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(54) Title: DIPHENYLAMINE SALAN CATALYST

(57) Abstract: Catalysts comprising Salan ligands with bridged or unbridged diphenyl amine moieties. Also, catalyst systems comprising the catalyst and an activator; methods to prepare the ligands, catalysts and catalyst systems; processes to polymerize olefins using the catalysts and/or catalyst systems; and the olefin polymers prepared according to the processes.

## DIPHENYLAMINE SALAN CATALYST

### FIELD OF THE INVENTION

This invention relates to novel catalyst compounds comprising Salan ligands  
5 and catalyst systems comprising such and uses thereof.

### BACKGROUND OF THE INVENTION

Olefin polymerization catalysts are of great use in industry. Hence there is  
interest in finding new catalyst systems that increase the commercial usefulness of the  
catalyst and allow the production of polymers having improved properties.

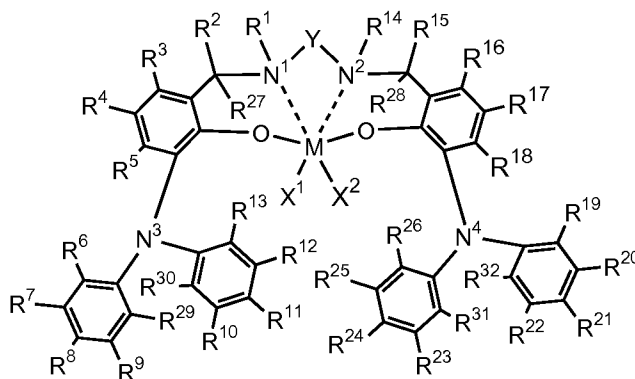
10 There is a need in the art for new and improved catalysts and catalyst systems  
to obtain new and improved polyolefins, polymerization processes, and the like.  
Accordingly, there is a need in the art for new and improved catalyst systems for the  
polymerization of olefins for one or more of the following purposes: to achieve one or  
more specific polymer properties, such as high polymer melting point and/or high  
15 polymer molecular weights; to increase conversion or comonomer incorporation;  
and/or to alter comonomer distribution without deterioration of the properties of the  
resulting polymer. The instant disclosure is directed to novel catalyst compounds,  
catalysts systems comprising such compounds, and processes for the polymerization  
of olefins using such compounds and systems in satisfaction of the need in the art.

### 20 SUMMARY OF THE INVENTION

The instant disclosure is directed to catalyst compounds, catalyst systems  
comprising such compounds, processes for the preparation of the catalyst compounds  
and systems, and processes for the polymerization of olefins using such catalyst  
compounds and systems.

25 In an embodiment of the invention, the catalyst compound comprises Group 3,  
4, 5 and/or 6 dialkyl compounds supported by a heteroaryl-substituted tetradentate di-  
anionic Salan ligand.

In an embodiment of the invention, a catalyst compound is represented by the  
formula:



wherein each solid line represents a covalent bond and each dashed line represents a bond having varying degrees of covalency and a varying degree of coordination;

5 M is a Group 3, 4, 5 or 6 transition metal;

$N^1$ ,  $N^2$ ,  $N^3$  and  $N^4$  are nitrogen;

each of  $X^1$  and  $X^2$  is, independently, a univalent  $C_1$  to  $C_{20}$  hydrocarbyl radical, a functional group comprising elements from Groups 13 – 17 of the periodic table of the elements, or  $X^1$  and  $X^2$  join together to form a  $C_4$  to  $C_{62}$  cyclic or polycyclic ring structure, provided however when M is trivalent  $X^2$  is not present;

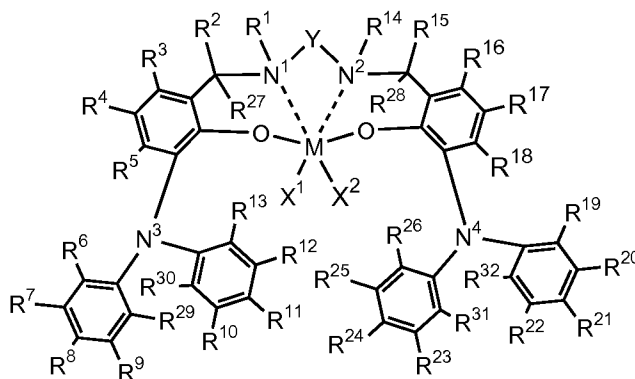
10

Y is a divalent  $C_1$  to  $C_{20}$  hydrocarbyl radical; and

each of  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ ,  $R^{11}$ ,  $R^{12}$ ,  $R^{13}$ ,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$ ,  $R^{17}$ ,  $R^{18}$ ,  $R^{19}$ ,  $R^{20}$ ,  $R^{21}$ ,  $R^{22}$ ,  $R^{23}$ ,  $R^{24}$ ,  $R^{25}$ ,  $R^{26}$ ,  $R^{27}$ ,  $R^{28}$ ,  $R^{29}$ ,  $R^{30}$ ,  $R^{31}$ , and  $R^{32}$  is, independently, a hydrogen, a  $C_1$ - $C_{40}$  hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of  $R^1$  to  $R^{32}$  may independently join together to form a  $C_4$  to  $C_{62}$  cyclic or polycyclic ring structure, or a combination thereof.

15

20 In an embodiment of the invention, a catalyst compound is represented by the formula:



wherein each solid line represents a covalent bond and each dashed line represents a bond having varying degrees of covalency and a varying degree of coordination;

5 M is a Group 3, 4, 5 or 6 transition metal;

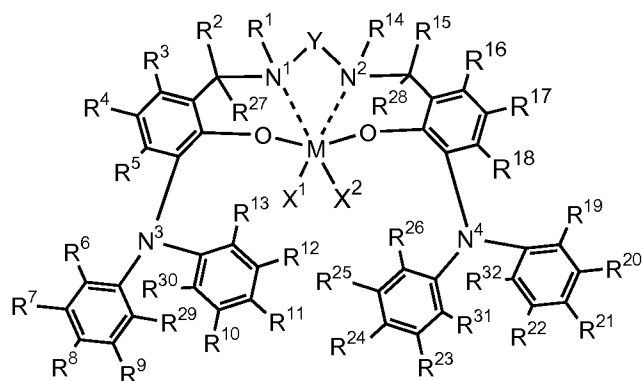
$N^1$ ,  $N^2$ ,  $N^3$  and  $N^4$  are nitrogen;

each of  $X^1$  and  $X^2$  is, independently, a univalent  $C_1$  to  $C_{20}$  hydrocarbyl radical, a functional group comprising elements from Groups 13 – 17 of the periodic table of the elements, or  $X^1$  and  $X^2$  join together to form a  $C_4$  to  $C_{62}$  cyclic or polycyclic ring structure, provided however when M is trivalent  $X^2$  is not present;

Y is a divalent  $C_1$  to  $C_{20}$  hydrocarbyl radical; and

each of  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ ,  $R^{11}$ ,  $R^{12}$ ,  $R^{13}$ ,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$ ,  $R^{17}$ ,  $R^{18}$ ,  $R^{19}$ ,  $R^{20}$ ,  $R^{21}$ ,  $R^{22}$ ,  $R^{23}$ ,  $R^{24}$ ,  $R^{25}$ ,  $R^{26}$ ,  $R^{27}$ ,  $R^{28}$ ,  $R^{29}$ ,  $R^{30}$ ,  $R^{31}$ , and  $R^{32}$  is, independently, a hydrogen, a  $C_1$ - $C_{40}$  hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of  $R^1$  to  $R^{32}$  may independently join together to form a  $C_4$  to  $C_{62}$  cyclic or polycyclic ring structure wherein neither of  $R^6$  nor  $R^{29}$  join together with  $R^{13}$  or  $R^{30}$  to form direct covalent bonds between the respective aromatic rings and wherein neither of  $R^{26}$  nor  $R^{31}$  join together with  $R^{19}$  or  $R^{32}$  to form direct covalent bonds between the respective aromatic rings, or a combination thereof.

In an embodiment of the invention, a catalyst system comprises an activator and a catalyst compound represented by the formula:



wherein M is a Group 3, 4, 5 or 6 transition metal;

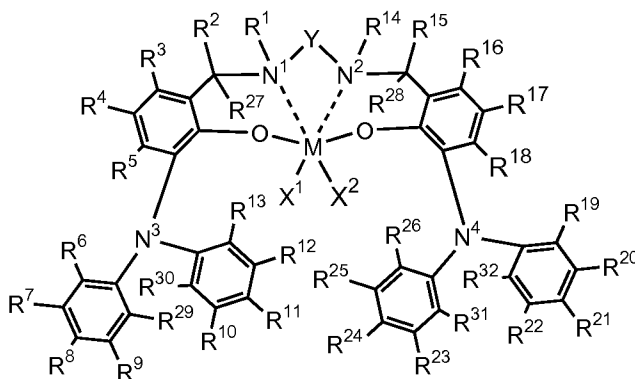
N<sup>1</sup>, N<sup>2</sup>, N<sup>3</sup> and N<sup>4</sup> are nitrogen;

each of X<sup>1</sup> and X<sup>2</sup> is, independently, a univalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical,  
 5 a functional group comprising elements from Groups 13 – 17 of the  
 periodic table of the elements, or X<sup>1</sup> and X<sup>2</sup> join together to form a C<sub>4</sub>  
 to C<sub>62</sub> cyclic or polycyclic ring structure, provided however when M is  
 trivalent X<sup>2</sup> is not present;

Y is a divalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical; and

10 each of R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>,  
 R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and  
 R<sup>32</sup> is, independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a  
 functional group comprising elements from Group 13 – 17 of the  
 periodic table of the elements, or two or more of R<sup>1</sup> to R<sup>32</sup> may  
 15 independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic  
 ring structure wherein neither of R<sup>6</sup> nor R<sup>29</sup> are directly bridged to R<sup>13</sup>  
 or R<sup>30</sup> and wherein neither of R<sup>26</sup> nor R<sup>31</sup> are directly bridged to R<sup>19</sup> or  
 R<sup>32</sup>, or a combination thereof.

