and then cooled to -20 °C at a rate of 10 °C/min. After being held at this temperature for 10 minutes, they were then heated to 200 °C at a rate of 10 °C/min. Melting points were collected during the heating period.

Activators and Catalyst Activation

[0039] The catalyst compound can be combined with one or more co-catalysts or activators. Activators that can be used include alumoxanes such as methyl alumoxane, modified methyl alumoxane, ethyl alumoxane, *iso*-butyl alumoxane and the like; Lewis acid activators include triphenyl boron, tris-perfluorophenyl boron, tris-perfluorophenyl aluminum and the like; Ionic activators include dimethylanilinium tetrakis perfluorophenyl borate, triphenyl carbonium tetrakis perfluorophenyl borate, dimethylanilinium tetrakis perfluorophenyl aluminate, and the like.

[0040] The alumoxane component useful as an activator typically is an oligomeric aluminum compound represented by the general formula $(R^x-Al-O)_n$, which is a cyclic compound, or $R^x (R^x-Al-O)_n AlR^x_2$, which is a linear compound. In the general alumoxane formula, R^x is independently a C_1 - C_{20} alkyl radical, for example, methyl, ethyl, propyl, butyl, pentyl, isomers thereof, and the like, and “n” is an integer from 1-50. Most preferably, R^x is methyl and “n” is at least 4. Methyl alumoxane and modified methyl alumoxanes are most preferred. For further descriptions see, EP 0 279 586, EP 0 594 218, EP 0 561 476, WO94/10180 and US Pat. Nos. 4,665,208, 4,874,734, 4,908,463, 4,924,018, 4,952,540, 4,968,827, 5,041,584, 5,091,352, 5,103,031, 5,157,137, 5,204,419, 5,206,199, 5,235,081, 5,248,801, 5,329,032, 5,391,793, and 5,416,229.

[0041] When an alumoxane or modified alumoxane is used, the catalyst-precursor-to-activator molar ratio is from about 1:3000 to 10:1; alternatively, 1:2000 to 10:1; alternatively 1:1000 to 10:1; alternatively, 1:500 to 1:1; alternatively 1:300 to 1:1; alternatively 1:200 to 1:1; alternatively 1:100 to 1:1; alternatively 1:50 to 1:1; alternatively 1:10 to 1:1. When the activator is an alumoxane (modified or unmodified), some embodiments select the maximum amount of activator at a 5000-fold molar excess over the catalyst precursor (per metal catalytic site). The preferred minimum activator-to-catalyst-precursor ratio is 1:1 molar ratio.

[0042] Ionic activators (at times used in combination with a co-activator) may be used in the practice of this invention. Preferably, discrete ionic activators such as

[Me₂PhNH][B(C₆F₅)₄], [Ph₃C][B(C₆F₅)₄], [Me₂PhNH][B((C₆H₃-3,5-(CF₃)₂))₄], [Ph₃C][B((C₆H₃-3,5-(CF₃)₂))₄], [NH₄][B(C₆H₅)₄] or Lewis acidic activators such as B(C₆F₅)₃ or B(C₆H₅)₃ can be used. Preferred co-activators, when used, are alumoxanes such as methyl alumoxane, modified alumoxanes such as modified methyl alumoxane, and aluminum alkyls
 5 such as tri-isobutyl aluminum, and trimethyl aluminum.

[0043] An ionizing or stoichiometric activator, neutral or ionic, such as tri(n-butyl) ammonium tetrakis(pentafluorophenyl)borate, a trisperfluorophenyl boron metalloid precursor or a trisperfluoronaphthyl boron metalloid precursor, polyhalogenated heteroborane anions (WO 98/43983), boric acid (U.S. Patent No. 5,942,459) or combination thereof can
 10 also be used. Examples of neutral stoichiometric activators include tri-substituted boron, aluminum, gallium and indium or mixtures thereof. The three substituent groups are each independently selected from alkyls, alkenyls, halogen, substituted alkyls, aryls, arylhalides, alkoxy and halides. Preferably, the three groups are independently selected from halogen, mono or multicyclic (including halosubstituted) aryls, alkyls, and alkenyl compounds and
 15 mixtures thereof, preferred are alkenyl groups having 1 to 20 carbon atoms, alkyl groups having 1 to 20 carbon atoms, alkoxy groups having 1 to 20 carbon atoms and aryl groups having 3 to 20 carbon atoms (including substituted aryls). More preferably, the three groups are alkyls having 1 to 4 carbon groups, phenyl, naphthyl or mixtures thereof. Even more preferably, the three groups are halogenated, preferably fluorinated, aryl groups. Most
 20 preferably, the neutral stoichiometric activator is trisperfluorophenyl boron or trisperfluoronaphthyl boron.

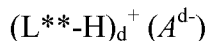
[0044] Ionic stoichiometric activator compounds may contain an active proton, or some other cation associated with, but not coordinated to, or only loosely coordinated to, the remaining ion of the ionizing compound. Such compounds and the like are described in
 25 European publications EP-A-0 570 982, EP-A-0 520 732, EP-A-0 495 375, EP-B1-0 500 944, EP-A-0 277 003 and EP-A-0 277 004, and U.S. Patent Nos. 5,153,157, 5,198,401, 5,066,741, 5,206,197, 5,241,025, 5,384,299 and 5,502,124 and U.S. Patent Application Serial No. 08/285,380, filed August 3, 1994, all of which are herein fully incorporated by reference.

[0045] Ionic catalysts can be prepared by reacting a catalyst compound with an activator,
 30 such as B(C₆F₆)₃, which upon reaction with the hydrolyzable ligand (X') of the catalyst compound forms an anion, such as ([B(C₆F₅)₃(X')])⁻, which stabilizes the cationic transition metal species generated by the reaction. The catalysts can be, and preferably are, prepared

with activator components which are ionic compounds or compositions. However preparation of activators utilizing neutral compounds is also contemplated by this invention.

[0046] Compounds useful as an activator component in the preparation of the ionic catalyst systems include a cation, which is preferably a Bronsted acid capable of donating a proton, and a compatible non-coordinating anion which anion is relatively large (bulky), capable of stabilizing the active catalyst species which is formed when the two compounds are combined and said anion will be sufficiently labile to be displaced by olefinic, diolefinic and acetylenically unsaturated substrates or other neutral Lewis bases such as ethers, nitriles and the like. Two classes of compatible non-coordinating anions have been disclosed in EPA 277,003 and EPA 277,004 published 1988: 1) anionic coordination complexes comprising a plurality of lipophilic radicals covalently coordinated to and shielding a central charge-bearing metal or metalloid core, and 2) anions comprising a plurality of boron atoms such as carboranes, metallocarboranes and boranes.

[0047] In a preferred embodiment, the stoichiometric activators include a cation and an anion component, and may be represented by the following formula:



wherein L^{**} is a neutral Lewis base;

H is hydrogen;

$(L^{**}-H)^+$ is a Bronsted acid

A^{d-} is a non-coordinating anion having the charge d-

d is an integer from 1 to 3.

[0048] The cation component, $(L^{**}-H)_d^+$ may include Bronsted acids such as protons or protonated Lewis bases or reducible Lewis acids capable of protonating or abstracting a moiety, such as an alkyl or aryl, from the pre-catalyst after alkylation.

[0049] The activating cation $(L^{**}-H)_d^+$ may be a Bronsted acid, capable of donating a proton to the alkylated transition metal catalytic precursor resulting in a transition metal cation, including ammoniums, oxoniums, phosphoniums, silyliums, and mixtures thereof, preferably ammoniums of methylamine, aniline, dimethylamine, diethylamine, N-methylaniline, diphenylamine, trimethylamine, triethylamine, N,N-dimethylaniline, methyldiphenylamine, pyridine, p-bromo N,N-dimethylaniline, p-nitro-N,N-dimethylaniline, phosphoniums from triethylphosphine, triphenylphosphine, and diphenylphosphine, oxoniums from ethers such as dimethyl ether, diethyl ether, tetrahydrofuran and dioxane, sulfoniums from thioethers, such as diethyl thioethers and tetrahydrothiophene, and mixtures

thereof. The activating cation $(L^{**}-H)_d^+$ may also be a moiety such as silver, tropylium, carbeniums, ferroceniums and mixtures, preferably carboniums and ferroceniums; most preferably triphenyl carbonium.

[0050] The anion component A^{d-} include those having the formula $[M^{k+}Q_n]^{d-}$ wherein k is an integer from 1 to 3; n is an integer from 2-6; $n - k = d$; M is an element selected from Group 13 of the Periodic Table of the Elements, preferably boron or aluminum, and Q is independently a hydride, bridged or unbridged dialkylamido, halide, alkoxide, aryloxy, hydrocarbyl, substituted hydrocarbyl, halocarbyl, substituted halocarbyl, and halosubstituted-hydrocarbyl radicals, said Q having up to 20 carbon atoms with the proviso that in not more than one occurrence is Q a halide. Preferably, each Q is a fluorinated hydrocarbyl group having 1 to 20 carbon atoms, more preferably each Q is a fluorinated aryl group, and most preferably each Q is a pentafluorophenyl group. Examples of suitable A^{d-} also include diboron compounds as disclosed in U.S. Pat. No. 5,447,895, which is fully incorporated herein by reference.

[0051] Illustrative, but not limiting examples of boron compounds which may be used as an activating cocatalyst in combination with a co-activator in the preparation of the improved catalysts of this invention are tri-substituted ammonium salts such as: trimethylammonium tetraphenylborate, triethylammonium tetraphenylborate, tripropylammonium tetraphenylborate, tri(n-butyl)ammonium tetraphenylborate, tri(tert-butyl)ammonium tetraphenylborate, N,N-dimethylanilinium tetraphenylborate, N,N-diethylanilinium tetraphenylborate, N,N-dimethyl-(2,4,6-trimethylanilinium) tetraphenylborate, trimethylammonium tetrakis(pentafluorophenyl)borate, triethylammonium tetrakis(pentafluorophenyl)borate, tripropylammonium tetrakis(pentafluorophenyl)borate, tri(n-butyl)ammonium tetrakis(pentafluorophenyl)borate, tri(sec-butyl)ammonium tetrakis(pentafluorophenyl)borate, N,N-dimethylanilinium tetrakis(pentafluorophenyl)borate, N,N-diethylanilinium tetrakis(pentafluorophenyl)borate, N,N-dimethyl-(2,4,6-trimethylanilinium) tetrakis(pentafluorophenyl)borate, trimethylammonium tetrakis-(2,3,4,6-tetrafluorophenyl) borate, triethylammonium tetrakis-(2,3,4,6-tetrafluorophenyl)borate, tripropylammonium tetrakis-(2,3,4,6-tetrafluorophenyl)borate, tri(n-butyl)ammonium tetrakis-(2,3,4,6-tetrafluorophenyl)borate, dimethyl(tert-butyl)ammonium tetrakis-(2,3,4,6-tetrafluorophenyl)borate, N,N-dimethylanilinium tetrakis-(2,3,4,6-tetrafluorophenyl)borate, N,N-diethylanilinium tetrakis-(2,3,4,6-tetrafluorophenyl)borate, N,N-dimethyl-(2,4,6-trimethylanilinium) tetrakis-(2,3,4,6-tetrafluorophenyl)borate, trimethylammonium

tetrakis(perfluoronaphthyl)borate, triethylammonium tetrakis(perfluoronaphthyl)borate, tripropylammonium tetrakis(perfluoronaphthyl)borate, tri(*n*-butyl)ammonium tetrakis(perfluoronaphthyl)borate, tri(*tert*-butyl)ammonium tetrakis(perfluoronaphthyl)borate, N,N-dimethylanilinium tetrakis(perfluoronaphthyl)borate, N,N-diethylanilinium tetrakis(perfluoronaphthyl)borate, N,N-dimethyl-(2,4,6-trimethylanilinium) tetrakis(perfluoronaphthyl)borate, trimethylammonium tetrakis(perfluorobiphenyl)borate, triethylammonium tetrakis(perfluorobiphenyl)borate, tripropylammonium tetrakis(perfluorobiphenyl)borate, tri(*n*-butyl)ammonium tetrakis(perfluorobiphenyl)borate, tri(*tert*-butyl)ammonium tetrakis(perfluorobiphenyl)borate, N,N-dimethylanilinium tetrakis(perfluorobiphenyl)borate, N,N-diethylanilinium tetrakis(perfluorobiphenyl)borate, N,N-dimethyl-(2,4,6-trimethylanilinium) tetrakis(perfluorobiphenyl)borate, trimethylammonium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, triethylammonium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, tripropylammonium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, tri(*n*-butyl)ammonium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, tri(*tert*-butyl)ammonium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, N,N-dimethylanilinium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, N,N-diethylanilinium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, N,N-dimethyl-(2,4,6-trimethylanilinium) tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, and dialkyl ammonium salts such as: di-(*iso*-propyl)ammonium tetrakis(pentafluorophenyl)borate, and dicyclohexylammonium tetrakis(pentafluorophenyl)borate; and other salts such as tri(*o*-tolyl)phosphonium tetrakis(pentafluorophenyl)borate, tri(2,6-dimethylphenyl)phosphonium tetrakis(pentafluorophenyl)borate, tropillium tetraphenylborate, triphenylcarbenium tetraphenylborate, triphenylphosphonium tetraphenylborate, triethylsilylium tetraphenylborate, benzene(diazonium)tetraphenylborate, tropillium tetrakis(pentafluorophenyl)borate, triphenylcarbenium tetrakis(pentafluorophenyl)borate, triphenylphosphonium tetrakis(pentafluorophenyl)borate, triethylsilylium tetrakis(pentafluorophenyl)borate, benzene(diazonium) tetrakis(pentafluorophenyl)borate, tropillium tetrakis-(2,3,4,6-tetrafluorophenyl)borate, triphenylcarbenium tetrakis-(2,3,4,6-tetrafluorophenyl)borate, triphenylphosphonium tetrakis-(2,3,4,6-tetrafluorophenyl)borate, triethylsilylium tetrakis-(2,3,4,6-tetrafluorophenyl)borate, benzene(diazonium) tetrakis-(2,3,4,6-tetrafluorophenyl)borate, tropillium tetrakis(perfluoronaphthyl)borate, triphenylcarbenium tetrakis(perfluoronaphthyl)borate, triphenylphosphonium

tetrakis(perfluoronaphthyl)borate, triethylsilylium tetrakis(perfluoronaphthyl)borate,
benzene(diazonium) tetrakis(perfluoronaphthyl)borate, tropillium
tetrakis(perfluorobiphenyl)borate, triphenylcarbenium tetrakis(perfluorobiphenyl)borate,
triphenylphosphonium tetrakis(perfluorobiphenyl)borate, triethylsilylium
5 tetrakis(perfluorobiphenyl)borate, benzene(diazonium) tetrakis(perfluorobiphenyl)borate,
tropillium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, triphenylcarbenium tetrakis(3,5-
bis(trifluoromethyl)phenyl)borate, triphenylphosphonium tetrakis(3,5-
bis(trifluoromethyl)phenyl)borate, triethylsilylium tetrakis(3,5-
bis(trifluoromethyl)phenyl)borate, and benzene(diazonium) tetrakis(3,5-
10 bis(trifluoromethyl)phenyl)borate.