In an embodiment of the invention, a process to polymerize olefins comprises  
 20 contacting one or more olefins with a catalyst system at a temperature, a pressure, and  
 for a period of time sufficient to produce a polyolefin, the catalyst system comprising  
 an activator and a catalyst compound represented by the formula:



wherein M is a Group 3, 4, 5 or 6 transition metal;

N<sup>1</sup>, N<sup>2</sup>, N<sup>3</sup> and N<sup>4</sup> are nitrogen;

each of X<sup>1</sup> and X<sup>2</sup> is, independently, a univalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical,  
 5 a functional group comprising elements from Groups 13 – 17 of the  
 periodic table of the elements, or X<sup>1</sup> and X<sup>2</sup> join together to form a C<sub>4</sub>  
 to C<sub>62</sub> cyclic or polycyclic ring structure, provided however when M is  
 trivalent X<sup>2</sup> is not present;

Y is a divalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl; and

10 each of R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>,  
 R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and  
 R<sup>32</sup> is, independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a  
 functional group comprising elements from Group 13 – 17 of the  
 periodic table of the elements, or two or more of R<sup>1</sup> to R<sup>32</sup> may  
 15 independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic  
 ring structure, or a combination thereof.

This invention also relates to catalyst systems comprising such compounds,  
 processes for the preparation of the catalyst compounds and systems, processes for the  
 polymerization of olefins using such catalyst compounds and systems and the  
 20 polyolefins obtained from such processes.

### **DETAILED DESCRIPTION**

For the purposes of this invention and the claims thereto, the new numbering  
 scheme for the Periodic Table Groups is used as in Chem. Eng. News, 1985, 63, 27.  
 Therefore, a “Group 4 metal” is an element from Group 4 of the Periodic Table.

25 In the structures depicted throughout this specification and the claims, a solid  
 line indicates a bond, an arrow indicates that the bond may be dative, and each dashed  
 line represents a bond having varying degrees of covalency and a varying degree of

coordination.

The terms "hydrocarbyl radical," "hydrocarbyl" and "hydrocarbyl group" are used interchangeably throughout this document unless otherwise specified. For purposes of this disclosure, a hydrocarbyl radical is defined to be C<sub>1</sub> to C<sub>70</sub> radicals, or C<sub>1</sub> to C<sub>20</sub> radicals, or C<sub>1</sub> to C<sub>10</sub> radicals, or C<sub>6</sub> to C<sub>70</sub> radicals, or C<sub>6</sub> to C<sub>20</sub> radicals, or C<sub>7</sub> to C<sub>20</sub> radicals that may be linear, branched, or cyclic where appropriate (aromatic or non-aromatic); and includes hydrocarbyl radicals substituted with other hydrocarbyl radicals and/or one or more functional groups comprising elements from Groups 13 – 17 of the periodic table of the elements. In addition two or more such hydrocarbyl radicals may together form a fused ring system, including partially or fully hydrogenated fused ring systems, which may include heterocyclic radicals.

The term "substituted" means that a hydrogen atom and/or a carbon atom in the base structure has been replaced with a hydrocarbyl radical, and/or a functional group, and/or a heteroatom or a heteroatom containing group. Accordingly, the term hydrocarbyl radical includes heteroatom containing groups. For purposes herein, a heteroatom is defined as any atom other than carbon and hydrogen. For example, methyl cyclopentadiene (Cp) is a Cp group, which is the base structure, substituted with a methyl radical, which may also be referred to as a methyl functional group, ethyl alcohol is an ethyl group, which is the base structure, substituted with an -OH functional group, and pyridine is a phenyl group having a carbon in the base structure of the benzene ring substituted with a nitrogen atom.

For purposes herein, a hydrocarbyl radical may be independently selected from substituted or unsubstituted 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.

5 For purposes herein, hydrocarbyl radicals may also include isomers of saturated, partially unsaturated and aromatic cyclic structures wherein the radical may additionally be subjected to the types of substitutions described above. The term “aryl”, “aryl radical”, and/or “aryl group” refers to aromatic cyclic structures, which may be substituted with hydrocarbyl radicals and/or functional groups as defined  
10 herein. Examples of aryl radicals include: acenaphthenyl, acenaphthylenyl, acridinyl, anthracenyl, benzanthracenyls, benzimidazolyl, benzisoxazolyl, benzofluoranthenyls, benzofuranyl, benzoperylenyls, benzopyrenyls, benzothiazolyl, benzothiophenyls, benzoxazolyl, benzyl, carbazolyl, carbolinyl, chrysenyl, cinnolinyl, coronenyl, cyclohexyl, cyclohexenyl, methylcyclohexyl, dibenzoanthracenyls, fluoranthenyl,  
15 fluorenyl, furanyl, imidazolyl, indazolyl, indenopyrenyls, indolyl, indolinyl, isobenzofuranyl, isoindolyl, isoquinolinyl, isoxazolyl, methyl benzyl, methylphenyl, naphthyl, oxazolyl, phenanthrenyl, phenyl, purinyl, pyrazinyl, pyrazolyl, pyrenyl, pyridazinyl, pyridinyl, pyrimidinyl, pyrrolyl, quinazoliny, quinolonyl, quinoxaliny, thiazolyl, thiophenyl, and the like.

20 It is to be understood that for purposes herein, when a radical is listed, it indicates that the base structure of the radical (the radical type) and all other radicals formed when that radical 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,  
25 *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-1-propenyl, 1-methyl-2-propenyl, 2-methyl-1-propenyl, and 2-methyl-2-propenyl (and cyclobutenyls and  
30 cyclopropenyls). Cyclic compounds 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-dimethylphenyl.

Likewise the terms “functional group”, “group” and “substituent” are also used interchangeably throughout this document unless otherwise specified. For purposes  
5 herein, a functional group includes both organic and inorganic radicals or moieties comprising elements from Groups 13, 14, 15, 16, 17 of the periodic table of elements. Suitable functional groups may include hydrocarbyl radicals, e.g., alkyl radicals, alkene radicals, aryl radicals, and/or halogen (Cl, Br, I, F), O, S, Se, Te, NR\*<sub>x</sub>, OR\*, SeR\*, TeR\*, PR\*<sub>x</sub>, AsR\*<sub>x</sub>, SbR\*<sub>x</sub>, SR\*, BR\*<sub>x</sub>, SiR\*<sub>x</sub>, GeR\*<sub>x</sub>, SnR\*<sub>x</sub>, PbR\*<sub>x</sub>, and/or  
10 the like, wherein R is a C<sub>1</sub> to C<sub>20</sub> hydrocarbyl as defined above and wherein x is the appropriate integer to provide an electron neutral moiety. Other examples of functional groups include those typically referred to as amines, imides, amides, ethers, alcohols (hydroxides), sulfides, sulfates, phosphides, halides, phosphonates, alkoxides, esters, carboxylates, aldehydes, and the like.

15 For purposes herein “direct bonds,” “direct covalent bonds” or “directly bridged” are used interchangeably to refer to covalent bonds directly between atoms that do not have any intervening atoms. Where reference is made herein to two substituents joining together to form a cyclic or polycyclic ring structure, one substituent is directly bridged to another substituent when the two substituents  
20 together form only a covalent bond containing no atoms, i.e., the substituents are not directly bridged if they together comprise a bridge of at least one atom.

For purposes herein an “olefin,” alternatively referred to as “alkene,” is a linear, branched, or cyclic compound comprising carbon and hydrogen having at least one double bond. For purposes of this specification and the claims appended thereto,  
25 when a polymer or copolymer is referred to as comprising an olefin, the olefin present in such polymer or copolymer is the polymerized form of the olefin. For example, when a copolymer is said to have an “ethylene” content of 35 wt% to 55 wt%, it is understood that the mer unit in the copolymer is derived from ethylene in the polymerization reaction and said derived units are present at 35 wt% to 55 wt%, based  
30 upon the weight of the copolymer.

For purposes herein a “polymer” has two or more of the same or different “mer” units. A “homopolymer” is a polymer having mer units that are the same. A

“copolymer” is a polymer having two or more mer units that are different from each other. A “terpolymer” is a polymer having three mer units that are different from each other. “Different” in reference to mer units indicates that the mer units differ from each other by at least one atom or are different isomerically. Accordingly, the definition of copolymer, as used herein, includes terpolymers and the like. An oligomer is typically a polymer having a low molecular weight, such as an Mn of less than 25,000 g/mol, or in an embodiment of the invention less than 2,500 g/mol, or a low number of mer units, such as 75 mer units or less. An “ethylene polymer” or “ethylene copolymer” is a polymer or copolymer comprising at least 50 mole% ethylene derived units, a “propylene polymer” or “propylene copolymer” is a polymer or copolymer comprising at least 50 mole% propylene derived units, and so on.

For the purposes of this disclosure, the term “ $\alpha$ -olefin” includes C<sub>2</sub>-C<sub>22</sub> olefins. Non-limiting examples of  $\alpha$ -olefins include ethylene, 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, 3,5,5-trimethyl-1-hexene, vinylcyclohexane, and vinylnorbornane. Non-limiting examples of cyclic olefins and diolefins include cyclopropene, 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-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.

The terms “catalyst”, “catalyst compound”, and “transition metal compound” are defined to mean a compound capable of initiating polymerization catalysis under the appropriate conditions. In the description herein, the catalyst may be described as a catalyst precursor, a pre-catalyst compound, or a transition metal compound, and these terms are used interchangeably. 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. A “catalyst system” is combination of at least one catalyst compound, at least one  
5 activator, an optional co-activator, and an optional support material, where the system can polymerize monomers to polymer. For the purposes of this invention and the claims thereto, when catalyst systems are described as comprising neutral stable forms of the components it is well understood by one of ordinary skill in the art that the ionic form of the component is the form that reacts with the monomers to produce  
10 polymers.

For purposes herein the term “catalyst productivity” is a measure of how many grams of polymer (P) are produced using a polymerization catalyst comprising W grams of catalyst (cat), over a period of time of T hours; and may be expressed by the following formula:  $P/(T \times W)$  and expressed in units of  $\text{gPgcat}^{-1}\text{hr}^{-1}$ . Conversion is  
15 the amount of monomer that is converted to polymer product, and is reported as mol% and is calculated based on the polymer yield and the amount of monomer fed into the reactor. Catalyst activity is a measure of how active the catalyst is and is reported as the mass of product polymer (P) produced per mole of catalyst (cat) used ( $\text{kg P/mol cat}$ ).

20 An “anionic ligand” is a negatively charged ligand which donates one or more pairs of electrons to a metal ion. A “neutral donor ligand” is a neutrally charged ligand which donates one or more pairs of electrons to a metal ion.

A scavenger is a compound that is typically added to facilitate oligomerization or polymerization by scavenging impurities. Some scavengers may also act as  
25 activators and may be referred to as co-activators. A co-activator, that is not a scavenger, may also be used in conjunction with an activator in order to form an active catalyst. In an embodiment of the invention a co-activator can be pre-mixed with the catalyst compound to form an alkylated catalyst compound.

A propylene polymer is a polymer having at least 50 mol% of propylene. As  
30 used herein,  $M_n$  is number average molecular weight as determined by proton nuclear magnetic resonance spectroscopy ( $^1\text{H NMR}$ ) unless stated otherwise,  $M_w$  is weight average molecular weight determined by gel permeation chromatography (GPC), and

Mz is z average molecular weight determined by GPC, wt% is weight percent, and mol% is mole percent. Molecular weight distribution (MWD) is defined to be Mw divided by Mn. Unless otherwise noted, all molecular weight units, e.g., Mw, Mn, Mz, are g/mol.

5 The following abbreviations may be 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, iso-butyl is isobutyl, sec-butyl refers to secondary butyl, tert-butyl, refers to tertiary butyl, n-butyl is normal butyl, pMe is para-methyl, Bn is benzyl, THF is tetrahydrofuran, Mes is mesityl, also known as 1,3,5-trimethylbenzene, Tol is toluene,  
 10 TMS is trimethylsilyl, TIBAL is triisobutylaluminum, TNOAL is triisobutyl n-octylaluminum, MAO is methylalumoxane, MOMO is methoxymethoxy (also referred to as methoxymethyl ether), N is nitrogen (including that N<sup>1</sup>, N<sup>2</sup>, N<sup>3</sup> and N<sup>4</sup> are nitrogen) and O is oxygen.

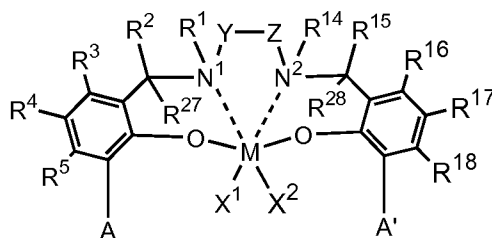
For purposes herein, RT is room temperature, which is defined as 25 °C unless  
 15 otherwise specified. All percentages are weight percent (wt%) unless otherwise specified.

In the description herein, the Salan catalyst may be described as a catalyst precursor, a pre-catalyst compound, Salan catalyst compound or a transition metal compound, and these terms are used interchangeably.

## 20 CATALYST COMPOUNDS

In an embodiment of the invention, the catalyst comprises Group 3, 4, 5 and/or 6 dialkyl compounds supported by a tetradentate di-anionic Salan ligand, useful to polymerize olefins and/or  $\alpha$ -olefins to produce polyolefins and/or poly( $\alpha$ -olefins).

25 In an embodiment of the invention, the catalyst compounds are represented by the formula:



wherein A and A' are heteroaryl radicals subject to the proviso that neither A nor A' are substituted or unsubstituted carbazolyl radicals;

M is a Group 3, 4, 5 or 6 transition metal;

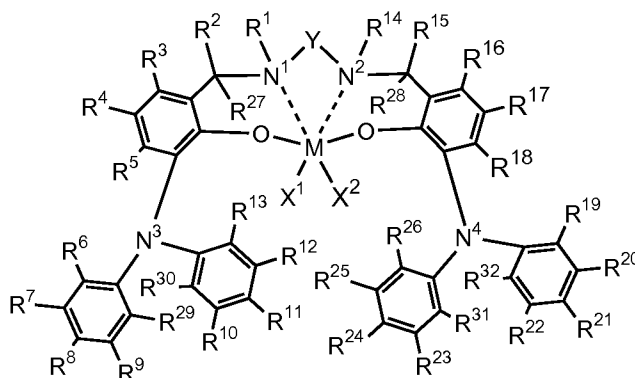
$N^1$  and  $N^2$  are nitrogen;

each of  $X^1$  and  $X^2$  is, independently, a univalent  $C_1$  to  $C_{20}$  hydrocarbyl radical, a functional group comprising elements from Groups 13 – 17 of the periodic table of the elements, or  $X^1$  and  $X^2$  join together to form a  $C_4$  to  $C_{62}$  cyclic or polycyclic ring structure, provided however when M is trivalent  $X^2$  is not present;

each  $R^1, R^2, R^3, R^4, R^5, R^{14}, R^{15}, R^{16}, R^{17}, R^{18}, R^{27}$ , and  $R^{28}$  is, independently, a hydrogen, a  $C_1$ - $C_{40}$  hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or a combination thereof; and

Y and Z together form a divalent  $C_1$  to  $C_{20}$  hydrocarbyl radical, preferably a  $C_2$  to  $C_{20}$  hydrocarbyl radical, preferably Y and Z form a  $C_1$ - $C_{40}$  hydrocarbyl radical comprising a portion that comprises a linker backbone comprising from 1 to 18 carbon atoms linking the nitrogen atoms  $N^1$  and  $N^2$  wherein the hydrocarbyl comprises O, S, S(O), S(O)<sub>2</sub>, Si( $R^*$ )<sub>2</sub>, P( $R^*$ ), N or N( $R^*$ ), wherein each  $R^*$  is independently a  $C_1$ - $C_{18}$  hydrocarbyl, preferably in any embodiment of the invention, Y-Z is selected from the group consisting of ethylene (-CH<sub>2</sub>CH<sub>2</sub>-) and 1,2-cyclohexylene, and/or -CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>- derived from propylene. In an embodiment of the invention, Y-Z is -CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>- derived from propylene..

In an embodiment of the invention, the catalyst compounds are represented by the following structure:



wherein each solid line represents a covalent bond and each dashed line represents a bond having varying degrees of covalency and a varying degree of coordination;

M is a Group 3, 4, 5 or 6 transition metal covalently bonded to each oxygen atom, and bonded with varying degrees of covalency and coordination to each of nitrogen atoms N<sup>1</sup> and N<sup>2</sup>;

N<sup>3</sup> and N<sup>4</sup> are nitrogen;

5 each of X<sup>1</sup> and X<sup>2</sup> is, independently, a univalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical, a functional group comprising elements from Groups 13 – 17 of the periodic table of the elements, or X<sup>1</sup> and X<sup>2</sup> join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure, provided however when M is trivalent X<sup>2</sup> is not present;

10 Y is a divalent hydrocarbyl radical covalently bonded to and bridging between both of the nitrogen atoms N<sup>1</sup> and N<sup>2</sup>, subject to the proviso that the diphenyl amine ligands attached to N<sup>3</sup> and N<sup>4</sup> are not directly bridged to each other to form a carbazole moiety; and

15 each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> is, independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of R<sup>1</sup> to R<sup>32</sup> may independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure wherein R<sup>6</sup> and R<sup>29</sup> are not directly bridged to R<sup>13</sup> or R<sup>30</sup> and wherein R<sup>26</sup> and R<sup>31</sup> are not directly bridged to R<sup>19</sup> or R<sup>32</sup>, or a combination thereof.

20 In any embodiment of the invention, M is a Group 4 metal, or M is Hf, Ti and/or Zr, or M is Hf or Zr.

25 In any embodiment of the invention, each of X<sup>1</sup> and X<sup>2</sup> is independently selected from the group consisting of hydrocarbyl radicals having from 1 to 20 carbon atoms, hydrides, amides, alkoxides having from 1 to 20 carbon atoms, sulfides, phosphides, halides, amines, phosphines, ethers, and combinations thereof.

30 In any embodiment of the invention, X<sup>1</sup> and X<sup>2</sup> together form a part of a fused ring or a ring system having from 4 to 62 carbon atoms.

In any embodiment of the invention, each of X<sup>1</sup> and X<sup>2</sup> is independently selected from the group consisting of halides, alkyl radicals having from 1 to 7 carbon

atoms, benzyl radicals, or a combination thereof. In an embodiment of the invention, each X is, independently, a halogen or a C<sub>1</sub> to C<sub>7</sub> hydrocarbyl radical.

In any embodiment of the invention, Y is a divalent hydrocarbyl radical covalently bonded to and bridging between both of the nitrogen atoms N<sup>1</sup> and N<sup>2</sup>, subject to the proviso that the diphenyl amine ligands attached to N<sup>3</sup> and N<sup>4</sup> are not directly bridged to each other to form a carbazole moiety.