[0052] Most preferably, the ionic stoichiometric activator $(L^{**}-H)_d^+ (A^{d-})$ is N,N-
dimethylanilinium tetrakis(perfluorophenyl)borate, N,N-dimethylanilinium
tetrakis(perfluoronaphthyl)borate, N,N-dimethylanilinium tetrakis(perfluorobiphenyl)borate,
N,N-dimethylanilinium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, triphenylcarbenium
15 tetrakis(perfluoronaphthyl)borate, triphenylcarbenium tetrakis(perfluorobiphenyl)borate,
triphenylcarbenium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, or triphenylcarbenium
tetra(perfluorophenyl)borate.

[0053] Invention catalyst precursors can also be activated with cocatalysts or activators
that comprise non-coordinating anions containing metalloid-free cyclopentadienide ions.
20 These are described in U.S. Patent Publication 2002/0058765 A1, published on 16 May 2002,
and for the instant invention, require the addition of a co-activator to the catalyst pre-cursor.

[0054] The term "non-coordinating anion" (NCA) means an anion that does not
coordinate to the catalyst metal cation or that does coordinate to the metal cation, but only
weakly. An NCA coordinates weakly enough that a neutral Lewis base, such as an
25 olefinically or acetylenically unsaturated monomer can displace it from the catalyst center.
"Compatible" non-coordinating anions are those which are not degraded to neutrality when
the initially formed complex decomposes. Further, the anion will not transfer an anionic
substituent or fragment to the cation so as to cause it to form a neutral catalyst compound and
a neutral by-product from the anion. Non-coordinating anions useful in accordance with this
30 invention are those that are compatible, stabilize the transition metal complex cation in the
sense of balancing its ionic charge at +1, yet retain sufficient lability to permit displacement
by an ethylenically or acetylenically unsaturated monomer during polymerization. These
types of cocatalysts sometimes use scavengers such as but not limited to tri-*iso*-butyl

aluminum, tri-*n*-octyl aluminum, tri-*n*-hexyl aluminum, triethylaluminum or trimethylaluminum.

[0055] Cocatalyst compounds or activator compounds that are initially neutral Lewis acids but form a cationic metal complex and a noncoordinating anion, or a zwitterionic complex upon reaction with the alkylated catalyst compounds can also be used. The alkylated invention compound is formed from the reaction of the catalyst pre-cursor and the co-activator. For example, tris(pentafluorophenyl) boron or aluminum act to abstract a hydrocarbyl ligand to yield an invention cationic transition metal complex and stabilizing noncoordinating anion, see EP-A-0 427 697 and EP-A-0 520 732 for illustrations of analogous Group-4 metallocene compounds. Also, see the methods and compounds of EP-A-0 495 375. For formation of zwitterionic complexes using analogous Group 4 compounds, see U.S. Patents 5,624,878; 5,486,632; and 5,527,929.

[0056] Additional neutral Lewis-acids are known in the art and are suitable for abstracting formal anionic ligands. See in particular the review article by E. Y.-X. Chen and T.J. Marks, "Cocatalysts for Metal-Catalyzed Olefin Polymerization: Activators, Activation Processes, and Structure-Activity Relationships", *Chem. Rev.*, 100, 1391-1434 (2000).

[0057] When the cations of noncoordinating anion precursors are Bronsted acids such as protons or protonated Lewis bases (excluding water), or reducible Lewis acids such as ferrocenium or silver cations, or alkali or alkaline earth metal cations such as those of sodium, magnesium or lithium, the catalyst-precursor-to-activator molar ratio may be any ratio. Combinations of the described activator compounds may also be used for activation.

[0058] When an ionic or neutral stoichiometric activator is used, the catalyst-precursor-to-activator molar ratio is typically from 1:10 to 1:1; 1:10 to 10:1; 1:10 to 2:1; 1:10 to 3:1; 1:10 to 5:1; 1:2 to 1.2:1; 1:2 to 10:1; 1:2 to 2:1; 1:2 to 3:1; 1:2 to 5:1; 1:3 to 1.2:1; 1:3 to 10:1; 1:3 to 2:1; 1:3 to 3:1; 1:3 to 5:1; 1:5 to 1:1; 1:5 to 10:1; 1:5 to 2:1; 1:5 to 3:1; 1:5 to 5:1; 1:1 to 1:1.2. The catalyst-precursor-to-co-activator molar ratio is from 1:100 to 100:1; 1:75 to 75:1; 1:50 to 50:1; 1:25 to 25:1; 1:15 to 15:1; 1:10 to 10:1; 1:5 to 5:1; 1:2 to 2:1; 1:100 to 1:1; 1:75 to 1:1; 1:50 to 1:1; 1:25 to 1:1; 1:15 to 1:1; 1:10 to 1:1; 1:5 to 1:1; 1:2 to 1:1; 1:10 to 2:1.

[0059] Preferred activators and activator/co-activator combinations include methylalumoxane, modified methylalumoxane, mixtures of methylalumoxane with dimethylanilinium tetrakis(pentafluorophenyl)borate or tris(pentafluorophenyl)boron, and

mixtures of trimethyl aluminum with dimethylanilinium tetrakis(pentafluorophenyl)borate or tris(pentafluorophenyl)boron.

[0060] In some embodiments, scavenging compounds are used with stoichiometric activators. Typical aluminum or boron alkyl components useful as scavengers are represented by the general formula R^xJZ_2 where J is aluminum or boron, R^x is a hydrocarbyl group (such as a C1 to C20 alkyl), and each Z is independently R^x or a different univalent anionic ligand such as halogen (Cl, Br, I), alkoxide (OR^x) and the like. Most preferred aluminum alkyls include triethylaluminum, diethylaluminum chloride, tri-*iso*-butylaluminum, tri-*n*-octylaluminum, tri-*n*-hexylaluminum, trimethylaluminum and the like. Preferred boron alkyls include triethylboron. Scavenging compounds may also be alumoxanes and modified alumoxanes including methylalumoxane and modified methylalumoxane.

Supported Catalysts

[0061] The catalyst compound(s) can be supported or non-supported. To prepare uniform supported catalysts, the catalyst or catalyst precursor preferably dissolves in the chosen solvent. The term "uniform supported catalyst" means that the catalyst, or the catalyst precursor and the activator, and or the activated catalyst approach uniform distribution upon the support's accessible surface area, including the interior pore surfaces of porous supports. Some embodiments of supported catalysts prefer uniform supported catalysts; other embodiments show no such preference.

[0062] Invention supported catalyst systems may be prepared by any method effective to support other coordination catalyst systems, effective meaning that the catalyst so prepared can be used for oligomerizing or polymerizing olefin in a heterogeneous process. The catalyst precursor, activator, co-activator if needed, suitable solvent, and support may be added in any order or simultaneously.

[0063] By one method, the activator, dissolved in an appropriate solvent such as toluene may be stirred with the support material for 1 minute to 10 hours. The total solution volume may be greater than the pore volume of the support, but some embodiments limit the total solution volume below that needed to form a gel or slurry (about 90% to 400%, preferably about 100-200% of the pore volume). The mixture is optionally heated from 30-200 °C during this time. The catalyst precursor may be added to this mixture as a solid, if a suitable solvent is employed in the previous step, or as a solution. Or alternatively, this mixture can be filtered, and the resulting solid mixed with a catalyst precursor solution. Similarly, the mixture may be vacuum dried and mixed with a catalyst precursor solution. The resulting

catalyst mixture is then stirred for 1 minute to 10 hours, and the catalyst is either filtered from the solution and vacuum dried or evaporation alone removes the solvent.

[0064] Alternatively, the catalyst precursor and activator may be combined in solvent to form a solution. Then the support is added, and the mixture is stirred for 1 minute to 10
5 hours. The total solution volume may be greater than the pore volume of the support, but some embodiments limit the total solution volume below that needed to form a gel or slurry (about 90% to 400%, preferably about 100-200% of the pore volume). After stirring, the residual solvent is removed under vacuum, typically at ambient temperature and over 10-16 hours. But greater or lesser times and temperatures are possible.

10 [0065] The catalyst precursor may also be supported absent the activator; in that case, the activator (and co-activator if needed) is added to a polymerization process's liquid phase. For example, a solution of catalyst precursor may be mixed with a support material for a period of about 1 minute to 10 hours. The resulting pre-catalyst mixture may be filtered from the solution and dried under vacuum, or evaporation alone removes the solvent. The total
15 catalyst-precursor-solution volume may be greater than the support's pore volume, but some embodiments limit the total solution volume below that needed to form a gel or slurry (about 90% to 400%, preferably about 100-200% of the pore volume).

[0066] Additionally, two or more different catalyst precursors may be placed on the same support using any of the support methods disclosed above. Likewise, two or more activators
20 or an activator and co-activator may be placed on the same support.

[0067] Suitable solid particle supports are typically comprised of polymeric or refractory oxide materials, each being preferably porous. Any support material that has an average particle size greater than 10 μm is suitable for use in this invention. Various embodiments select a porous support material, such as for example, talc, inorganic oxides, inorganic
25 chlorides, for example magnesium chloride and resinous support materials such as polystyrene polyolefin or polymeric compounds or any other organic support material and the like. Some embodiments select inorganic oxide materials as the support material including Group -2, -3, -4, -5, -13, or -14 metal or metalloid oxides. Some embodiments select the catalyst support materials to include silica, alumina, silica-alumina, and their mixtures. Other
30 inorganic oxides may serve either alone or in combination with the silica, alumina, or silica-alumina. These are magnesia, titania, zirconia, and the like. Lewis acidic materials such as montmorillonite and similar clays may also serve as a support. In this case, the support can optionally double as the activator component. But additional activator may also be used.

[0068] The support material may be pretreated by any number of methods. For example, inorganic oxides may be calcined, chemically treated with dehydroxylating agents such as aluminum alkyls and the like, or both.

[0069] As stated above, polymeric carriers will also be suitable in accordance with the invention, see for example the descriptions in WO 95/15815 and U.S. Patent 5,427,991. The methods disclosed may be used with the catalyst complexes, activators or catalyst systems of this invention to adsorb or absorb them on the polymeric supports, particularly if made up of porous particles, or may be chemically bound through functional groups bound to or in the polymer chains.

[0070] Invention catalyst carriers may have a surface area of from 10-700 m²/g, a pore volume of 0.1-4.0 cc/g and an average particle size of 10-500 μm. Some embodiments select a surface area of 50-500 m²/g, a pore volume of 0.5-3.5 cc/g, or an average particle size of 20-200 μm. Other embodiments select a surface area of 100-400 m²/g, a pore volume of 0.8-3.0 cc/g, and an average particle size of 30-100 μm. Invention carriers typically have a pore size of 10-1000 Angstroms, alternatively 50-500 Angstroms, or 75-350 Angstroms.

[0071] Invention catalysts are generally deposited on the support at a loading level of 10-100 micromoles of catalyst precursor per gram of solid support; alternately 20-80 micromoles of catalyst precursor per gram of solid support; or 40-60 micromoles of catalyst precursor per gram of support. But greater or lesser values may be used provided that the total amount of solid catalyst precursor does not exceed the support's pore volume.

[0072] Invention catalysts can be supported for gas-phase, bulk, or slurry polymerization, or otherwise as needed. Numerous support methods are known for catalysts in the olefin polymerization art, particularly alumoxane-activated catalysts; all are suitable for this invention's broadest practice. See, for example, U.S. Patents 5,057,475 and 5,227,440. An example of supported ionic catalysts appears in WO 94/03056. U.S. Patent 5,643,847 and WO 96/04319A describe a particularly effective method. A bulk or slurry process using this invention's supported metal complexes activated with alumoxane can be used for ethylene-propylene rubber as described in U.S. Patents 5,001,205 and 5,229,478. Additionally, those processes suit this invention's catalyst systems. Both polymers and inorganic oxides may serve as supports, as is known in the art. See U.S. Patents 5,422,325, 5,427,991, 5,498,582 and 5,466,649, and international publications WO 93/11172 and WO 94/07928.

Monomers

[0073] The catalyst compounds can be used to polymerize or oligomerize any unsaturated monomer or monomers. Preferred monomers include C₂ to C₁₀₀ olefins, preferably C₂ to C₆₀ olefins, preferably C₂ to C₄₀ olefins preferably C₂ to C₂₀ olefins, preferably C₂ to C₁₂ olefins.