In any embodiment of the invention, Y is a divalent C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical comprising a portion that comprises a linker backbone comprising from 1 to 18 carbon atoms linking or bridging between nitrogen atoms N<sup>1</sup> and N<sup>2</sup>. In an embodiment of the invention, Y is a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical comprising a portion that comprises a linker backbone comprising from 1 to 18 carbon atoms linking the nitrogen atoms N<sup>1</sup> and N<sup>2</sup> wherein the hydrocarbyl comprises O, S, S(O), S(O)<sub>2</sub>, Si(R<sup>\*</sup>)<sub>2</sub>, P(R<sup>\*</sup>), N or N(R<sup>\*</sup>), wherein each R<sup>\*</sup> is independently a C<sub>1</sub>-C<sub>18</sub> hydrocarbyl. In an embodiment of the invention, Y is selected from the group consisting of ethylene (-CH<sub>2</sub>CH<sub>2</sub>-) and 1,2-cyclohexylene, and/or -CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>- derived from propylene. In an embodiment of the invention, Y is -CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>- derived from propylene.

Preferably, each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> is, independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> may independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure other than carbazole, or a combination thereof.

In an embodiment of the invention, M is Zr; X<sup>1</sup> and X<sup>2</sup> are benzyl radicals; R<sup>1</sup> and R<sup>14</sup> are methyl radicals; R<sup>2</sup> through R<sup>13</sup> and R<sup>15</sup> through R<sup>32</sup> are hydrogen; and Y is ethylene (-CH<sub>2</sub>CH<sub>2</sub>-).

In an embodiment of the invention, M is Zr; X<sup>1</sup> and X<sup>2</sup> are benzyl radicals; R<sup>1</sup>, R<sup>4</sup>, R<sup>14</sup> and R<sup>17</sup> are methyl radicals; R<sup>2</sup>, R<sup>3</sup>, R<sup>5</sup> through R<sup>13</sup>, R<sup>15</sup>, R<sup>16</sup> and R<sup>18</sup> through R<sup>32</sup> are hydrogen; and Y is ethylene (-CH<sub>2</sub>CH<sub>2</sub>-).

Preferably, each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>,

$R^{18}$ ,  $R^{20}$ ,  $R^{21}$ ,  $R^{22}$ ,  $R^{23}$ ,  $R^{24}$ ,  $R^{25}$ ,  $R^{27}$ , and  $R^{28}$  is, independently, a hydrogen, a  $C_1$ - $C_{40}$  hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of each  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ ,  $R^{11}$ ,  $R^{12}$ ,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$ ,  $R^{17}$ ,  $R^{18}$ ,  $R^{20}$ ,  $R^{21}$ ,  $R^{22}$ ,  $R^{23}$ ,  $R^{24}$ ,  $R^{25}$ ,  $R^{27}$ , and  $R^{28}$  may  
 5 independently join together to form a  $C_4$  to  $C_{62}$  cyclic or polycyclic ring structure, or a combination thereof; and each  $R^6$ ,  $R^{13}$ ,  $R^{26}$ ,  $R^{29}$ ,  $R^{30}$ ,  $R^{31}$  and  $R^{32}$  is, independently, a hydrogen, a  $C_1$ - $C_{40}$  hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or a combination thereof.

In an embodiment of the invention, each  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  
 10  $R^{10}$ ,  $R^{11}$ ,  $R^{12}$ ,  $R^{13}$ ,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$ ,  $R^{17}$ ,  $R^{18}$ ,  $R^{19}$ ,  $R^{20}$ ,  $R^{21}$ ,  $R^{22}$ ,  $R^{23}$ ,  $R^{24}$ ,  $R^{25}$ ,  $R^{26}$ ,  $R^{27}$ ,  $R^{28}$ ,  $R^{29}$ ,  $R^{30}$ ,  $R^{31}$ , and  $R^{32}$  is, independently, hydrogen, a halogen, or a  $C_1$  to  $C_{30}$  hydrocarbyl radical, or a  $C_1$  to  $C_{10}$  hydrocarbyl radical. In an embodiment of the invention, one or more of  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ ,  $R^{11}$ ,  $R^{12}$ ,  $R^{13}$ ,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$ ,  $R^{17}$ ,  $R^{18}$ ,  $R^{19}$ ,  $R^{20}$ ,  $R^{21}$ ,  $R^{22}$ ,  $R^{23}$ ,  $R^{24}$ ,  $R^{25}$ ,  $R^{26}$ ,  $R^{27}$ ,  $R^{28}$ ,  $R^{29}$ ,  $R^{30}$ ,  $R^{31}$ , and  $R^{32}$  is a  
 15 methyl radical, a fluoride, or a combination thereof, subject to the proviso that the diphenyl amine ligands attached to  $N^3$  and  $N^4$  are not directly bridged to each other to form a carbazole moiety.

In an embodiment of the invention,  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ ,  $R^{11}$ ,  $R^{12}$ ,  $R^{13}$ ,  $R^{19}$ ,  $R^{20}$ ,  
 20  $R^{21}$ ,  $R^{22}$ ,  $R^{23}$ ,  $R^{24}$ ,  $R^{25}$ ,  $R^{26}$ ,  $R^{29}$ ,  $R^{30}$ ,  $R^{31}$ , and  $R^{32}$  are selected to provide steric bulk, also referred to as steric hindrance. In an embodiment of the invention, one or more of  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ ,  $R^{11}$ ,  $R^{12}$ ,  $R^{13}$ ,  $R^{19}$ ,  $R^{20}$ ,  $R^{21}$ ,  $R^{22}$ ,  $R^{23}$ ,  $R^{24}$ ,  $R^{25}$ ,  $R^{26}$ ,  $R^{29}$ ,  $R^{30}$ ,  $R^{31}$ , and  $R^{32}$  has a molecular volume of greater than 250 cubic Å, or greater than 300 cubic Å, or greater than 500 cubic Å. For purposes herein, molecular volume is used as an approximation of spatial steric bulk. Comparison of substituents with differing  
 25 molecular volumes allows the substituent with the smaller molecular volume to be considered “less bulky” in comparison to the substituent with the larger molecular volume. Conversely, a substituent with a larger molecular volume may be considered “more bulky” than a substituent with a smaller molecular volume.

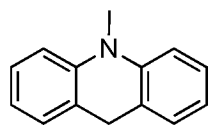
In an embodiment of the invention, one or more of  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ ,  
 30  $R^{11}$ ,  $R^{12}$ ,  $R^{13}$ ,  $R^{19}$ ,  $R^{20}$ ,  $R^{21}$ ,  $R^{22}$ ,  $R^{23}$ ,  $R^{24}$ ,  $R^{25}$ ,  $R^{26}$ ,  $R^{29}$ ,  $R^{30}$ ,  $R^{31}$ , and  $R^{32}$  comprise  $C_1$  to  $C_{20}$ , or  $C_4$  to  $C_{20}$  hydrocarbyl radicals;  $-SR^{33}$ ,  $-NR^{34}_2$ , and  $-PR^{35}_2$ , where each  $R^{33}$ ,  $R^{34}$ , or  $R^{35}$  is independently a  $C_1$  to  $C_{30}$  hydrocarbyl as defined above.



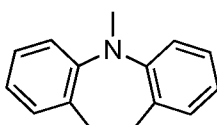
In an embodiment of the invention, one or more of R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> are selected to prevent free rotation of the phenyl rings attached to N<sup>3</sup> or N<sup>4</sup> relative to the adjoining phenyl ring attached to the same nitrogen atom at 0°C, at 25°C, at 50°C, and/or at 100°C, as determined by NMR spectroscopy.

Accordingly, in an embodiment of the invention, the stereo chemistry of the polyolefins produced, in particular the stereochemistry of the polypropylene produced may be controlled by selecting the substituents on the each of the two sets of phenyl amine rings, i.e., by selecting the molecular size of one or more of R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup>.

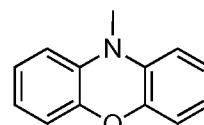
In an embodiment of the invention, R<sup>6</sup>, R<sup>13</sup>, R<sup>19</sup>, R<sup>26</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> are selected from the group consisting of hydrogen, halogen, and C<sub>1</sub>-C<sub>10</sub> hydrocarbyl. In an embodiment of the invention, any bridge between R<sup>6</sup> or R<sup>29</sup> and R<sup>13</sup> or R<sup>30</sup>, or any bridge between R<sup>26</sup> or R<sup>31</sup> and R<sup>19</sup> or R<sup>32</sup> comprises at least one additional atom from Group 13 – 17 of the periodic table of the elements (i.e., the carbon atoms in the phenyl rings are not directly bonded). In embodiments of the invention, R<sup>29</sup> and R<sup>30</sup>, and/or R<sup>31</sup> and R<sup>32</sup>, respectively, join together to form divalent radicals bridging the two respective phenyl rings in the diphenylamine, wherein the divalent radical may be selected from C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radicals and functional groups comprising elements from Group 13 – 17. In an embodiment of the invention the bridges are nonconjugated to form a diphenylamino substituent that is nonconjugated and has a non-flat geometry relative to carbazole. In embodiments of the invention, bridges of specific lengths between the two aromatic rings may retain some of the rigidity of the carbazole system while still not being aromatic, and overall may have a more predictable steric character relative to carbazole, for example. Bridges such as methylene, ethylene and higher alkylenes and oxo may be mentioned, as well as, for example, bridges formed as in the following diphenylamine derivatives 9,10-dihydroacridine, 10,11-dihydro-5H-dibenzo[b,f]azepine and 10H-phenoxazine:



9,10-dihydroacridine



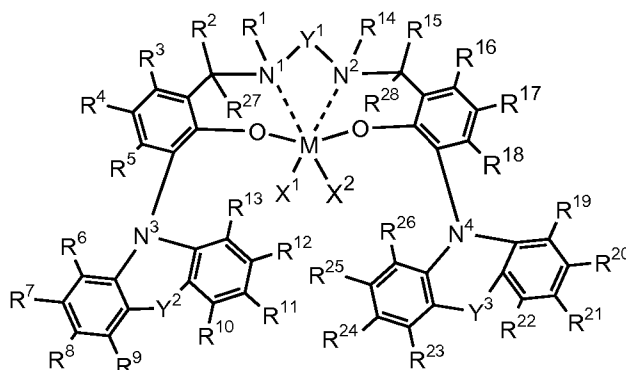
10,11-dihydro-5H-dibenzo[b,f]azepine



10H-phenoxazine

In an embodiment of the invention, a catalyst compound is represented by the

formula:



wherein each solid line represents a covalent bond and each dashed line represents a bond having varying degrees of covalency and a varying degree of coordination;

5

M is a Group 3, 4, 5 or 6 transition metal as described above;

N<sup>1</sup>, N<sup>2</sup>, N<sup>3</sup> and N<sup>4</sup> are nitrogen;

each of X<sup>1</sup> and X<sup>2</sup> is, independently, a univalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical, a functional group comprising elements from Groups 13 – 17 of the periodic table of the elements, or X<sup>1</sup> and X<sup>2</sup> join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure, provided however when M is trivalent X<sup>2</sup> is not present;

10

Y<sup>1</sup> is a divalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical corresponding to Y as described above;

15

Y<sup>2</sup> and Y<sup>3</sup> are independently a divalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical, a divalent functional group comprising elements from Group 13 – 16 of the periodic table of the elements, or a combination thereof; and

each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, and R<sup>28</sup> is, independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of R<sup>1</sup> to R<sup>28</sup> may independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure.

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In embodiments of the invention, Y<sup>2</sup> and Y<sup>3</sup> are independently divalent C<sub>1</sub> to C<sub>10</sub> hydrocarbyl radicals, oxo or a combination thereof. In embodiments of the invention, Y<sup>2</sup> and Y<sup>3</sup> are nonconjugated. In embodiments of the invention, Y<sup>2</sup> and Y<sup>3</sup> are independently methylene, ethylene, propylene, butylene, or oxo. In embodiments

25

of the invention,  $Y^2$  and  $Y^3$  are the same. In embodiments of the invention,  $Y^2$  and  $Y^3$  are different.

In an embodiment of the invention, two or more different catalyst compounds are present in the catalyst system used herein. In an embodiment of the invention, two or more different catalyst compounds are present in the reaction zone where the process(es) described herein occur. When two transition metal compound based catalysts are used in one reactor as a mixed catalyst system, the two transition metal compounds are chosen such that the two are compatible. Compatible catalysts are those catalysts having similar kinetics of termination and insertion of monomer and comonomer(s) and/or do not detrimentally interact with each other. For purposes herein, the term "incompatible catalysts" refers to and means catalysts that satisfy one or more of the following:

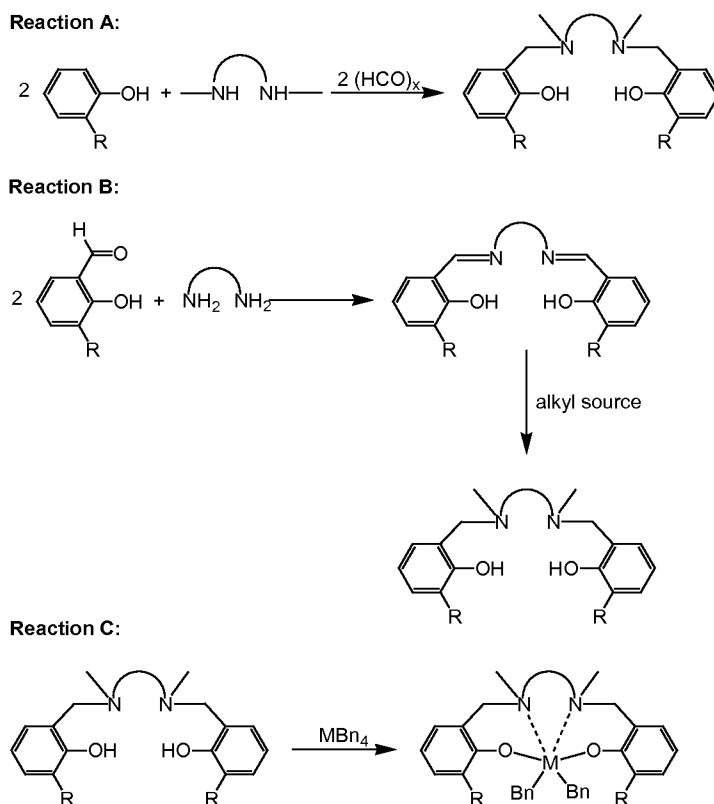
- 1) those catalysts that when present together reduce the activity of at least one of the catalysts by greater than 50%;
- 2) those catalysts that under the same reactive conditions produce polymers such that one of the polymers has a molecular weight that is more than twice the molecular weight of the other polymer; and
- 3) those catalysts that differ in comonomer incorporation or reactivity ratio under the same conditions by more than about 30%. A simple screening method such as by  $^1\text{H}$  or  $^{13}\text{C}$  NMR, known to those of ordinary skill in the art, can be used to determine which transition metal compounds are compatible. In an embodiment of the invention, the catalyst systems use the same activator for the catalyst compounds. In an embodiment of the invention, two or more different activators, such as a non-coordinating anion activator and an alumoxane, can be used in combination. If one or more catalyst compounds contain an  $X^1$  or  $X^2$  ligand which is not a hydride, or a hydrocarbyl, then in an embodiment of the invention the alumoxane is contacted with the catalyst compounds prior to addition of the non-coordinating anion activator.

In an embodiment of the invention, when two transition metal compounds (pre-catalysts) are utilized, they may be used in any ratio. In an embodiment of the invention, a molar ratio of a first transition metal compound (A) to a second transition metal compound (B) will fall within the range of (A:B) 1:1000 to 1000:1, or 1:100 to 500:1, or 1:10 to 200:1, or 1:1 to 100:1, or 1:1 to 75:1, or 5:1 to 50:1. The particular

ratio chosen will depend on the exact pre-catalysts chosen, the method of activation, and the end product desired. In an embodiment of the invention, when using two pre-catalysts, where both are activated with the same activator, useful mole percents, based upon the total moles of the pre-catalysts, are 10:90 to 0.1:99, or 25:75 to 99:1, or 50:50 to 99.5:0.5, or 50:50 to 99:1, or 75:25 to 99:1, or 90:10 to 99:1.

#### Methods to Prepare the Catalyst Compounds.

In an embodiment of the invention, the transition metal compounds may be prepared by two general synthetic routes. In an embodiment of the invention, the parent Salan ligands may be prepared by a one-step Mannich reaction from the parent phenol (reaction A) or by a two-step imine-condensation/alkylation procedure if an aldehyde located ortho to a hydroxy functional group (e.g., a substituted salicylaldehyde base structure) is used (reaction B). The Salan ligand is then converted into the metal di-substituted catalyst precursor by reaction with the metal tetra-substituted starting material to yield the finished complex. In an embodiment of the invention, the Salan ligand is then converted into the metal dibenzyl catalyst precursor by reaction with the metal tetra-aryl starting material, e.g., tetrabenzyl, to yield the finished complex (reaction C).



#### ACTIVATORS

The terms “cocatalyst” and “activator” are used interchangeably to describe activators and are defined to be any compound which can activate any one of the catalyst compounds described above by converting the neutral catalyst compound to a catalytically active catalyst compound cation. Non-limiting activators, for example, include alumoxanes, aluminum alkyls, ionizing activators, which may be neutral or ionic, and conventional-type cocatalysts. Activators may include alumoxane compounds, modified alumoxane compounds, and ionizing anion precursor compounds that abstract a reactive,  $\sigma$ -bound, metal ligand making the metal complex cationic and providing a charge-balancing noncoordinating or weakly coordinating anion.

In one embodiment of the invention, alumoxane activators are utilized as an activator in the catalyst composition. Alumoxanes are generally oligomeric compounds containing  $-\text{Al}(\text{R}^1)\text{-O-}$  sub-units, where  $\text{R}^1$  is an alkyl radical. Examples of alumoxanes include methylalumoxane (MAO), modified methylalumoxane (MMAO), ethylalumoxane and isobutylalumoxane. Alkylalumoxanes and modified alkylalumoxanes are suitable as catalyst activators, particularly when the catalyst precursor compound comprises an abstractable ligand which is an alkyl, halide, alkoxide or amide. Mixtures of different alumoxanes and modified alumoxanes may also be used. In an embodiment of the invention, visually clear methylalumoxane may be used. A cloudy or gelled alumoxane can be filtered to produce a clear solution or clear alumoxane can be decanted from the cloudy solution. A useful alumoxane is a modified methyl alumoxane (MMAO) described in U.S. Patent No. 5,041,584 and/or commercially available from Akzo Chemicals, Inc. under the trade designation Modified Methylalumoxane type 3A.

When the activator is an alumoxane (modified or unmodified), the maximum amount of activator is typically a 5000-fold molar excess Al/M over the catalyst compound (per metal catalytic site). The minimum activator-to-catalyst-compound, which is determined according to molar concentration of the transition metal M, is typically 1 mole aluminum or less to mole of transition metal M. In an embodiment of the invention, the activator comprises alumoxane and the alumoxane is present at a ratio of 1 mole aluminum or more to mole of catalyst compound. In an embodiment of the invention, the minimum activator-to-catalyst-compound molar ratio is a 1:1

molar ratio. Other examples of Al:M ranges include from 1:1 to 500:1, or from 1:1 to 200:1, or from 1:1 to 100:1, or from 1:1 to 50:1.