5 In some embodiments preferred monomers include linear, branched or cyclic alpha-olefins, preferably C₂ to C₁₀₀ alpha-olefins, preferably C₂ to C₆₀ alpha-olefins, preferably C₂ to C₄₀ alpha-olefins preferably C₂ to C₂₀ alpha-olefins, preferably C₂ to C₁₂ alpha-olefins. Preferred olefin monomers may be one or more of ethylene, propylene, butene, pentene, hexene, heptene, octene, nonene, decene, dodecene, 4-methylpentene-1, 3-methylpentene-1, 3,5,5-trimethylhexene-1, and 5-ethylnonene-1.

[0074] In another embodiment the polymer produced herein is a copolymer of one or more linear or branched C₃ to C₃₀ prochiral alpha-olefins or C₅ to C₃₀ ring containing olefins or combinations thereof capable of being polymerized by either stereospecific and non-stereospecific catalysts. Prochiral, as used herein, refers to monomers that favor the formation of isotactic or syndiotactic polymer when polymerized using stereospecific catalyst(s).

[0075] Preferred monomers may also include aromatic-group-containing monomers containing up to 30 carbon atoms. Suitable aromatic-group-containing monomers comprise at least one aromatic structure, preferably from one to three, more preferably a phenyl, indenyl, fluorenyl, or naphthyl moiety. The aromatic-group-containing monomer further comprises at least one polymerizable double bond such that after polymerization, the aromatic structure will be pendant from the polymer backbone. The aromatic-group containing monomer may further be substituted with one or more hydrocarbyl groups including but not limited to C₁ to C₁₀ alkyl groups. Additionally two adjacent substitutions may be joined to form a ring structure. Preferred aromatic-group-containing monomers contain at least one aromatic structure appended to a polymerizable olefinic moiety. Particularly preferred aromatic monomers include styrene, alpha-methylstyrene, para-alkylstyrenes, vinyltoluenes, vinylnaphthalene, allyl benzene, and indene, especially styrene, para-methylstyrene, 4-phenyl-1-butene and allyl benzene.

30 [0076] Non aromatic cyclic group containing monomers are also preferred. These monomers can contain up to 30 carbon atoms. Suitable non-aromatic cyclic group containing monomers preferably have at least one polymerizable olefinic group that is either pendant on the cyclic structure or is part of the cyclic structure. The cyclic structure may also be further

substituted by one or more hydrocarbyl groups such as, but not limited to, C₁ to C₁₀ alkyl groups. Preferred non-aromatic cyclic group containing monomers include vinylcyclohexane, vinylcyclohexene, cyclopentadiene, cyclopentene, 4-methylcyclopentene, cyclohexene, 4-methylcyclohexene, cyclobutene, vinyladamantane, norbornene, 5-methylnorbornene, 5-ethylnorbornene, 5-propylnorbornene, 5-butylnorbornene, 5-pentylnorbornene, 5-hexylnorbornene, 5-heptylnorbornene, 5-octylnorbornene, 5-nonylnorbornene, 5-decylnorbornene, 5-phenylnorbornene, vinylnorbornene, ethylidene norbornene, 5,6-dimethylnorbornene, 5,6-dibutylnorbornene and the like.

[0077] Preferred diolefin monomers useful in this invention include any hydrocarbon structure, preferably C₄ to C₃₀, having at least two unsaturated bonds, wherein at least one, typically two, of the unsaturated bonds are readily 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). More preferably, the diolefin monomers are linear di-vinyl monomers, most preferably those containing from 4 to 30 carbon atoms. Examples of preferred dienes include butadiene, pentadiene, hexadiene, heptadiene, octadiene, 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, 1,11-dodecadiene, 1,12-tridecadiene, 1,13-tetradecadiene, and low molecular weight polybutadienes (Mw less than 1000 g/mol). Preferred cyclic dienes include cyclopentadiene, vinylnorbornene, norbornadiene, ethylidene norbornene, divinylbenzene, dicyclopentadiene or higher ring containing diolefins with or without substituents at various ring positions.

[0078] Non-limiting examples of preferred polar unsaturated monomers useful in this invention, particularly with group 4 and 6 metal compounds, include nitro substituted monomers including 6-nitro-1-hexene; amine substituted monomers including N-methylallylamine, N-allylcyclopentylamine, and N-allyl-hexylamine; ketone substituted monomers including methyl vinyl ketone, ethyl vinyl ketone, and 5-hexen-2-one; aldehyde substituted monomers including acrolein, 2,2-dimethyl-4-pentenal, undecylenic aldehyde, and 2,4-dimethyl-2,6-heptadienal; alcohol substituted monomers including allyl alcohol, 7-octen-1-ol, 7-octene-1,2-diol, 10-undecen-1-ol, 10-undecene-1,2-diol, 2-methyl-3-buten-1-ol;

acetal, epoxide and or ether substituted monomers including 4-hex-5-enyl-2,2-dimethyl-
[1,3]dioxolane, 2,2- dimethyl-4-non-8-enyl-[1,3]dioxolane, acrolein dimethyl acetal,
butadiene monoxide, 1,2-epoxy-7-octene, 1,2-epoxy-9-decene, 1,2-epoxy-5-hexene, 2-
methyl-2-vinyloxirane, allyl glycidyl ether, 2,5-dihydrofuran, 2-cyclopenten-1-one ethylene
5 ketal, 11-methoxyundec-1-ene, and 8-methoxyoct-1-ene; sulfur containing monomers
including allyl disulfide; acid and ester substituted monomers including acrylic acid,
vinylacetic acid, 4-pentenoic acid, 2,2-dimethyl-4-pentenoic acid, 6-heptenoic acid, trans-2,4-
pentadienoic acid, 2,6-heptadienoic acid, methyl acrylate, ethyl acrylate, *tert*-butyl acrylate,
n-butyl acrylate, methacrylic acid, methyl methacrylate, ethyl methacrylate, *tert*-butyl
10 methacrylate, *n*-butyl methacrylate, hydroxypropyl acrylate, acetic acid oct-7-enyl ester, non-
8-enoic acid methyl ester, acetic acid undec-10-enyl ester, dodec-11-enoic acid methyl ester,
propionic acid undec-10-enyl ester, dodec-11-enoic acid ethyl ester, and
nonylphenoxypolyethoxy acrylate; siloxy containing monomers including trimethyloct-7-
enyloxy silane, and trimethylundec-10-enyloxy silane, polar functionalized norbornene
15 monomers including 5-norbornene-2-carbonitrile, 5-norbornene-2-carboxaldehyde, 5-
norbornene-2-carboxylic acid, cis-5-norbornene-endo-2,3-dicarboxylic acid, 5-norbornene-
2,2,-dimethanol, cis-5-norbornene-endo-2,3-dicarboxylic anhydride, 5-norbornene-2-endo-3-
endo-dimethanol, 5-norbornene-2-endo-3-exo-dimethanol, 5-norbornene-2-methanol, 5-
norbornene-2-ol, 5-norbornene-2-yl acetate, 1-[2-(5-norbornene-2-yl)ethyl]-3,5,7,9,11,13,15-
20 heptacyclopentylpentacyclo[9.5.1.1^{3,9}.1^{5,15}.1^{7,13}]octasiloxane, 2-benzoyl-5-norbornene, 2-
acetyl-5-norbornene, 7-syn methoxymethyl-5-norbornen-2-one, 5-norbornen-2-ol, and 5-
norbornen-2-yloxy-trimethylsilane, and partially fluorinated monomers including nonafluoro-
1-hexene, allyl-1,1,2,2,-tetrafluoroethyl ether, 2,2,3,3-tetrafluoro-non-8-enoic acid ethyl ester,
1,1,2,2-tetrafluoro-2-(1,1,2,2-tetrafluoro-oct-7-enyloxy)-ethanesulfonyl fluoride, acrylic acid
25 2,2,3,3,4,4,5,5,6,6,7,7,8,8,8-pentadecafluoro-octyl ester, and 1,1,2,2-tetrafluoro-2-
(1,1,2,2,3,3,4,4-octafluoro-dec-9-enyloxy)-ethanesulfonyl fluoride.

[0079] In an embodiment herein, the process described herein is used to produce an
oligomer of any of the monomers listed above. Preferred oligomers include oligomers of any
C₂ to C₂₀ olefins, preferably C₂ to C₁₂ alpha-olefins, most preferably oligomers comprising
30 ethylene, propylene and or butene are prepared. A preferred feedstock for the
oligomerization process is the alpha-olefin, ethylene. But other alpha-olefins, including but
not limited to propylene and 1-butene, may also be used alone or combined with ethylene.
Preferred alpha-olefins include any C₂ to C₄₀ alpha-olefin, preferably and C₂ to C₂₀ alpha-

olefin, preferably any C₂ to C₁₂ alpha-olefin, preferably ethylene, propylene, and butene, most preferably ethylene. Dienes may be used in the processes described herein, preferably alpha-omega-dienes are used alone or in combination with mono-alpha olefins.

[0080] In a preferred embodiment the process described herein may be used to produce
5 homopolymers or copolymers. For the purposes of this invention and the claims thereto a copolymer may comprise two, three, four or more different monomer units. Preferred polymers produced herein include homopolymers or copolymers of any of the above monomers. In a preferred embodiment the polymer is a homopolymer of any C₂ to C₁₂ alpha-olefin. Preferably the polymer is a homopolymer of ethylene or a homopolymer of
10 propylene. In another embodiment the polymer is a copolymer comprising ethylene and one or more of any of the monomers listed above. In another embodiment the polymer is a copolymer comprising propylene and one or more of any of the monomers listed above. In another preferred embodiment the homopolymers or copolymers described, additionally comprise one or more diolefin comonomers, preferably one or more C₄ to C₄₀ diolefins.

15 [0081] In another preferred embodiment the polymer produced herein is a copolymer of ethylene and one or more C₃ to C₂₀ linear, branched or cyclic monomers, preferably one or more C₃ to C₁₂ linear, branched or cyclic alpha-olefins. Preferably the polymer produced herein is a copolymer of ethylene and one or more of propylene, butene, pentene, hexene, heptene, octene, nonene, decene, dodecene, 4-methylpentene-1, 3-methylpentene-1, 3,5,5-
20 trimethylhexene-1, cyclopentene, 4-methylcyclopentene, cyclohexene, and 4-methylcyclohexene.

[0082] In another preferred embodiment the polymer produced herein is a copolymer of propylene and one or more C₂ or C₄ to C₂₀ linear, branched or cyclic monomers, preferably one or more C₂ or C₄ to C₁₂ linear, branched or cyclic alpha-olefins. Preferably the polymer
25 produced herein is a copolymer of propylene and one or more of ethylene, butene, pentene, hexene, heptene, octene, nonene, decene, dodecene, 4-methylpentene-1, 3-methylpentene-1, and 3,5,5-trimethylhexene-1.

[0083] In a preferred embodiment, the polymer produced herein is a homopolymer of norbornene or a copolymer of norbornene and a substituted norbornene, including polar
30 functionalized norbornenes.

[0084] In a preferred embodiment the copolymers described herein comprise at least 50 mole% of a first monomer and up to 50 mole% of other monomers.

[0085] In another embodiment, the polymer comprises a first monomer present at from 40 to 95 mole%, preferably 50 to 90 mole%, preferably 60 to 80 mole%, and a comonomer present at from 5 to 60 mole%, preferably 10 to 40 mole%, more preferably 20 to 40 mole%, and a termonomer present at from 0 to 10 mole%, more preferably from 0.5 to 5 mole%,
5 more preferably 1 to 3 mole%.

[0086] In a preferred embodiment the first monomer comprises one or more of any C₃ to C₈ linear branched or cyclic alpha-olefins, including propylene, butene, (and all isomers thereof), pentene (and all isomers thereof), hexene (and all isomers thereof), heptene (and all isomers thereof), and octene (and all isomers thereof). Preferred monomers include
10 propylene, 1-butene, 1-hexene, 1-octene, cyclopentene, cyclohexene, cyclooctene, hexadiene, cyclohexadiene and the like.

[0087] In a preferred embodiment the comonomer comprises one or more of any C₂ to C₄₀ linear, branched or cyclic alpha-olefins (provided ethylene, if present, is present at 5 mole% or less), including ethylene, propylene, butene, pentene, hexene, heptene, and octene,
15 nonene, decene, undecene, dodecene, hexadecene, butadiene, hexadiene, heptadiene, pentadiene, octadiene, nonadiene, decadiene, dodecadiene, styrene, 3,5,5-trimethylhexene-1, 3-methylpentene-1, 4-methylpentene-1, cyclopentadiene, and cyclohexene.

[0088] In a preferred embodiment the termonomer comprises one or more of any C₂ to C₄₀ linear, branched or cyclic alpha-olefins, (provided ethylene, if present, is present at 5
20 mole% or less), including ethylene, propylene, butene, pentene, hexene, heptene, and octene, nonene, decene, undecene, dodecene, hexadecene, butadiene, hexadiene, heptadiene, pentadiene, octadiene, nonadiene, decadiene, dodecadiene, styrene, 3,5,5-trimethylhexene-1, 3-methylpentene-1, 4-methylpentene-1, cyclopentadiene, and cyclohexene.

[0089] In a preferred embodiment the polymers described above further comprise one or
25 more dienes at up to 10 weight%, preferably at 0.00001 to 1.0 weight%, preferably 0.002 to 0.5 weight%, even more preferably 0.003 to 0.2 weight%, based upon the total weight of the composition. In some embodiments 500 ppm or less of diene is added to the polymerization, preferably 400 ppm or less, preferably or 300 ppm or less. In other embodiments at least 50 ppm of diene is added to the polymerization, or 100 ppm or more, or 150 ppm or more.

30 **Polymerization Processes**

[0090] The catalyst compounds can be used to polymerize and/or oligomerize one or more monomers using any one or more solution, slurry, gas-phase, and high-pressure polymerization processes. The catalyst compound and optional co-catalyst(s), can be

delivered as a solution or slurry, either separately to a reactor, activated in-line just prior to a reactor, or preactivated and pumped as an activated solution or slurry to a reactor. Polymerizations can be carried out in either single reactor operations, in which monomer, comonomers, catalyst/activator/co-activator, optional scavenger, and optional modifiers are added continuously to a single reactor or in series reactor operations, in which the above components are added to each of two or more reactors connected in series. The catalyst components can be added to the first reactor in the series. The catalyst component may also be added to both reactors, with one component being added to first reaction and another component to other reactors. In one preferred embodiment, the pre-catalyst is activated in the reactor in the presence of olefin.

[0091] The catalyst compositions can be used individually or can be mixed with other known polymerization catalysts to prepare polymer blends. Monomer and catalyst selection allows polymer blend preparation under conditions analogous to those using individual catalysts. Polymers having increased MWD for improved processing and other traditional benefits available from polymers made with mixed catalyst systems can thus be achieved.

[0092] One or more scavenging compounds can be used. Here, the term scavenging compound means a compound that removes polar impurities from the reaction environment. These impurities adversely affect catalyst activity and stability. Typically, purifying steps are usually used before introducing reaction components to a reaction vessel. But such steps will rarely allow polymerization without using some scavenging compounds. Normally, the polymerization process will still use at least small amounts of scavenging compounds.

[0093] Typically, the scavenging compound will be an organometallic compound such as the Group-13 organometallic compounds of U.S. Patents 5,153,157, 5,241,025 and WO-A-91/09882, WO-A-94/03506, WO-A-93/14132, and that of WO 95/07941. Exemplary compounds include triethyl aluminum, triethyl borane, tri-*iso*-butyl aluminum, methyl alumoxane, *iso*-butyl alumoxane, and tri-*n*-octyl aluminum. Those scavenging compounds having bulky or C₆-C₂₀ linear hydrocarbyl substituents connected to the metal or metalloid center usually minimize adverse interaction with the active catalyst. Examples include triethylaluminum, but more preferably, bulky compounds such as tri-*iso*-butyl aluminum, tri-*iso*-propyl aluminum, and long-chain linear alkyl-substituted aluminum compounds, such as tri-*n*-hexyl aluminum, tri-*n*-octyl aluminum, or tri-*n*-dodecyl aluminum. When alumoxane is used as the activator, any excess over that needed for activation will scavenge impurities and additional scavenging compounds may be unnecessary. Alumoxanes also may be added in

scavenging quantities with other activators, e.g., methylalumoxane, $[\text{Me}_2\text{HNPh}]^+[\text{B}(\text{pfp})_4]^-$ or $\text{B}(\text{pfp})_3$ (perfluorophenyl = pfp = C_6F_5).

[0094] In terms of polymer density, the polymers capable of production in accordance the invention, can range from about 0.85 to about 0.95, preferably from 0.87 to 0.93, more preferably 0.89 to 0.920. Polymer molecular weights can range from about 50,000 Mn to about 2,000,000 Mn or greater. Molecular weight distributions can range from about 1.1 to about 50.0, with molecular weight distributions from 1.2 to about 5.0 being more typical. Pigments, antioxidants and other additives, as is known in the art, may be added to the polymer.

10 Gas phase polymerization

[0095] Generally, in a fluidized gas bed process 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 can be withdrawn from the fluidized bed and recycled back into the reactor. Simultaneously, polymer product can be 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.)

[0096] The reactor pressure in a gas phase process may vary from about 10 psig (69 kPa) to about 500 psig (3448 kPa), preferably from about 100 psig (690 kPa) to about 500 psig (3448 kPa), preferably in the range of from about 200 psig (1379 kPa) to about 400 psig (2759 kPa), more preferably in the range of from about 250 psig (1724 kPa) to about 350 psig (2414 kPa).

[0097] The reactor temperature in the gas phase process may vary from about 30 °C to about 120 °C, preferably from about 60 °C to about 115 °C, more preferably in the range of from about 70 °C to 110 °C, and most preferably in the range of from about 70 °C to about 95 °C. In another embodiment when high density polyethylene is desired then the reactor temperature is typically between 70 °C and 105 °C.

[0098] The productivity of the catalyst or catalyst system in a gas phase system is influenced by the partial pressure of the main monomer. The preferred mole percent of the main monomer, ethylene or propylene, preferably ethylene, is from about 25 to 90 mole percent and the comonomer partial pressure is in the range of from about 138 kPa to about

517 kPa, preferably about 517 kPa to about 2069 kPa, which are typical conditions in a gas phase polymerization process. Also in some systems the presence of comonomer can increase productivity.

[0099] In a preferred embodiment, the reactor utilized in the present invention is capable of producing more than 500 lbs of polymer per hour (227 Kg/hr) to about 200,000 lbs/hr (90,900 Kg/hr) or higher, preferably greater than 1000 lbs/hr (455 Kg/hr), more preferably greater than 10,000 lbs/hr (4540 Kg/hr), even more preferably greater than 25,000 lbs/hr (11,300 Kg/hr), still more preferably greater than 35,000 lbs/hr (15,900 Kg/hr), still even more preferably greater than 50,000 lbs/hr (22,700 Kg/hr) and preferably greater than 65,000 lbs/hr (29,000 Kg/hr) to greater than 100,000 lbs/hr (45,500 Kg/hr), and most preferably over 100,000 lbs/hr (45,500 Kg/hr).

[00100] Other gas phase processes contemplated by the process of the invention include those described in U.S. Patent Nos. 5,627,242, 5,665,818 and 5,677,375, and European publications EP-A- 0 794 200, EP-A- 0 802 202 and EP-B- 634 421 all of which are herein fully incorporated by reference.

[00101] In another preferred embodiment the catalyst system is in liquid form and is introduced into the gas phase reactor into a resin particle lean zone. For information on how to introduce a liquid catalyst system into a fluidized bed polymerization into a particle lean zone, please see US 5,693,727, which is incorporated by reference herein.

20 **Slurry phase polymerization**

[00102] A slurry polymerization process generally operates between 1 to about 50 atmosphere pressure range (15 psig to 735 psig, 103 kPa to 5068 kPa) or even greater and temperatures in the range 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 catalyst 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.

[00103] In one embodiment, a preferred polymerization technique of the invention is referred to as a particle form polymerization, or a slurry process where the temperature is kept below the temperature at which the polymer goes into solution. Such technique is well known in the art, and described in for instance U.S. Patent No. 3,248,179 which is fully incorporated herein by reference. The preferred temperature in the particle form process is within the range of about 85 °C to about 110 °C. Two preferred polymerization methods for the slurry process are those employing a loop reactor and those utilizing a plurality of stirred reactors in series, parallel, or combinations thereof. Non-limiting examples of slurry processes include continuous loop or stirred tank processes. Also, other examples of slurry processes are described in U.S. Patent No. 4,613,484, which is herein fully incorporated by reference.

[00104] In another embodiment, the slurry process is carried out continuously in a loop reactor. The catalyst, as a slurry in isobutane or as a dry free flowing powder, is injected regularly to the reactor loop, which is itself filled with circulating slurry of growing polymer particles in a diluent of isobutane containing monomer and comonomer. Hydrogen, optionally, may be added as a molecular weight control. The reactor is maintained at a pressure of 3620 kPa to 4309 kPa and at a temperature in the range of about 60 °C to about 104 °C depending on the desired polymer melting characteristics. Reaction heat is removed through the loop wall since much of the reactor is in the form of a double-jacketed pipe. The slurry is allowed to exit the reactor at regular intervals or continuously to a heated low pressure flash vessel, rotary dryer and a nitrogen purge column in sequence for removal of the isobutane diluent and all unreacted monomer and comonomers. The resulting hydrocarbon free powder is then compounded for use in various applications.

[00105] In another embodiment, the reactor used in the slurry process of the invention is capable of and the process of the invention is producing greater than 2000 lbs of polymer per hour (907 Kg/hr), more preferably greater than 5000 lbs/hr (2268 Kg/hr), and most preferably greater than 10,000 lbs/hr (4540 Kg/hr). In another embodiment the slurry reactor used in the process of the invention is producing greater than 15,000 lbs of polymer per hour (6804 Kg/hr), preferably greater than 25,000 lbs/hr (11,340 Kg/hr) to about 100,000 lbs/hr (45,500 Kg/hr).

[00106] In another embodiment in the slurry process of the invention the total reactor pressure is in the range of from 400 psig (2758 kPa) to 800 psig (5516 kPa), preferably 450

psig (3103 kPa) to about 700 psig (4827 kPa), more preferably 500 psig (3448 kPa) to about 650 psig (4482 kPa), most preferably from about 525 psig (3620 kPa) to 625 psig (4309 kPa).

[00107] In yet another embodiment in the slurry process of the invention the concentration of predominant monomer in the reactor liquid medium is in the range of from about 1 to 10
5 weight percent, preferably from about 2 to about 7 weight percent, more preferably from about 2.5 to about 6 weight percent, most preferably from about 3 to about 6 weight percent.

[00108] Another process of the invention is where the process, preferably a slurry or gas phase process is operated in the absence of or essentially free of any scavengers, such as triethylaluminum, trimethylaluminum, tri-*iso*-butylaluminum and tri-*n*-hexylaluminum and
10 diethyl aluminum chloride, dibutyl zinc and the like. This process is described in PCT publication WO 96/08520 and U.S. Patent No. 5,712,352, which are herein fully incorporated by reference.

[00109] In another embodiment the process is run with scavengers. Typical scavengers include trimethyl aluminum, tri-*iso*-butyl aluminum and an excess of alumoxane or modified
15 alumoxane.

Homogeneous, bulk or solution phase polymerization

[00110] The catalysts described herein can be used advantageously in homogeneous solution processes. Generally this involves polymerization in a continuous reactor in which the polymer formed and the starting monomer and catalyst materials supplied, are agitated to
20 reduce or avoid concentration gradients. Suitable processes operate above the melting point of the polymers at high pressures, from 1 to 3000 bar (10-30,000 MPa), in which the monomer acts as diluent or in solution polymerization using a solvent.

[00111] Temperature control in the reactor is obtained by balancing the heat of polymerization and with reactor cooling by reactor jackets or cooling coils to cool the
25 contents of the reactor, auto refrigeration, pre-chilled feeds, vaporization of liquid medium (diluent, monomers or solvent) or combinations of all three. Adiabatic reactors with pre-chilled feeds may also be used. The reactor temperature depends on the catalyst used. In general, the reactor temperature preferably can vary between about 0 °C and about 160 °C, more preferably from about 10 °C to about 140 °C, and most preferably from about 40 °C to
30 about 120 °C. In series operation, the second reactor temperature is preferably higher than the first reactor temperature. In parallel reactor operation, the temperatures of the two reactors are independent. The pressure can vary from about 1 mm Hg to 2500 bar (25,000

MPa), preferably from 0.1 bar to 1600 bar (1-16,000 MPa), most preferably from 1.0 to 500 bar (10-5000MPa).

[00112] Each of these processes may also be employed in single reactor, parallel or series reactor configurations. The liquid processes comprise contacting olefin monomers with the above described catalyst system in a suitable diluent or solvent and allowing said monomers to react for a sufficient time to produce the desired polymers. Hydrocarbon solvents are suitable, both aliphatic and aromatic. Alkanes, such as hexane, pentane, isopentane, and octane, are preferred.

[00113] The process can be carried out in a continuous stirred tank reactor, batch reactor, or plug flow reactor, or more than one reactor operated in series or parallel. These reactors may have or may not have internal cooling and the monomer feed may or may not be refrigerated. See the general disclosure of U.S. patent 5,001,205 for general process conditions. See also, international application WO 96/33227 and WO 97/22639.

Medium and High Pressure Polymerizations

[00114] In the high pressure process for the polymerization of ethylene alone or in combination with C₃ to C₁₀ alpha-olefins and optionally other copolymerizable olefins, the temperature of the medium within which the polymerization reaction occurs is at least 120 °C and preferably above 140 °C and may range to 350 °C, but below the decomposition temperature of said polymer product, typically from 310 °C to 325 °C. Preferably, the polymerization is completed at a temperature within the range of 130 °C to 230 °C. The polymerization is completed at a pressure above 200 bar (20 MPa), and generally at a pressure within the range of 500 bar (50 MPa) to 3500 bar (350 MPa). Preferably, the polymerization is completed at a pressure within the range from 800 bar (80 MPa) to 2500 bar (250 MPa).

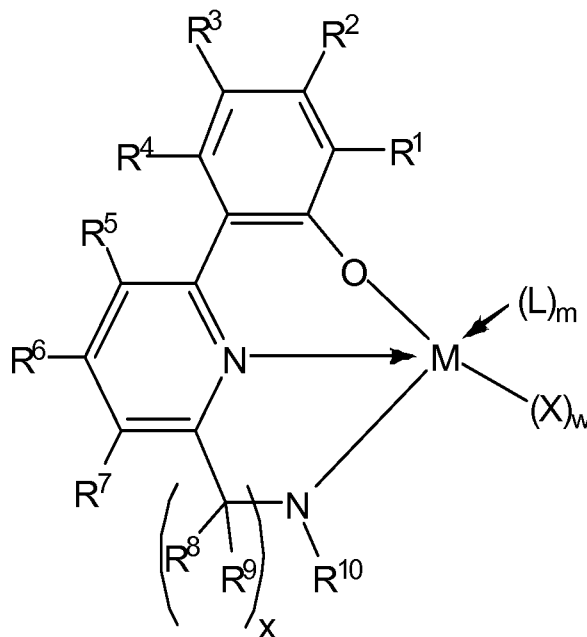
[00115] For medium pressure process, the temperature within which the polymerization reaction occurs is at least 80 °C and ranges from 80 °C to 250 °C, preferably from 100 °C to 220 °C, and should for a given polymer in the reactor, be above the melting point of said polymer so as to maintain the fluidity of the polymer-rich phase. The pressure can be varied between 100 and 1000 bar for ethylene homopolymers and from 30 bar (3 MPa) to 1000 bar (100 MPa), especially 50 bar (5 MPa) to 500 bar (50 MPa) for processes producing ethylene copolymers containing C₃ to C₁₀ olefins and optionally other copolymerizable olefins.