In an embodiment of the invention, little or no alumoxane (i.e., less than 0.001wt%) is used in the polymerization processes described herein. In an  
5 embodiment of the invention, alumoxane is present at 0.00 mole %, or the alumoxane is present at a molar ratio of aluminum to catalyst compound transition metal less than 500:1, or less than 300:1, or less than 100:1, or less than 1:1.

The term "non-coordinating anion" (NCA) refers to an anion which either does not coordinate to a cation, or which is only weakly coordinated to a cation thereby  
10 remaining sufficiently labile to be displaced by a neutral Lewis base. "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 transition metal compound and a neutral by-product from the anion. Non-coordinating anions useful  
15 in accordance with this invention are those that are compatible with the polymerization or catalyst system, stabilize the transition metal cation in the sense of balancing its ionic charge at +1, and yet are sufficiently labile to permit displacement during polymerization.

In an embodiment of the invention, an ionizing or stoichiometric activator may  
20 be used, which may be neutral or ionic, such as tri (n-butyl) ammonium boron metalloid precursor, polyhalogenated heteroborane anions (WO 98/43983), boric acid (U.S. Patent No. 5,942,459), or a combination thereof. In an embodiment of the invention, neutral or ionic activators alone or in combination with alumoxane or modified alumoxane activators may be used.

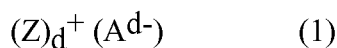
25 Examples of neutral stoichiometric activators include tri-substituted boron, tellurium, aluminum, gallium, and indium, or mixtures thereof. The three substituent groups or radicals can be the same or different and in an embodiment of the invention are each independently selected from substituted or unsubstituted alkyls, alkenyls, alkynes, aryls, alkoxy, and halogens. In an embodiment of the invention, the three  
30 groups are independently selected from halogen, mono or multicyclic (including halosubstituted) aryls, alkyls, and alkenyl compounds, and mixtures thereof; or independently selected from alkenyl radicals having 1 to 20 carbon atoms, alkyl

radicals having 1 to 20 carbon atoms, alkoxy radicals having 1 to 20 carbon atoms and aryl or substituted aryl radicals having 3 to 20 carbon atoms. In an embodiment of the invention, the three substituent groups are alkyl radicals having 1 to 20 carbon atoms, phenyl, naphthyl, or mixtures thereof. In an embodiment of the invention, the three  
 5 groups are halogenated aryl groups, e.g., fluorinated aryl groups. Preferably, the neutral stoichiometric activator is tris perfluorophenyl boron or tris perfluoronaphthyl boron.

In an embodiment of the invention, ionic stoichiometric activator compounds may include an active proton, or some other cation associated with, but not  
 10 coordinated to, or only loosely coordinated to the remaining ion of the ionizing compound. Suitable examples include compounds and the like described in European publications EP 0 570 982 A; EP 0 520 732 A; EP 0 495 375 A; EP 0 500 944 B1; EP 0 277 003 A; EP 0 277 004 A; U.S. Patent Nos. 5,153,157; 5,198,401; 5,066,741; 5,206,197; 5,241,025; 5,384,299; 5,502,124; and WO 1996/04319; all of which are  
 15 herein fully incorporated by reference.

In an embodiment of the invention compounds useful as an activator comprise a cation, which is, for example, 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 (the Group 4 cation, e.g.) which is formed when  
 20 the two compounds are combined and said anion will be sufficiently labile to be displaced by olefinic, diolefinic or acetylenically unsaturated substrates or other neutral Lewis bases, such as ethers, amines, and the like. Two classes of useful compatible non-coordinating anions are disclosed in EP 0 277,003 A1, and EP 0 277,004 A1, which include anionic coordination complexes comprising a plurality of  
 25 lipophilic radicals covalently coordinated to and shielding a central charge-bearing metal or metalloid core; and anions comprising a plurality of boron atoms such as carboranes, metallacarboranes, and boranes.

In an embodiment of the invention, the stoichiometric activators include a cation and an anion component, and may be represented by the following formula (1):  
 30



wherein Z is (L-H) or a reducible Lewis Acid, L is a neutral Lewis base; H is hydrogen; (L-H)<sup>+</sup> is a Bronsted acid; A<sup>d-</sup> is a non-coordinating anion having the

charge  $d^-$ ; and  $d$  is an integer from 1 to 3.

When  $Z$  is  $(L-H)$  such that the cation component is  $(L-H)_d^+$ , the cation component may include Bronsted acids such as protonated Lewis bases capable of protonating a moiety, such as an alkyl or aryl, from the catalyst precursor, resulting in a cationic transition metal species, or the activating cation  $(L-H)_d^+$  is a Bronsted acid, capable of donating a proton to the catalyst precursor resulting in a transition metal cation, including ammoniums, oxoniums, phosphoniums, silyliums, and mixtures thereof, or 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.

When  $Z$  is a reducible Lewis acid it may be represented by the formula:  $(Ar_3C^+)$ , where Ar is aryl or aryl substituted with a heteroatom, or a  $C_1$  to  $C_{40}$  hydrocarbyl, the reducible Lewis acid may be represented by the formula:  $(Ph_3C^+)$ , where Ph is phenyl or phenyl substituted with a heteroatom, and/or a  $C_1$  to  $C_{40}$  hydrocarbyl. In an embodiment of the invention, the reducible Lewis acid is triphenyl carbenium.

Examples of the anion component  $A^{d-}$  include those having the formula  $[M^k+Q_n]^{d-}$  wherein  $k$  is 1, 2, or 3;  $n$  is 1, 2, 3, 4, 5 or 6, or 3, 4, 5 or 6;  $n - k = d$ ;  $M$  is an element selected from Group 13 of the Periodic Table of the Elements, or boron or aluminum, and  $Q$  is independently a hydride, bridged or unbridged dialkylamido, halide, alkoxide, aryloxy, hydrocarbyl radicals, said  $Q$  having up to 20 carbon atoms with the proviso that in not more than one occurrence is  $Q$  a halide, and two  $Q$  groups may form a ring structure. Each  $Q$  may be a fluorinated hydrocarbyl radical having 1 to 20 carbon atoms, or each  $Q$  is a fluorinated aryl radical, or each  $Q$  is a pentafluoryl aryl radical. Examples of suitable  $A^{d-}$  components also include diboron compounds as disclosed in U.S. Patent No. 5,447,895, which is fully incorporated herein by reference.

In an embodiment of the invention, this invention relates to a method to



polymerize olefins comprising contacting olefins (e.g., ethylene) with a Salan catalyst compound, a chain transfer agent (CTA) and a boron containing NCA activator represented by the formula (1) where: Z is (L-H) or a reducible Lewis acid; L is a neutral Lewis base (as further described above); H is hydrogen; (L-H) is a Bronsted acid (as further described above); A<sup>d-</sup> is a boron containing non-coordinating anion having the charge d<sup>-</sup> (as further described above); d is 1, 2, or 3.

In an embodiment of the invention in any of the NCA's represented by Formula 1 described above, the anion component A<sup>d-</sup> is represented by the formula [M<sup>\*k\*</sup>+Q<sup>\*n\*</sup>]<sup>d\*</sup>- wherein k\* is 1, 2, or 3; n\* is 1, 2, 3, 4, 5, or 6 (or 1, 2, 3, or 4); n\* - k\* = d\*; M\* is boron; and Q\* is independently selected from hydride, bridged or unbridged dialkylamido, halogen, alkoxide, aryloxy, hydrocarbyl radicals, said Q\* having up to 20 carbon atoms with the proviso that in not more than 1 occurrence is Q\* a halogen.

This invention also relates to a method to polymerize olefins comprising contacting olefins (such as ethylene) with a Salan catalyst compound as described above, optionally with a CTA and an NCA activator represented by the Formula (2):



where R is a monoanionic ligand; M<sup>\*\*</sup> is a Group 13 metal or metalloid; ArNHal is a halogenated, nitrogen-containing aromatic ring, polycyclic aromatic ring, or aromatic ring assembly in which two or more rings (or fused ring systems) are joined directly to one another or together; and n is 0, 1, 2, or 3. Typically the NCA comprising an anion of Formula 2 also comprises a suitable cation that is essentially non-interfering with the ionic catalyst complexes formed with the transition metal compounds, or the cation is Z<sub>d</sub><sup>+</sup> as described above.

In an embodiment of the invention in any of the NCA's comprising an anion represented by Formula 2 described above, R is selected from the group consisting of C<sub>1</sub> to C<sub>30</sub> hydrocarbyl radicals. In an embodiment of the invention, C<sub>1</sub> to C<sub>30</sub> hydrocarbyl radicals may be substituted with one or more C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radicals, halide, hydrocarbyl substituted organometalloid, dialkylamido, alkoxy, aryloxy, alkylsulfido, arylsulfido, alkylphosphido, arylphosphide, or other anionic substituent; fluoride; bulky alkoxides, where bulky means C<sub>4</sub> to C<sub>20</sub> hydrocarbyl radicals; -SR<sup>33</sup>, -NR<sup>34</sup><sub>2</sub>, and -PR<sup>35</sup><sub>2</sub>, where each R<sup>33</sup>, R<sup>34</sup>, or R<sup>35</sup> is independently a

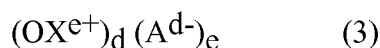
C<sub>1</sub> to C<sub>30</sub> hydrocarbyl as defined above; or a C<sub>1</sub> to C<sub>30</sub> hydrocarbyl substituted organometalloid.

In an embodiment of the invention in any of the NCA's comprising an anion represented by Formula 2 described above, the NCA also comprises cation comprising a reducible Lewis acid represented by the formula: (Ar<sub>3</sub>C<sup>+</sup>), where Ar is aryl or aryl substituted with a heteroatom, and/or a C<sub>1</sub> to C<sub>40</sub> hydrocarbyl, or the reducible Lewis acid represented by the formula: (Ph<sub>3</sub>C<sup>+</sup>), where Ph is phenyl or phenyl substituted with one or more heteroatoms, and/or C<sub>1</sub> to C<sub>40</sub> hydrocarbyls.