[00116] More recently, polymerization conditions for high pressure and or temperature polymerizations to prepare propylene homopolymers and copolymers of propylene with C₃ to C₁₀ olefins and optionally other copolymerizable olefins have been reported. See US patent applications 60/431,185 filed December 5, 2002; 60/431,077, filed December 5, 2002; and
 5 60/412,541, filed September 20, 2002.

[00117] After polymerization and deactivation of the catalyst, the polymer product can be recovered by processes well known in the art. Any excess reactants may be flashed off from the polymer and the polymer obtained extruded into water and cut into pellets or other suitable comminuted shapes. For general process conditions, see the general disclosure of
 10 U.S. patents 5,084,534, 5,408,017, 6,127,497, 6,255,410, which are incorporated herein by reference.

[00118] In another embodiment, this invention relates to:

1. A transition metal catalyst compound represented by the structure:



15 each X is, independently, a hydride, a halogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl;

w is 2;

each R¹, R², R³, and R⁴ is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an
 20 hydrocarbyl, a halocarbyl, a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an

amide, a phosphide, a silyl or another anionic heteroatom-containing group, or independently, may join together to form a C₄ to C₆₂ cyclic or polycyclic ring structure;

each R⁵, R⁶, and R⁷ is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group, or independently, may join together to form a C₄ to C₆₂ cyclic or polycyclic ring structure;

each R⁸ and R⁹, is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group;

R¹⁰ is a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group;

x is 1, 2, 3 or 4;

L is a neutral ligand bonded to M;

M is titanium, zirconium or hafnium; and

m is 0, 1 or 2.

2. The compound according to paragraph 1, wherein X is selected from the group consisting of fluoride, chloride, bromide, iodide, methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, pentadecyl, hexadecyl, heptadecyl, octadecyl, nonadecyl, eicosyl, heneicosyl, docosyl, tricosyl, tetracosyl, pentacosyl, hexacosyl, heptacosyl, octacosyl, nonacosyl, triacontyl, hydride, phenyl, benzyl, phenethyl, tolyl, trimethylsilylmethyl, bis(trimethylsilyl)methyl, methoxy, ethoxy, propoxy, butoxy, dimethylamido, diethylamido, methylethylamido, phenoxy, benzoxy, and allyl, preferably X is benzyl.

3. The compound according to paragraph 1 or 2, wherein each R¹, R², R³, R⁴, R⁵, R⁶, and R⁷ is, independently, a hydrogen, a C₁ to C₃₀ hydrocarbyl, a C₁ to C₃₀ substituted hydrocarbyl, a C₁ to C₃₀ halocarbyl, a C₁ to C₃₀ substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group; or independently, may join together to form a C₄ to C₆₂ cyclic or polycyclic ring structure.

4. The compound according to any of paragraphs 1 to 3, wherein each R¹, R², R³, R⁴, R⁵, R⁶, and R⁷ is, independently, a hydrogen, a C₁ to C₁₀ hydrocarbyl, a C₁ to C₁₀ substituted

hydrocarbyl, a C₁ to C₁₀ halocarbyl, a C₁ to C₁₀ substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group; or independently, may join together to form a C₄ to C₆₂ cyclic or polycyclic ring structure.

5 5. The compound according to any of paragraphs 1 to 4, wherein each R⁸, R⁹, and R¹⁰ is independently, a hydrogen, a C₁ to C₃₀ hydrocarbyl, a C₁ to C₃₀ substituted hydrocarbyl, a C₁ to C₃₀ halocarbyl, or a C₁ to C₃₀ substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, or a silyl.

10 6. The compound according to any of paragraphs 1 to 4, wherein each R⁸, R⁹, and R¹⁰ is independently, a hydrogen, a C₁ to C₁₀ hydrocarbyl, a C₁ to C₁₀ substituted hydrocarbyl, a C₁ to C₁₀ halocarbyl, or a C₁ to C₁₀ substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, or a silyl.

15 7. The compound according to any of paragraphs 1 to 6, wherein L is selected from the group consisting of pyridine, acetonitrile, diethyl ether, tetrahydrofuran, dimethylaniline, trimethylamine, tributylamine, trimethylphosphine, triphenylphosphine, lithium chloride, ethylene, propylene, butene, octene, and styrene.

8. The compound according to any of paragraphs 1 to 7, wherein x is 1.

20 9. The compound according to claim 1, wherein: R¹ is phenyl; each R², R⁴, R⁵, R⁶, R⁷, and R⁸ is hydrogen; R³ is tert-butyl or methyl; R⁹ is methyl, phenyl, 2-isopropylphenyl, or benzyl; R¹⁰ is 2,6-diisopropylphenyl; each X is benzyl; x is 1, 2 or 3 and m is 0.

25 10. The compound of paragraph 1 wherein, w is 2 and each X is benzyl; each R¹, R², and R⁴ is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group, or independently, may join together to form a C₄ to C₆₂ cyclic or polycyclic ring structure; R³ is methyl or tert-butyl; each R⁵, R⁶, and R⁷ is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group, or independently, may join together to form a C₄ to C₆₂ cyclic or polycyclic ring structure; R⁸ is hydrogen; R⁹ is methyl, phenyl, 2-isopropylphenyl, or benzyl; R¹⁰ is a 2,6-diisopropylphenyl; L is a neutral ligand bonded to M; M is titanium, zirconium or hafnium; x is 1; and m is 0, 1 or 2.

30

11. The compound according to paragraph 1 wherein w is 2 and each X is benzyl; each R^1 , R^2 , and R^4 is a hydrogen or independently, may join together to form a C_4 to C_{62} cyclic or polycyclic ring structure; R^3 is methyl or tert-butyl; each R^5 , R^6 , and R^7 is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, a substituted halocarbyl, or
5 independently, may join together to form a C_4 to C_{62} cyclic or polycyclic ring structure; R^8 is hydrogen; R^9 is methyl, phenyl, 2-isopropylphenyl, or benzyl; R^{10} is a 2,6-diisopropylphenyl; L is a neutral ligand bonded to M; M is titanium, zirconium or hafnium; x is 1; and m is 0, 1 or 2.
12. The compound according to paragraph 1, 9, 10, or 11 wherein M is titanium.
- 10 13. The compound according to paragraph 1, 9, 10, or 11 wherein M is hafnium.
14. The compound according to paragraph 1, 9, 10, or 11 wherein M is zirconium.
15. A process for polymerization comprising contacting ethylene and optionally one or more unsaturated monomers with the catalyst compound of any of paragraphs 1 to 14.
16. The process of claim 15 wherein R^1 is a phenyl or substituted phenyl.
- 15 [00119] The following abbreviations are used through this specification: Me is methyl, Ph is phenyl, Et is ethyl, Pr is propyl, iPr is isopropyl, n-Pr is normal propyl, Bu is butyl, iBu is isobutyl, tBu is tertiary butyl, p-tBu is para-tertiary butyl, nBu is normal butyl, TMS is trimethylsilyl, TIBA is triisobutylaluminum, MAO is methylalumoxane, pMe is para-methyl, Ar* is 2,6-diisopropylaryl, Bz is benzyl, THF is tetrahydrofuran, RT is room temperature,
20 NBS is n-bromosuccinimide, DMF is dimethylformamide, and tol is toluene.

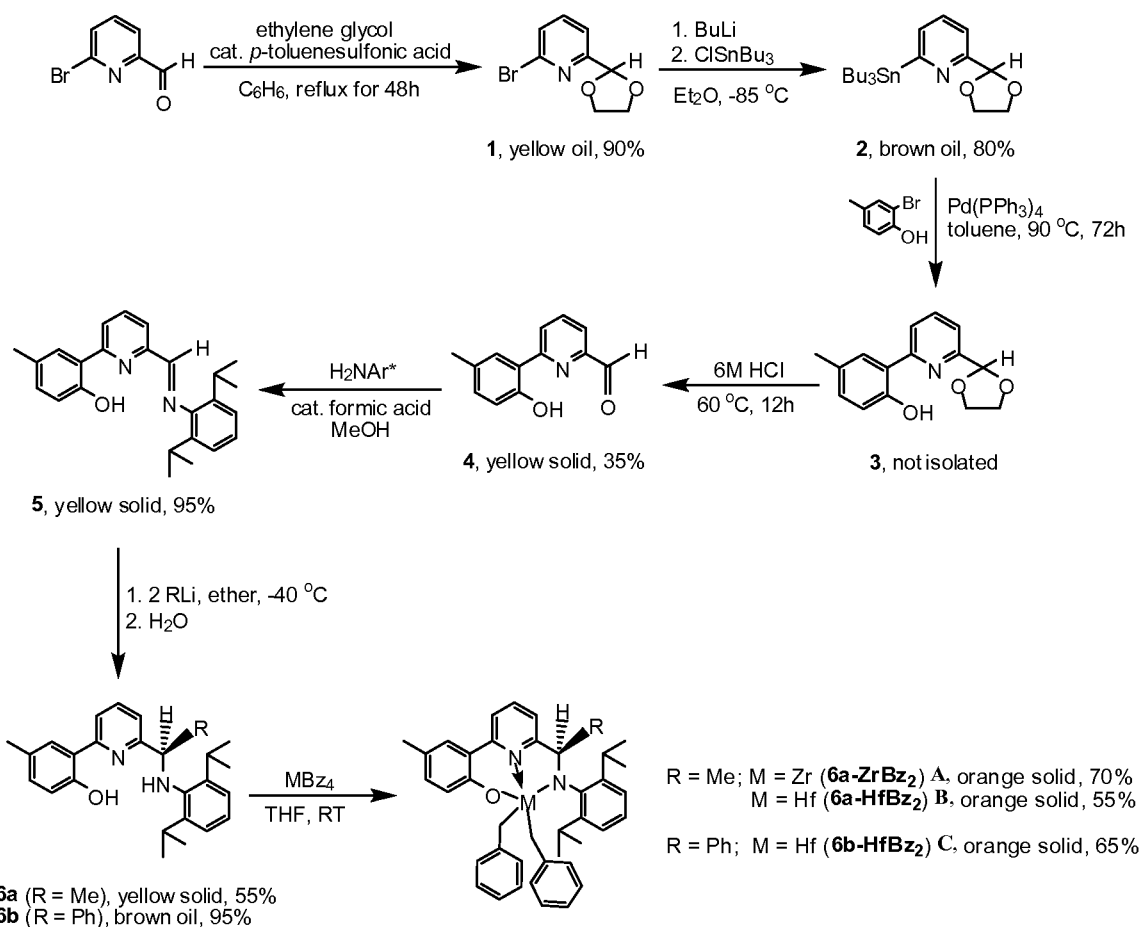
EXAMPLES

- [00120] The foregoing discussion can be further described with reference to the following non-limiting examples. Thirteen illustrative catalyst compounds (A through M), each according to one or more embodiments described, were synthesized and used to polymerize
25 ethylene monomer. All reactions were carried out under a purified nitrogen atmosphere using standard glovebox, high vacuum or Schlenk techniques, unless otherwise noted. All solvents used were anhydrous, de-oxygenated and purified according to known procedures. All starting materials were either purchased from Aldrich and purified prior to use or prepared according to procedures known to those skilled in the art.

Synthesis of Compounds A, B, and C:

- [00121] The syntheses of compounds A, B and C can be represented in the following reaction scheme:

Synthesis of phenoxy-pyridylamino complexes



Synthesis of 6-bromo-2-(1',3'-dioxolan-2'-yl)pyridine (1):

[00122] A solution of 2-acetyl-6-bromopyridine (8.04 g, 43.2 mmol), 1,2-ethanediol (2.89 mL, 51.9 mmol) and *p*-toluenesulfonic acid (0.822 g, 4.32 mmol) in benzene (200 mL) was heated for 48 h under reflux in a Dean-Stark apparatus. The mixture was cooled to room temperature and 300 mL 0.5M aqueous NaOH introduced. The aqueous phase was extracted with benzene (200 mL) and the combined organic extracts washed with 0.5M aqueous NaOH (2 x 100 mL) and water (2 x 100 mL). Following drying of the organic phase, 6-bromo-2-(1',3'-dioxolan-2'-yl)pyridine was isolated as a pale yellow oil. Yield: 8.80 g (90%).

Synthesis of 6-tributylstannyl-2-(1',3'-dioxolan-2'-yl)pyridine (2):

[00123] Under an atmosphere of nitrogen, 6-bromo-2-(1',3'-dioxolan-2'-yl)pyridine (1) (4.00 g, 17.4 mmol) was dissolved in anhydrous diethyl ether (40 mL) and cooled to -85 °C. *n*BuLi (10.9 mL of a 1.6 M hexanes solution, 17.4 mmol) was added dropwise over 15 min. After stirring the mixture for 1 h, the solution was warmed to -65 °C and stirred for 1 h. The

solution was re-cooled to -85 °C before addition of freshly distilled $\text{ClSn}(\text{nBu})_3$ (4.72 mL, 17.4 mmol). The solution was stirred for 1 h at -85 °C and allowed to warm to room temperature with further stirring overnight. The resulting cloudy yellow mixture was filtered through Celite and concentrated under reduced pressure to give a brown/black oil. Normally the residue is suitable for subsequent transformations but if necessary (based on ^1H NMR spectroscopy), the resulting oil can be distilled (Kugelrohr, 210 °C/0.1 mmHg) to afford 6-tributylstannyl-2-(1',3'-dioxolan-2'-yl)pyridine (2) as a clear brown oil. Yield: 6.12 g (80%).

Synthesis of 6-(5'-methyl-2'-hydroxyphenyl)-2-formyl-pyridine (4):

[00124] (i) 2-Bromo-4-methylphenol (1.94 g, 10.3 mmol), 6-(tributylstannyl)-2-(1',3'-dioxolan-2'-yl)pyridine (2) (5.00 g, 11.4 mmol) and tetrakis(triphenylphosphine)palladium(0) (0.783 g, 0.684 mmol) were loaded in a Schlenk tube under N_2 and stirred in dry toluene (100 mL) for 72 h at 90 °C. The reaction mixture was then concentrated under reduced pressure to give an oily residue containing 3 (see reaction scheme above). No further purification of 3 was carried out. (ii) Compound 3 (prepared above) was stirred overnight at 60 °C in 6M HCl (40 mL). After cooling to room temperature, the yellow solution was poured into a large beaker. The Schlenk flask was further rinsed with small portions of 6M HCl to remove/dissolve material on the sides of the flask. Approx. 100 mL water was added to the beaker and the contents vigorously stirred. Solid NaHCO_3 was slowly added until the solution was neutralized. During this time, yellow solid came out of solution until at pH 7, a large amount of yellow precipitate was present. The solid was collected by filtration and dissolved in 100 mL chloroform. This was then extracted with 2 x 100 mL water, 2 x 100 mL brine, dried over MgSO_4 and filtered to give a yellow solution. The solvent was removed on a rotary evaporator to give a waxy yellow solid, which ^1H NMR showed to be the intended product 4 and Bu_3SnBr . The solid was washed with multiple portions of hexane to remove the tin residue, yielding 4 as a yellow powder. Yield: 2.20 g (35%).

Synthesis of 6-(5'-methyl-2'-hydroxyphenyl)-2-(N-(2,6-diisopropylphenyl)imino)pyridine (5):

[00125] To a solution of 6-(5'-methyl-2'-hydroxyphenyl)-2-formyl-pyridine (4) (640 mg, 3.00 mmol) in the minimum volume of methanol was added 1.5 equivalents of 2,6-diisopropylaniline (780 mg, 4.50 mmol). After the addition of a few drops of formic acid, the solution was stirred overnight. The cloudy yellow reaction mixture was then filtered through a frit, and the solid washed with methanol (3 x 5 mL), giving 6-(5'-methyl-2'-

hydroxyphenyl)-2-(N-(2,6-diisopropylphenyl)imino)pyridine (5) as a yellow solid. Yield: 1.06 g (95%).

Synthesis of 6-(5'-methyl-2'-hydroxyphenyl)-2-(1'-(2,6-diisopropylanilido)ethyl)pyridine (6a):

5 [00126] In the glovebox, compound 5 (300 mg, 0.805 mmol) was dissolved in a 1:1 mixture of THF and diethyl ether (20 mL) and cooled to -40 °C. MeLi (1.30 mL of a 1.4 M solution in ether, 1.82 mmol) was slowly added via syringe, forming a dark brown solution. After stirring for 30 minutes, the reaction was quenched by the addition of water (1 mL), generating an orange solution. The solution was dried over MgSO₄ and filtered, and the
10 solvent removed under vacuum to yield a yellow solid. Yield: 170 mg (55%). An X-ray crystal structure of this compound is shown in Figure 1. The phenyl analogue, 6-(5'-methyl-2'-hydroxyphenyl)-2-(1'-(2,6-diisopropylanilido)benzyl)pyridine (6b), was synthesized in a similar manner from 5 and PhLi.

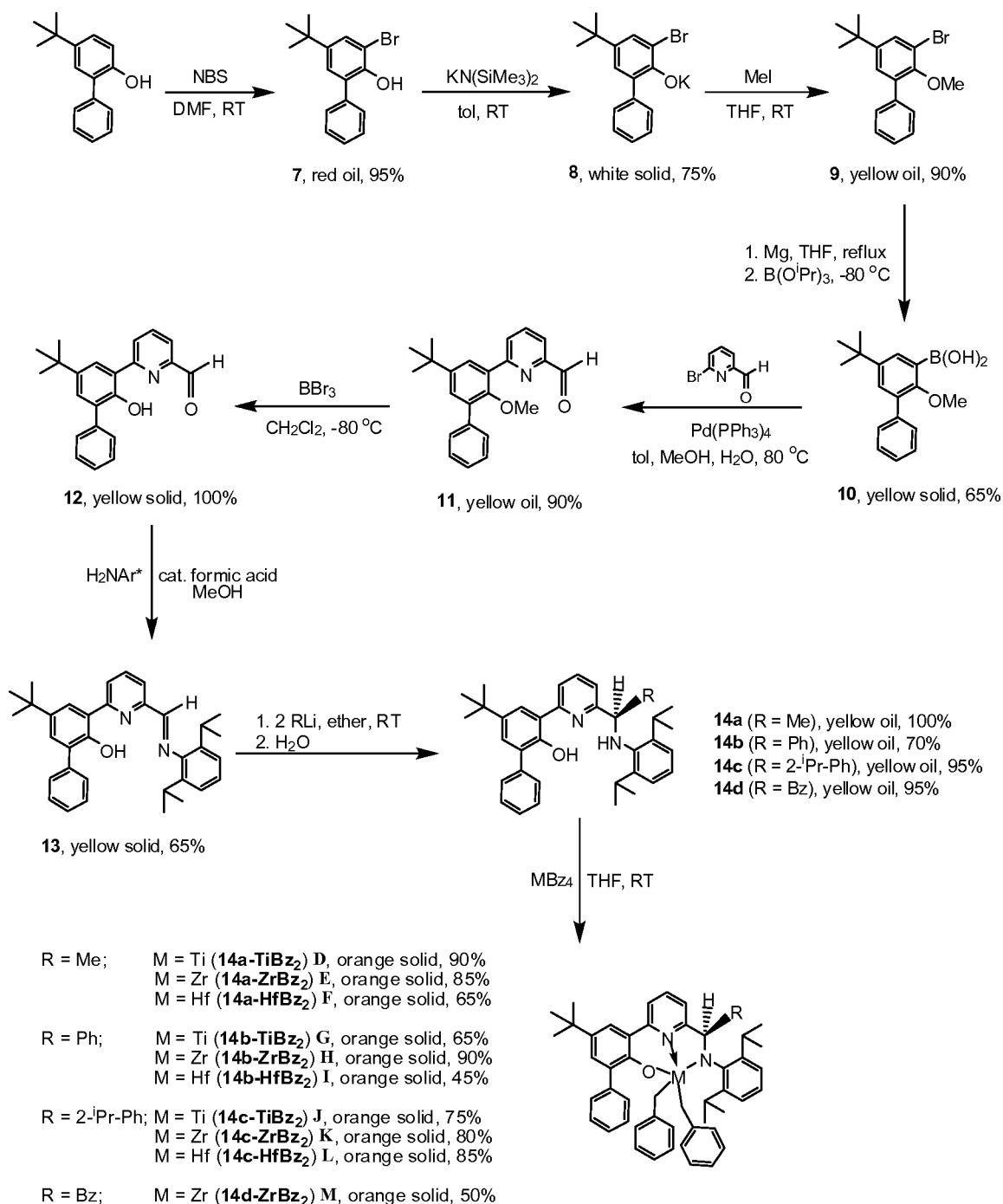
Synthesis of [6-(5'-methyl-2'-hydroxyphenyl)-2-(1'-(2,6-diisopropylanilido)ethyl)pyridine]-zirconium(IV)dibenzyl (A):

15 [00127] Under a nitrogen atmosphere, a yellow THF solution (20 mL) of 6a (75 mg, 193 mmol) was added to a yellow THF solution (20 mL) of ZrBz₄ (88 mg, 193 mmol), forming an orange solution. After stirring at room temperature for 8 h, the solvent was removed to give a brown sticky solid. The product was washed with pentane and dried under vacuum to
20 give an orange solid. Yield: 86 mg (70%). Compounds 6a-HfBz₂ (B) and 6b-HfBz₂ (C) were made in a similar fashion from compounds 6a and 6b, and hafnium tetrabenzyl, respectively.

Synthesis of compounds D through M:

[00128] The syntheses of compounds D through M can be represented as follows:

Synthesis of *ortho*-phenyl phenoxy-pyridylamino complexes



Synthesis of 2-bromo-4-tert-butyl-6-phenylphenol (7):

[00129] A 20 mL DMF solution of N-bromosuccinimide (4.07 g, 22.9 mmol) was slowly added to a DMF solution (100 mL) of 2-phenyl-4-tert-butylphenol (4.93 g, 21.8 mmol), forming a dark green solution. After stirring in the dark for 48 h, the resultant dark red solution was poured into 500 mL of water, forming a cloudy solution. This was extracted

with 95:5 hexane/toluene (3 x 200 mL), dried over MgSO_4 , filtered and the solvent removed to give 7 as a thick red oil. Yield: 6.32 g (95%).

Synthesis of potassium [2-bromo-4-tert-butyl-6-phenylphenoxide] (8):

[00130] In the glovebox, compound 7 (9.11 g, 29.8 mmol) was dissolved in 200 mL
5 toluene and a toluene solution (40 mL) of $\text{KN}(\text{SiMe}_3)_2$ (5.95 g, 29.8 mmol) was added dropwise. A large amount of precipitate formed by the end of the addition. After stirring for 1 h, the thick white slurry was filtered, washed with toluene and dried under vacuum to give a white solid. Yield: 7.20 g (75%).

Synthesis of (2-methoxy-3-phenyl-5-tert-butyl)phenylbromide (9):

10 [00131] Under a nitrogen atmosphere, a THF solution (10 mL) of iodomethane (2.93 g, 20.7 mmol) was added to a THF solution (100 mL) of potassium[2-bromo-4-tert-butyl-6-phenylphenoxide] (8) (7.10 g, 20.7 mmol). After 3 h, a large amount of white precipitate had formed (KI). The reaction mixture was stirred overnight, and was then filtered through a frit lined with Celite to remove insoluble KI, yielding a yellow solution. The THF was removed
15 under vacuum to give (2-methoxy-3-phenyl-5-tert-butyl) phenylbromide (9) as a yellow oil. Yield: 5.93 g (90%).

Synthesis of (2-methoxy-3-phenyl-5-tert-butyl)phenylboronic acid (10):

[00132] Under an atmosphere of nitrogen, magnesium turnings (500 mg, 20.5 mmol) in THF (100 mL) were activated by the addition of a few drops of 1,2-dibromoethane and
20 stirred for 1 h. A THF solution (20 mL) of (2-methoxy-3-phenyl-5-tert-butyl)phenylbromide (9) (5.93 g, 18.6 mmol) was added dropwise and the contents of the flask were heated to reflux and stirred overnight. The cloudy yellow slurry was cooled to room temperature and filtered through a frit lined with Celite to give a yellow solution of the Grignard (2-methoxy-3-phenyl-5-tert-butyl)phenylmagnesiumbromide. The Grignard solution was cooled to -30
25 °C and added to a THF solution (100 mL) of triisopropylborate (7.00 g, 37.2 mmol) maintained at -80 °C. After stirring for 30 min, the reaction mixture was left to warm to room temperature and stir overnight. The cloudy yellow mixture was then removed from the inert atmosphere and 100 mL 10% HCl/water added. This was then partitioned with diethyl ether (100 mL) and the water layer washed with diethyl ether (2 x 100 mL). The organic
30 fractions were then combined, washed with water (2 x 100 mL) and dried over MgSO_4 . This was then filtered and the solvent removed to give a yellow oil. Upon standing, this turned into a yellow waxy solid. The solid was washed with pentane to yield a slightly yellow powder. Yield: 3.43 g (65%).

Synthesis of 6-(2'-methoxy-3'-phenyl-5'-tert-butylphenyl)-2-formyl-pyridine (11):

[00133] In the glovebox, 2-acetyl-6-bromopyridine (2.51 g, 13.5 mmol) and tetrakis-(triphenylphosphine)palladium(0) (156 mg, 0.135 mmol) were dissolved in 50 mL toluene and taken up in a large syringe. (2-methoxy-3-phenyl-5-tert-butyl)phenylboronic acid (10)
5 (4.08 g, 14.3 mmol) and Na₂CO₃ (3.58 g, 33.8 mmol) were weighed into a 250 mL round-bottomed flask and charged with 30 mL dry degassed methanol. The flask was taken out of the glovebox and under a nitrogen purge, 60 mL degassed water was added, forming a white bubbly paste. The bromopyridine/Pd mixture was then added via syringe and the yellow biphasic mixture was fitted with a reflux condenser and heated to 80 °C overnight. The
10 heating was then removed and 100 mL diethyl ether was added to the reaction mixture. The contents of the flask were then transferred to a separatory funnel where the water layer was washed with dichloromethane (100 mL). The organic fractions were combined and washed with water (2 x 100 mL), dried over MgSO₄, filtered and the solvent removed to give 11 as a yellow oil. The product may be further purified by column chromatography if necessary
15 (silica, hexanes/ethyl acetate eluent). Yield: 4.43 g (90%).