In an embodiment of the invention in any of the NCA's comprising an anion represented by Formula 2 described above, the NCA may also comprise a cation represented by the formula, (L-H)<sub>d</sub><sup>+</sup>, wherein L is a neutral Lewis base; H is hydrogen; (L-H) is a Bronsted acid; and d is 1, 2, or 3, or (L-H)<sub>d</sub><sup>+</sup> is a Bronsted acid selected from ammoniums, oxoniums, phosphoniums, silyliums, and mixtures thereof.

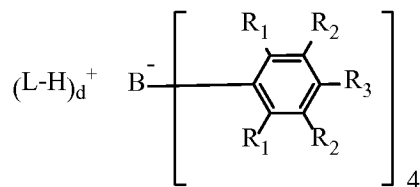
Further examples of useful activators include those disclosed in U.S. Patent Nos. 7,297,653 and 7,799,879, which are fully incorporated by reference herein.

In an embodiment of the invention, an activator useful herein comprises a salt of a cationic oxidizing agent and a noncoordinating, compatible anion represented by the Formula (3):



wherein OX<sup>e+</sup> is a cationic oxidizing agent having a charge of e+; e is 1, 2, or 3; d is 1, 2 or 3; and A<sup>d-</sup> is a non-coordinating anion having the charge of d- (as further described above). Examples of cationic oxidizing agents include: ferrocenium, hydrocarbyl-substituted ferrocenium, Ag<sup>+</sup>, or Pb<sup>+2</sup>. Suitable embodiments of A<sup>d-</sup> include tetrakis(pentafluorophenyl)borate.

In an embodiment of the invention, the Salan catalyst compounds, CTA's, and/or NCA's described herein can be used with bulky activators. A "bulky activator" as used herein refers to anionic activators represented by the formula:



wherein each R<sub>1</sub> is, independently, a halide, or a fluoride;

each R<sub>2</sub> is, independently, a halide, a C<sub>6</sub> to C<sub>20</sub> substituted aromatic hydrocarbyl

radical or a siloxy group of the formula  $-O-Si-R_a$ , where  $R_a$  is a  $C_1$  to  $C_{20}$  hydrocarbyl or hydrocarbylsilyl radical (or  $R_2$  is a fluoride or a perfluorinated phenyl radical);

5 each  $R_3$  is a halide,  $C_6$  to  $C_{20}$  substituted aromatic hydrocarbyl radical or a siloxy group of the formula  $-O-Si-R_a$ , where  $R_a$  is a  $C_1$  to  $C_{20}$  hydrocarbyl radical or hydrocarbylsilyl group (or  $R_3$  is a fluoride or a  $C_6$  perfluorinated aromatic hydrocarbyl radical); wherein  $R_2$  and  $R_3$  can form one or more saturated or unsaturated, substituted or unsubstituted rings (or  $R_2$  and  $R_3$  form a perfluorinated phenyl ring);

10 L is an neutral Lewis base;  $(L-H)^+$  is a Bronsted acid; d is 1, 2, or 3;

wherein the anion has a molecular weight of greater than 1020 g/mol; and

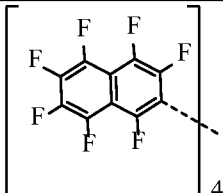
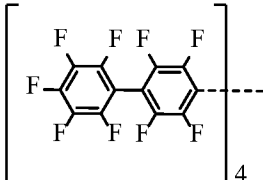
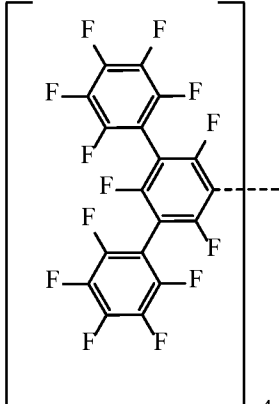
wherein at least three of the substituents on the B atom each have a molecular volume of greater than 250 cubic Å, or greater than 300 cubic Å, or greater than 500 cubic Å.

15 As discussed above, "Molecular volume" is used herein as an approximation of spatial steric bulk of an activator molecule in solution. Comparison of substituents with differing molecular volumes allows the substituent with the smaller molecular volume to be considered "less bulky" in comparison to the substituent with the larger molecular volume. Conversely, a substituent with a larger molecular volume may be  
20 considered "more bulky" than a substituent with a smaller molecular volume.

Molecular volume may be calculated as reported in "A Simple "Back of the Envelope" Method for Estimating the Densities and Molecular Volumes of Liquids and Solids," Journal of Chemical Education, , Vol. 71, No. 11, November 1994, pp. 962-964. Molecular volume (MV), in units of cubic Å, is calculated using the  
25 formula:  $MV = 8.3V_s$ , where  $V_s$  is the scaled volume.  $V_s$  is the sum of the relative volumes of the constituent atoms, and is calculated from the molecular formula of the substituent using the following table of relative volumes. For fused rings, the  $V_s$  is decreased by 7.5% per fused ring.

Element	Relative Volume
H	1
1 <sup>st</sup> short period, Li to F	2
2 <sup>nd</sup> short period, Na to Cl	4
1 <sup>st</sup> long period, K to Br	5
2 <sup>nd</sup> long period, Rb to I	7.5
3 <sup>rd</sup> long period, Cs to Bi	9

Exemplary bulky substituents of activators suitable herein and their respective scaled volumes and molecular volumes are shown in the table below. The dashed bonds indicate binding to boron, as in the general formula above.

Activator	Structure of boron substituents	Molecular Formula of each substituent	MV Per subst. (Å <sup>3</sup> )	Total MV (Å <sup>3</sup> )
Dimethylanilinium tetrakis(perfluoronaphthyl)borate		C <sub>10</sub> F <sub>7</sub>	261	1044
Dimethylanilinium tetrakis(perfluorobiphenyl)borate		C <sub>12</sub> F <sub>9</sub>	349	1396
[4-tButyl-PhNMe <sub>2</sub> H] [(C <sub>6</sub> F <sub>3</sub> (C <sub>6</sub> F <sub>5</sub> ) <sub>2</sub> ) <sub>4</sub> B]		C <sub>18</sub> F <sub>13</sub>	515	2060

5

Exemplary bulky activators useful in catalyst systems herein include:

trimethylammonium tetrakis(perfluoronaphthyl)borate,

triethylammonium tetrakis(perfluoronaphthyl)borate,

tripropylammonium tetrakis(perfluoronaphthyl)borate,

10 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,  
 5 tropillium tetrakis(perfluoronaphthyl)borate,  
 triphenylcarbenium tetrakis(perfluoronaphthyl)borate,  
 triphenylphosphonium tetrakis(perfluoronaphthyl)borate,  
 triethylsilylium tetrakis(perfluoronaphthyl)borate,  
 benzene(diazonium) tetrakis(perfluoronaphthyl)borate,  
 10 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,  
 15 N,N-dimethylanilinium tetrakis(perfluorobiphenyl)borate,  
 N,N-diethylanilinium tetrakis(perfluorobiphenyl)borate,  
 N,N-dimethyl-(2,4,6-trimethylanilinium) tetrakis(perfluorobiphenyl)borate,  
 tropillium tetrakis(perfluorobiphenyl)borate,  
 triphenylcarbenium tetrakis(perfluorobiphenyl)borate,  
 20 triphenylphosphonium tetrakis(perfluorobiphenyl)borate,  
 triethylsilylium tetrakis(perfluorobiphenyl)borate,  
 benzene(diazonium) tetrakis(perfluorobiphenyl)borate,  
 [4-tert-butyl-PhNMe<sub>2</sub>H][(C<sub>6</sub>F<sub>3</sub>(C<sub>6</sub>F<sub>5</sub>)<sub>2</sub>)<sub>4</sub>B], and the types disclosed in U.S. Patent  
 No. 7,297,653, which is fully incorporated by reference herein.

25 Illustrative, but not limiting, examples of boron compounds which may be used as an activator in the processes according to the instant disclosure include:

- trimethylammonium tetraphenylborate,  
 triethylammonium tetraphenylborate,  
 tripropylammonium tetraphenylborate,  
 30 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,  
tropillium tetraphenylborate,  
triphenylcarbenium tetraphenylborate,  
5 triphenylphosphonium tetraphenylborate,  
triethylsilylium tetraphenylborate,  
benzene(diazonium)tetraphenylborate,  
trimethylammonium tetrakis(pentafluorophenyl)borate,  
triethylammonium tetrakis(pentafluorophenyl)borate,  
10 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,  
15 N,N-dimethyl-(2,4,6-trimethylanilinium) tetrakis(pentafluorophenyl)borate,  
tropillium tetrakis(pentafluorophenyl)borate,  
triphenylcarbenium tetrakis(pentafluorophenyl)borate,  
triphenylphosphonium tetrakis(pentafluorophenyl)borate,  
triethylsilylium tetrakis(pentafluorophenyl)borate,  
20 benzene(diazonium) 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-tetrafluoro-phenyl)borate,  
25 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,  
tropillium tetrakis-(2,3,4,6-tetrafluorophenyl)borate,  
30 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,  
trimethylammonium tetrakis(perfluoronaphthyl)borate,  
triethylammonium tetrakis(perfluoronaphthyl)borate,  
tripropylammonium tetrakis(perfluoronaphthyl)borate,  
5 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,  
10 tropillium tetrakis(perfluoronaphthyl)borate,  
triphenylcarbenium tetrakis(perfluoronaphthyl)borate,  
triphenylphosphonium tetrakis(perfluoronaphthyl)borate,  
triethylsilylium tetrakis(perfluoronaphthyl)borate,  
benzene(diazonium) tetrakis(perfluoronaphthyl)borate,  
15 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,  
20 N,N-dimethylanilinium tetrakis(perfluorobiphenyl)borate,  
N,N-diethylanilinium tetrakis(perfluorobiphenyl)borate,  
N,N-dimethyl-(2,4,6-trimethylanilinium) tetrakis(perfluorobiphenyl)borate,  
tropillium tetrakis(perfluorobiphenyl)borate,  
triphenylcarbenium tetrakis(perfluorobiphenyl)borate,  
25 triphenylphosphonium tetrakis(perfluorobiphenyl)borate,  
triethylsilylium tetrakis(perfluorobiphenyl)borate,  
benzene(diazonium) tetrakis(perfluorobiphenyl)borate,  
trimethylammonium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate,  
triethylammonium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate,  
30 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,  
 5 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,  
 benzene(diazonium) tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, and  
 10 dialkyl ammonium salts, such as:  
 di-(i-propyl)ammonium tetrakis(pentafluorophenyl)borate, and  
 dicyclohexylammonium tetrakis(pentafluorophenyl)borate; and additional tri-  
 substituted phosphonium salts, such as tri(o-tolyl)phosphonium tetrakis  
 (pentafluorophenyl) borate, and tri(2,6-dimethylphenyl)phosphonium  
 15 tetrakis(pentafluorophenyl)borate.