Synthesis of 6-(2'-hydroxy-3'-phenyl-5'-tert-butylphenyl)-2-formyl-pyridine (12):

[00134] In the glovebox, 6-(2'-methoxy-3'-phenyl-5'-tert-butylphenyl)-2-formyl-pyridine (11) (4.43 g, 12.3 mmol) was dissolved in 75 mL dichloromethane and cooled to -80 °C. A 20 mL dichloromethane solution of BBr₃ (4.62 g, 18.5 mmol) was slowly added dropwise
20 and the solution was left to stir at -80 °C for 1 hour. After warming to room temperature, the orange solution was taken out of the glovebox and under a purge of nitrogen, ~1 mL of water was added, causing a large amount of smoke to form. A further 5 mL of water was slowly added, followed by 30 mL of dichloromethane and another 10 mL portion of water. This was stirred for 30 minutes, neutralized with 1M Na₂CO₃ and the water layer separated from the
25 organic layer. The water layer was extracted with 2 x 75 mL dichloromethane, the organic layers combined and washed with water (2 x 100 mL), dried over MgSO₄, filtered and dried to give compound 12 as a yellow solid. Yield: 4.25 g (100%).

Synthesis of 6-(2'-hydroxy-3'-phenyl-5'-tert-butylphenyl)-2-(N-(2,6-diisopropylphenyl)-imino)pyridine (13):

[00135] To a solution of 6-(2'-hydroxy-3'-phenyl-5'-tert-butylphenyl)-2-formyl-pyridine (12) (3.17 g, 9.17 mmol) in the minimum volume of methanol was added 2,6-diisopropylaniline (1.79 g, 10.1 mmol). After the addition of a few drops of formic acid, the

solution was stirred overnight. The cloudy yellow reaction mixture was then filtered through a frit, and the solid washed with methanol (3 x 5 mL), giving compound 13 as a yellow solid. Yield: 2.92 g (65%).

5 Synthesis of 6-(2'-hydroxy-3'-phenyl-5'-tert-butylphenyl)-2-(1'-(2,6-diisopropylanilido)-ethyl)pyridine (14a):

[00136] In the glovebox, compound 13 (320 mg, 0.65 mmol) was dissolved in 20 mL diethyl ether (20 mL). Solid MeLi (115 mg, 5.20 mmol) was slowly added, forming a cloudy yellow solution. After stirring for 30 minutes, the reaction was quenched by the addition of water (1 mL), generating an orange solution. The solution was dried over MgSO₄ and
10 filtered, and the solvent removed under vacuum to yield a yellow oil. Yield: 330 mg (100%). The phenyl, 2-isopropylphenyl and benzyl analogues, 14b-d were synthesized in a similar manner from 13 and ~2.5 equiv. PhLi, (2-ⁱPr-Ph)Li and BzMgCl, respectively.

Synthesis of [6-(2'-hydroxy-3'-phenyl-5'-tert-butylphenyl)-2-(1'-(2,6-diisopropylanilido)-ethyl)pyridine]titanium(IV)dibenzyl (D):

15 [00137] Under a nitrogen atmosphere, a yellow THF solution (20 mL) of 14a (330 mg, 651 mmol) was added to a red THF solution (20 mL) of TiBz₄ (270 mg, 651 mmol), forming a dark red/brown solution. After stirring at room temperature for 8 h, the solvent was removed to give a brown sticky solid. The product was washed with pentane and dried under vacuum to give an orange solid. Yield: 440 mg (90%).

20 Synthesis of compounds E through M:

[00138] Compounds E through M were made in a similar manner from compounds 14a to 14d and the corresponding Group IV tetrabenzyl precursors. An X-ray crystal structure of compound K is shown in Figure 2.

Polymerization Process:

25 [00139] Ethylene/1-octene copolymerizations were carried out in a parallel pressure reactor, which is described in U.S. Patent Nos. 6,306,658, 6,455,316 and 6,489,168l; WO 00/09255; and Murphy et al., J. Am. Chem. Soc., 2003, 125, 4306-4317, each of which is incorporated herein by reference. A pre-weighed glass vial insert and disposable stirring paddle were fitted to each reaction vessel of the reactor, which contains 48 individual
30 reaction vessels. The reactor was then closed and each vessel was individually heated to a set temperature (usually between 50 °C and 100 °C) and pressurized to a pre-determined pressure of ethylene (generally between 75 and 350 psi). 100 uL of 1-octene (637 umol) was injected into each reaction vessel through a valve, followed by 500 uL of hexane. 100 uL of

tri-n-octylaluminum solution (10 mmol/L in hexane, 1 μ mol) was then added to act as a co-catalyst/scavenger. The contents of the vessel were then stirred at 800 rpm. An activator solution (usually N,N'-dimethylanilinium tetrakis(pentafluorophenyl)borate in toluene, 0.40 mmol/L, $\sim$ 1 equiv) was then injected into the reaction vessel along with 500 μ L hexane, followed by a toluene solution of catalyst (A - M, 0.40 mmol/L, 20 - 120 nmol) and another aliquot of hexane (500 μ L). In a typical run, reaction conditions were varied such that two temperatures, three pressures and four catalyst concentrations were investigated. All runs were performed in duplicate. The reaction was then allowed to proceed until a set time limit (usually 30 min) or until a set amount of ethylene had been taken up by the reaction (ethylene pressure was maintained in each reaction vessel at the pre-set level by computer control). At this point, the reaction was quenched by exposure to air. After the polymerization reaction, the glass vial insert containing the polymer product and solvent was removed from the pressure cell and the inert atmosphere glovebox and the volatile components were removed using a Genevac HT-12 centrifuge and Genevac VC3000D vacuum evaporator operating at elevated temperature and reduced pressure. The vial was then weighed to determine the yield of the polymer product. The resultant polymer was analyzed by Rapid GPC (see below) to determine the molecular weight, by FT-IR (see below) to determine comonomer incorporation, and by DSC (see below) to determine melting point.

[00140] High temperature size exclusion chromatography was performed using an automated "Rapid GPC" system as described in U.S. Pat. Nos. 6,491,816, 6,491,823, 6,475,391, 6,461,515, 6,436,292, 6,406,632, 6,175,409, 6,454,947, 6,260,407 and 6,294,388 each of which is incorporated herein by reference. This apparatus has a series of three 30 cm x 7.5 mm linear columns, each containing PLgel 10 μ m, Mix B. The GPC system was calibrated using polystyrene standards ranging from 580 - 3,390,000 g/mol. The system was operated at an eluent flow rate of 2.0 mL/min and an oven temperature of 165 $^{\circ}$ C. 1,2,4-trichlorobenzene was used as the eluent. The polymer samples were dissolved in 1,2,4-trichlorobenzene at a concentration of 0.1 - 0.9 mg/mL. 250 μ L of a polymer solution were injected into the system. The concentration of the polymer in the eluent was monitored using an evaporative light scattering detector. The molecular weights obtained are relative to linear polystyrene standards.

[00141] Differential Scanning Calorimetry (DSC) measurements were performed on a TA-Q100 instrument to determine the melting point of the polymers. Samples were pre-annealed at 220 $^{\circ}$ C for 15 minutes and then allowed to cool to room temperature overnight. The

samples were then heated to 220 °C at a rate of 100 °C/min and then cooled at a rate of 50 °C/min. Melting points were collected during the heating period.

[00142] The ratio of 1-octene to ethylene incorporated in the polymers (weight %) was determined by rapid FT-IR spectroscopy on a Bruker Equinox 55+ IR in reflection mode.

5 Samples were prepared in a thin film format by evaporative deposition techniques. Weight % 1-octene was obtained from the ratio of peak heights at 1378 and 4322 cm⁻¹. This method was calibrated using a set of ethylene/1-octene copolymers with a range of known wt. % 1-octene content.

10 [00143] Polymerization data shown in Table 1 is intended to be representative of the catalytic behavior of compounds A - M and not comprehensive.

Table 1. Selected High Throughput Polymerization Results

Example	Catalyst	Amount (nmol)	Temp (°C)	Pressure (psi)	Time (sec)	Yield (mg)	Activity (g/mmol h bar)	Mw (kDa)	MWD (Mw/Mn)	Tm (°C)
1	A	80	50	75	1345	27	172	3259	5.3	132
2	A	80	50	200	451	23	166	3924	1.7	134
3	A	80	50	350	285	23	149	4536	2.3	134
4	A	80	80	75	1802	31	149	801	2.5	130
5	A	80	80	200	721	36	162	2273	2.2	133
6	A	80	80	350	205	13	118	806	2.3	134
7	B	125	50	200	1800	11	13	2661	3.5	134
8	C	80	50	200	3600	15	14	3554	2.1	132
9	C	80	50	350	3600	24	12	3665	2.8	134
10	C	80	80	200	3600	13	12	206	2.8	132
11	C	125	50	200	3600	24	14	3686	2.2	134
12	C	125	50	350	3600	33	11	3453	3.5	134
13	C	125	80	200	3600	19	11	211	2	132
14	D	80	50	75	1595	70	382	3154	2	136
15	D	80	50	200	562	84	490	2975	1.6	137
16	D	80	50	350	394	102	481	3176	1.7	138
17	D	80	80	75	1801	14	66	2880	1.5	134
18	D	80	80	200	1802	27	49	2858	2.1	135
19	D	80	80	350	1802	54	56	2586	1.8	135
20	E	40	50	75	1177	80	1186	2973	8.5	136
21	E	40	50	200	1082	112	672	4118	3.6	136
22	E	40	50	350	620	80	480	4148	3.8	136
23	E	40	80	75	390	110	4914	754	2.1	135
24	E	40	80	200	539	205	2482	1332	3.7	135
25	E	40	80	350	442	289	2440	2942	3.6	133

WO 2009/082556

PCT/US2008/083128

26	F	80	50	75	1117	73	571	905	3.6	ND
27	F	80	50	200	672	111	539	1220	3.8	ND
28	F	80	50	350	437	104	444	1312	2.8	ND
29	F	80	80	75	1801	39	187	264	3.7	ND
30	F	80	80	200	852	91	348	514	3.1	ND
31	F	80	80	350	733	175	444	685	2.9	ND
32	G	20	50	75	1601	27	576	4995	1.2	136
33	G	20	50	200	804	34	553	4693	1.3	137
34	G	20	50	350	413	24	426	4924	1.3	137
35	G	20	80	75	1801	20	390	4631	1.4	135
36	G	20	80	200	768	37	632	4854	1.4	137
37	G	20	80	350	750	53	527	4562	1.3	137
38	H	20	50	75	1215	82	2341	3118	4.8	137
39	H	20	50	200	745	96	1683	4134	2	136
40	H	20	50	350	609	106	1295	4478	1.4	136
41	H	20	80	75	442	99	7830	762	1.9	136
42	H	20	80	200	304	166	7144	2472	2.4	137
43	H	20	80	350	217	141	4850	3585	2	138
44	H	20	90	75	534	78	5085	628	2.1	135
45	H	20	100	75	397	138	12137	650	2	134
46	H	20	110	75	471	57	4228	474	1.8	134
47	H	20	120	75	1801	33	632	391	1.7	133
49	I	80	50	75	1800	16	80	ND	ND	ND
50	I	80	50	200	1801	33	60	1213	12.9	ND
51	I	80	50	350	1801	41	42	ND	ND	ND
52	I	80	80	75	1801	23	110	ND	ND	ND
53	I	80	80	200	1801	64	116	1128	3.1	ND
54	I	80	80	350	1528	117	142	1381	3.1	ND
55	J	80	50	75	1172	30	223	4645	1.3	137
56	J	80	50	200	452	30	216	4775	1.3	137
57	J	80	50	350	280	35	232	4741	1.3	137
58	J	80	80	75	703	37	461	4353	1.3	135
59	J	80	80	200	367	56	498	4696	1.3	137
60	J	80	80	350	109	33	556	4005	1.3	136
61	K	40	50	75	621	55	1527	3517	2.8	136
62	K	40	50	200	492	77	1021	4558	1.7	137
63	K	40	50	350	344	56	602	4933	1.7	137
64	K	40	80	75	246	72	5102	1340	1.9	135
65	K	40	80	200	212	154	4725	2806	1.7	135
66	K	40	80	350	118	127	4007	3993	1.7	135
67	K	20	90	75	405	66	5690	773	1.8	136
68	K	20	100	75	456	125	9505	671	1.8	134
69	K	20	110	75	373	57	5348	610	1.6	134

70	K	20	120	75	1802	43	826	551	1.7	134
72	L	80	50	75	1801	10	50	3244	2.8	137
73	L	80	50	200	1801	22	39	4613	1.4	ND
74	L	80	50	350	1146	18	30	4404	2	133
75	L	80	80	75	1528	32	182	2060	2.4	136
76	L	80	80	200	959	40	137	3434	1.6	136
77	L	80	80	350	181	6	59	ND	ND	ND
78	M	20	50	75	1801	28	533	3179	4.2	136
79	M	20	50	200	1801	45	323	5156	1.3	134
80	M	20	50	350	1802	73	300	3668	3.2	135
81	M	20	80	75	1728	81	1634	1964	4.5	135
82	M	20	80	200	1020	32	412	3214	4.3	135
83	M	20	80	350	1802	71	295	3397	2.8	135
84	M	20	90	75	1120	50	1554	867	2.6	136
85	M	20	100	75	1801	36	700	501	2.2	135
86	M	20	110	75	1802	14	274	320	1.9	134
87	M	20	120	75	1802	9	168	ND	ND	ND

ND = not determined

Solution Batch Polymerizations:

[00144] Due to its high activity in the initial polymerization runs (see Table 1, examples 64 - 69), catalyst K was selected to polymerize ethylene on a larger scale in a lab reactor.

5 Polymerizations were performed in a 1 L stainless steel autoclave manufactured by Autoclave Engineers. Triisobutylaluminum (TIBAL, 0.4M pentane solution) or tri-n-octylaluminum (TnOAL, 25 wt. % in toluene) was charged into the reactor followed by isohexane (400 - 500 mL) under an atmosphere of dinitrogen. The reactor contents were then heated to 80 or 100 °C and agitation was set to 850 rpm. Ethylene was introduced (~300 psi) and the pressure
10 maintained throughout the polymerization. Equimolar amounts of K and activator (N,N'-dimethylanilinium tetrakis(pentafluorophenyl)borate) were dissolved in toluene. An aliquot of the catalyst/activator solution was flushed into the reactor with high pressure nitrogen. The reaction was allowed to proceed for ~10 - 30 min and then the autoclave was cooled and depressurized. The polymer was transferred into a glass vessel and dried under vacuum at 70
15 °C for 4 hours.

[00145] Molecular weight distribution was characterized using a High Temperature Size Exclusion Chromatograph (Waters Alliance 2000) equipped with a differential refractive index detector (DRI). Three Polymer Laboratories PLgel 10mm Mixed-B columns were used. The nominal flow rate was 1.0 mL/min, and the nominal injection volume was 300 uL.
20 The various transfer lines, columns and differential refractometer (the DRI detector) were

contained in an oven maintained at 145 °C. Polymer solutions were prepared by dissolving the desired amount of dry polymer in the appropriate volume of 1,2,4-trichlorobenzene to yield concentrations ranging from 0.25 to 1.5 mg/mL. The sample mixtures were heated at 160 °C with continuous agitation for ~2 hours. The solution was filtered through a 2 micron stainless steel filter (Polymer Labs) into scintillation vials using a Polymer Labs SP260 Sample Prep Station. The separation efficiency of the column set was calibrated using a series of narrow MWD polystyrene standards (Polymer Laboratories), which reflects the expected MW range for samples and the exclusion limits of the column set. Seventeen individual polystyrene standards, ranging from Mp ~580 to 10,000,000, were used to generate the calibration curve.

[00146] Differential Scanning Calorimetry (DSC) measurements were performed on a Perkin Elmer Pyris 1 instrument to determine the melting point of the polymers. Samples were heated to 200 °C for 10 minutes and then cooled to -20 °C at a rate of 10 °C/min. After being held at this temperature for 10 minutes, they were then heated to 200 °C at a rate of 10 °C/min. Melting points were collected during the heating period.

Table 2: Selected Solution Batch Polymerization Results for Catalyst K

Example	Temp (°C)	Amount (mmol)	Pressure (psi)	Time (min)	Co- catalyst	Yield (g)	Activity (g/mmol h bar)	MW (kDa)	MWD (Mw/Mn)	Tm (°C)
88	80	0.0034	325	30	TIBAL	1.51	40	161	1.69	141
89	80	0.0272	331	10	TnOAL	28.42	275	1365	4.71	138
90	80	0.009	295	12	TnOAL	51.25	1400	711	4.07	133
91	100	0.0062	316	10	TnOAL	26.47	1165	895	4.28	134
92	80	0.0041	316	32	TnOAL	1.32	30	ND	ND	134

ND = not determined

Supported Batch Polymerizations:

[00147] Synthesis of SMAO-757: Ineous ES-757 silica gel, 40 g (calcined at 600 °C) was slurried in 125 mL toluene and reacted with 47 g MAO (Albemarle, 30 wt%) at room temperature for 2 hrs. The SMAO was then filtered through a glass frit and washed with hexane. Drying under vacuum for 1 to 2 hrs yielded 54 g of dry free-flowing SMAO.

[00148] Synthesis of supported catalyst K: SMAO-757 (2.0 g) was slurried in 30 mL toluene. N,N'-dimethylanilinium tetrakis(pentafluorophenyl)borate (22 mg) was added and the mixture stirred for 10 min. Catalyst K (24 mg) was then added and the mixture stirred for

2 hrs. The solid was filtered, washed with hexane and dried in a nitrogen atmosphere overnight.

[00149] The procedure for runs using supported catalyst were the same as described previously for the solution runs, with the exception that the supported catalyst (~100 mg) was added to the reactor as a solid using a purge of high pressure nitrogen.

Table 3: Selected Supported Batch Polymerization Results for Catalyst K

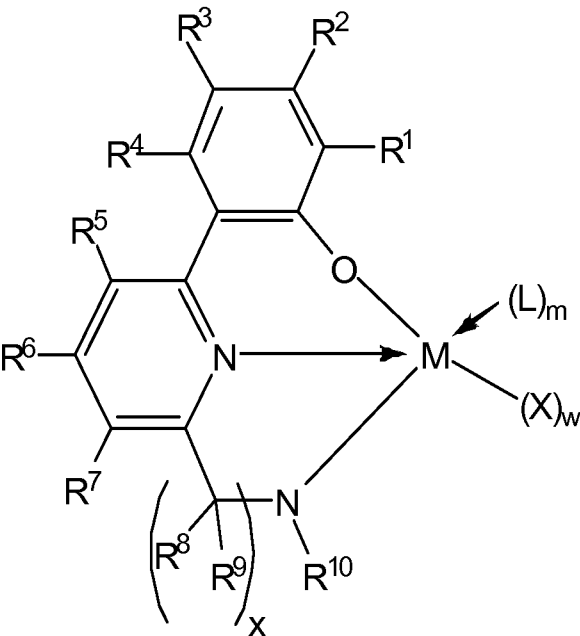
Example	Temp (°C)	Amount (mmol)	Pressure (psi)	Time (min)	Co- catalyst	Yield (g)	Activity (g/mmol h bar)	MW (kDa)	MWD (Mw/Mn)	Tm (°C)
93	80	0.0015	250	45	TIBAL	34.41	1750	2149	7.02	134
94	100	0.0013	250	45	TIBAL	10.26	610	1307	4.87	135

[00150] 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 forms of the invention have been illustrated and described, various modifications can be made without departing from the spirit and scope of the invention. Accordingly, it is not intended that the invention be limited thereby. Likewise, the term "comprising" is considered synonymous with the term "including" for purposes of Australian law.

CLAIMS

What is claimed is:

1. A process to polymerize ethylene comprising:
1) contacting ethylene and a transition metal catalyst compound represented by the structure:



5

each X is, independently, a hydride, a halogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl;

w is 2;

- 10 each R¹, R², R³, and R⁴ is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group, or independently, may join together to form a C₄ to C₆₂ cyclic or polycyclic ring structure;

- 15 each R⁵, R⁶, and R⁷ is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group, or independently, may join together to form a C₄ to C₆₂ cyclic or polycyclic ring structure;

- 20 each R⁸ and R⁹ is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group;

R^{10} is a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group;

x is 1, 2, 3 or 4;

5 L is a neutral ligand bonded to M;

M is titanium, zirconium or hafnium; and

m is 0, 1 or 2; and

2) obtaining a polyethylene having a weight average molecular weight of 500,000 g/mol or more,

10 wherein the activity is at least 1000 g/mmol h bar.

2. The process according to claim 1, wherein X is selected from the group consisting of fluoride, chloride, bromide, iodide, methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, pentadecyl, hexadecyl, heptadecyl, octadecyl, nonadecyl, eicosyl, heneicosyl, docosyl, tricosyl, tetracosyl, pentacosyl, hexacosyl, heptacosyl, octacosyl, nonacosyl, triacontyl, hydride, phenyl, benzyl, phenethyl, tolyl, trimethylsilylmethyl, bis(trimethylsilyl)methyl, methoxy, ethoxy, propoxy, butoxy, dimethylamido, diethylamido, methylethylamido, phenoxy, benzoxy, and allyl.

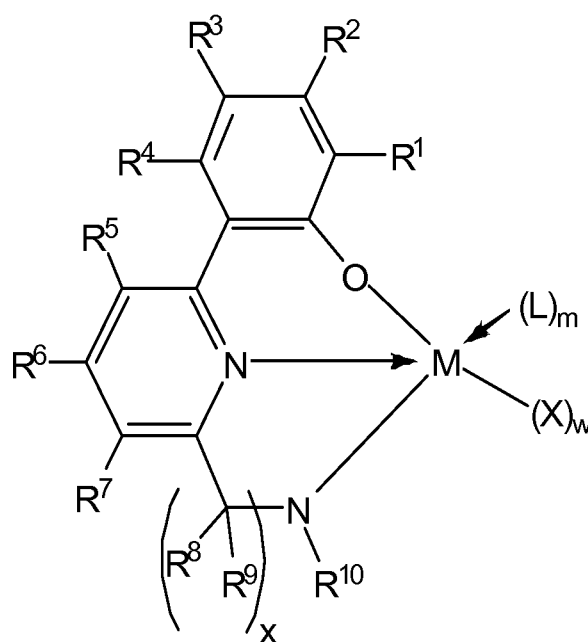
3. The process according to claim 1 or 2, wherein each R^1 , R^2 , R^3 , R^4 , R^5 , R^6 , and R^7 is, independently, a hydrogen, a C_1 to C_{30} hydrocarbyl, a C_1 to C_{30} substituted hydrocarbyl, a C_1 to C_{30} halocarbyl, a C_1 to C_{30} substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group; or independently, may join together to form a C_4 to C_{62} cyclic or polycyclic ring structure.

4. The process according to any of claims 1 to 3, wherein each R^1 , R^2 , R^3 , R^4 , R^5 , R^6 , and R^7 is, independently, a hydrogen, a C_1 to C_{10} hydrocarbyl, a C_1 to C_{10} substituted hydrocarbyl, a C_1 to C_{10} halocarbyl, a C_1 to C_{10} substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group; or independently, may join together to form a C_4 to C_{62} cyclic or polycyclic ring structure.

5. The process according to any of claims 1 to 4, wherein each R^8 , R^9 , and R^{10} is independently, a hydrogen, a C_1 to C_{30} hydrocarbyl, a C_1 to C_{30} substituted hydrocarbyl, a C_1 to C_{30} halocarbyl, or a C_1 to C_{30} substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, or a silyl.

6. The process according to any of claims 1 to 4, wherein each R^8 , R^9 , and R^{10} is independently, a hydrogen, a C_1 to C_{10} hydrocarbyl, a C_1 to C_{10} substituted hydrocarbyl, a C_1 to C_{10} halocarbyl, or a C_1 to C_{10} substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, or a silyl.
- 5 7. The process according to any of claims 1 to 6, wherein L is selected from the group consisting of pyridine, acetonitrile, diethyl ether, tetrahydrofuran, dimethylaniline, trimethylamine, tributylamine, trimethylphosphine, triphenylphosphine, lithium chloride, ethylene, propylene, butene, octene, and styrene.
8. The process according to any of claims 1 to 7, wherein x is 1.
- 10 9. The process according to claim 1, wherein: R^1 is phenyl; each R^2 , R^4 , R^5 , R^6 , R^7 , and R^8 is hydrogen; R^3 is tert-butyl or methyl; R^9 is methyl, phenyl, 2-isopropylphenyl, or benzyl; R^{10} is 2,6-diisopropylphenyl; each X is benzyl; x is 1, 2 or 3 and m is 0.
10. The compound of claim 1 wherein, w is 2 and each X is benzyl; each R^1 , R^2 , and R^4 is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or
15 another anionic heteroatom-containing group, or independently, may join together to form a C_4 to C_{62} cyclic or polycyclic ring structure; R^3 is methyl or tert-butyl; each R^5 , R^6 , and R^7 is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or
20 another anionic heteroatom-containing group, or independently, may join together to form a C_4 to C_{62} cyclic or polycyclic ring structure; R^8 is hydrogen; R^9 is methyl, phenyl, 2-isopropylphenyl, or benzyl; R^{10} is a 2,6-diisopropylphenyl; L is a neutral ligand bonded to M; M is titanium, zirconium or hafnium; x is 1; and m is 0, 1 or 2.
11. The process according to claim 1 wherein w is 2 and each X is benzyl; each R^1 , R^2 ,
25 and R^4 is a hydrogen or independently, may join together to form a C_4 to C_{62} cyclic or polycyclic ring structure; R^3 is methyl or tert-butyl; each R^5 , R^6 , and R^7 is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, a substituted halocarbyl, or independently, may join together to form a C_4 to C_{62} cyclic or polycyclic ring structure; R^8 is hydrogen; R^9 is methyl, phenyl, 2-isopropylphenyl, or benzyl; R^{10} is a 2,6-diisopropylphenyl;
30 L is a neutral ligand bonded to M; M is titanium, zirconium or hafnium; x is 1; and m is 0, 1 or 2.

12. The process according to any of claims 1 to 11, wherein R^1 is phenyl or substituted phenyl.
13. The process according to any of claims 1 to 11 having an activity of 2000 g/mmol h bar.
- 5 14. The process according to any of claims 1 to 11 wherein M is zirconium.
15. A transition metal compound for ethylene polymerization represented by the structure:



- 10 each X is, independently, a hydride, a halogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl;
w is 2;
each R^1 , R^2 , R^3 , and R^4 is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an
15 amide, a phosphide, a silyl or another anionic heteroatom-containing group, or independently, may join together to form a C_4 to C_{62} cyclic or polycyclic ring structure, provided that R^1 is not hydrogen;
each R^5 , R^6 , and R^7 is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an

amide, a phosphide, a silyl or another anionic heteroatom-containing group, or independently, may join together to form a C₄ to C₆₂ cyclic or polycyclic ring structure;

each R⁸ and R⁹, is, independently, a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group;

R¹⁰ is a hydrogen, a hydrocarbyl, a substituted hydrocarbyl, a halocarbyl, or a substituted halocarbyl, a halogen, an alkoxide, a sulfide, an amide, a phosphide, a silyl or another anionic heteroatom-containing group;

x is 1, 2, 3 or 4;

L is a neutral ligand bonded to M;

M is titanium, zirconium or hafnium; and

m is 0, 1 or 2; and

wherein the activity of the catalyst compound is at least 1000 g/mmol h bar.