Suitable activators include:

- N,N-dimethylanilinium tetrakis(perfluoronaphthyl)borate,  
 N,N-dimethylanilinium tetrakis(perfluorobiphenyl)borate,  
 N,N-dimethylanilinium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate,  
 20 triphenylcarbenium tetrakis(perfluoronaphthyl)borate,  
 triphenylcarbenium tetrakis(perfluorobiphenyl)borate,  
 triphenylcarbenium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate,  
 triphenylcarbenium tetrakis(perfluorophenyl)borate,  
 $[\text{Ph}_3\text{C}^+][\text{B}(\text{C}_6\text{F}_5)_4^-]$ ,  $[\text{Me}_3\text{NH}^+][\text{B}(\text{C}_6\text{F}_5)_4^-]$ ; 1-(4-(tris(pentafluorophenyl)borate)-  
 25 2,3,5,6-tetrafluorophenyl)pyrrolidinium; and tetrakis(pentafluorophenyl)borate,  
 4-(tris(pentafluorophenyl)borate)-2,3,5,6-tetrafluoropyridine.

- In an embodiment of the invention, the activator comprises a triaryl carbonium  
 (such as triphenylcarbenium tetraphenylborate,  
 triphenylcarbenium tetrakis(pentafluorophenyl)borate,  
 30 triphenylcarbenium tetrakis-(2,3,4,6-tetrafluorophenyl)borate,  
 triphenylcarbenium tetrakis(perfluoronaphthyl)borate,  
 triphenylcarbenium tetrakis(perfluorobiphenyl)borate,



triphenylcarbenium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate).

In an embodiment of the invention, the activator comprises one or more of trialkylammonium tetrakis(pentafluorophenyl)borate, N,N-dialkylanilinium tetrakis(pentafluorophenyl)borate, 5 N,N-dimethyl-(2,4,6-trimethylanilinium) tetrakis(pentafluorophenyl)borate, trialkylammonium tetrakis-(2,3,4,6-tetrafluorophenyl) borate, N,N-dialkylanilinium tetrakis-(2,3,4,6-tetrafluorophenyl)borate, trialkylammonium tetrakis(perfluoronaphthyl)borate, N,N-dialkylanilinium tetrakis(perfluoronaphthyl)borate, 10 trialkylammonium tetrakis(perfluorobiphenyl)borate, N,N-dialkylanilinium tetrakis(perfluorobiphenyl)borate, trialkylammonium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, N,N-dialkylanilinium tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, N,N-dialkyl-(2,4,6-trimethylanilinium) tetrakis(3,5-bis(trifluoromethyl)phenyl)borate, 15 di-(i-propyl)ammonium tetrakis(pentafluorophenyl)borate, (where alkyl is methyl, ethyl, propyl, n-butyl, sec-butyl, or tert-butyl).

In an embodiment of the invention, any of the activators described herein may be mixed together before or after combination with the catalyst compound and/or CTA and/or NCA, or before being mixed with the catalyst compound and/or CTA, 20 and/or NCA.

In an embodiment of the invention two NCA activators may be used in the polymerization and the molar ratio of the first NCA activator to the second NCA activator can be any ratio. In an embodiment of the invention, the molar ratio of the first NCA activator to the second NCA activator is 0.01:1 to 10,000:1, or 0.1:1 to 25 1000:1, or 1:1 to 100:1.

In an embodiment of the invention, the NCA activator-to-catalyst ratio is a 1:1 molar ratio, or 0.1:1 to 100:1, or 0.5:1 to 200:1, or 1:1 to 500:1 or 1:1 to 1000:1. In an embodiment of the invention, the NCA activator-to-catalyst ratio is 0.5:1 to 10:1, or 1:1 to 5:1.

30 In an embodiment of the invention, the catalyst compounds can be combined with combinations of alumoxanes and NCA's (see for example, US 5,153,157, US 5,453,410, EP 0 573 120 B1, WO 94/07928, and WO 95/14044 which discuss the use

of an alumoxane in combination with an ionizing activator, all of which are incorporated by reference herein).

Useful chain transfer agents are typically alkylalumoxanes, a compound represented by the formula  $AlR_3$ ,  $ZnR_2$  (where each R is, independently, a  $C_1$ - $C_8$  aliphatic radical, preferably methyl, ethyl, propyl butyl, pentyl, hexyl, octyl or an isomer thereof) or a combination thereof, such as diethyl zinc, methylalumoxane, trimethylaluminum, triisobutylaluminum, trioctylaluminum, or a combination thereof.

#### **SCAVENGERS OR CO-ACTIVATORS**

In an embodiment of the invention the catalyst system may further include scavengers and/or co-activators. Suitable aluminum alkyl or organoaluminum compounds which may be utilized as scavengers or co-activators include, for example, trimethylaluminum, triethylaluminum, triisobutylaluminum, tri-n-hexylaluminum, tri-n-octylaluminum and the like. Other oxophilic species such as diethyl zinc may be used.

#### **CATALYST SUPPORTS**

In an embodiment of the invention, the catalyst system may comprise an inert support material. In an embodiment of the invention, the support material comprises a porous support material, for example, talc, and/or inorganic oxides. Other suitable support materials include zeolites, clays, organoclays, or any other organic or inorganic support material and the like, or mixtures thereof.

In an embodiment of the invention, the support material is an inorganic oxide in a finely divided form. Suitable inorganic oxide materials for use in catalyst systems herein include Groups 2, 4, 13, and 14 metal oxides, such as silica, alumina, and mixtures thereof. Other inorganic oxides that may be employed either alone or in combination with the silica, and/or alumina include magnesia, titania, zirconia, montmorillonite, phyllosilicate, and/or the like. Other suitable support materials include finely divided functionalized polyolefins, such as finely divided polyethylene.

In an embodiment of the invention, the support material may have a surface area in the range of from about 10 to about 700  $m^2/g$ , pore volume in the range of from about 0.1 to about 4.0 cc/g and average particle size in the range of from about 5 to about 500  $\mu m$ , or the surface area of the support material is in the range of from about 50 to about 500  $m^2/g$ , pore volume of from about 0.5 to about 3.5 cc/g and

average particle size of from about 10 to about 200  $\mu\text{m}$ . In an embodiment of the invention, a majority portion of the surface area of the support material is in the range is from about 100 to about 400  $\text{m}^2/\text{g}$ , pore volume is from about 0.8 to about 3.0  $\text{cc}/\text{g}$  and average particle size is from about 5 to about 100  $\mu\text{m}$ . In an embodiment of the invention, the average pore size of the support material is in the range of from 10 to 5  
1000  $\text{\AA}$ , or 50 to about 500  $\text{\AA}$ , or 75 to about 350  $\text{\AA}$ . In an embodiment of the invention, the support material is a high surface area, amorphous silica having a surface area greater than or equal to about 300  $\text{m}^2/\text{g}$ , and/or a pore volume of 1.65  $\text{cm}^3/\text{gm}$ . Suitable silicas are marketed under the tradenames of Davison 952 or  
10 Davison 955 by the Davison Chemical Division of W.R. Grace and Company. In an embodiment of the invention the support may comprise Davison 948.

In an embodiment of the invention, the support material should be essentially dry, that is, essentially free of absorbed water. Drying of the support material can be effected by heating or calcining at about 100  $^{\circ}\text{C}$  to about 1000  $^{\circ}\text{C}$ , or at a temperature  
15 of at least about 400  $^{\circ}\text{C}$ , or 500  $^{\circ}\text{C}$ , or 600  $^{\circ}\text{C}$ . When the support material is silica, it is heated to at least 200  $^{\circ}\text{C}$ , or about 200  $^{\circ}\text{C}$  to about 850  $^{\circ}\text{C}$ , or at least 600  $^{\circ}\text{C}$  for a time of about 1 minute to about 100 hours, or from about 12 hours to about 72 hours, or from about 24 hours to about 60 hours. In an embodiment of the invention, the calcined support material must have at least some reactive hydroxyl (OH) groups to  
20 produce supported catalyst systems according to the instant disclosure.

In an embodiment of the invention, the calcined support material is contacted with at least one polymerization catalyst comprising at least one catalyst compound and an activator. In an embodiment of the invention, the support material, having reactive surface groups, typically hydroxyl groups, is slurried in a non-polar solvent  
25 and the resulting slurry is contacted with a solution of a catalyst compound and an activator. In an embodiment of the invention, the slurry of the support material is first contacted with the activator for a period of time in the range of from about 0.5 hours to about 24 hours, or from about 2 hours to about 16 hours, or from about 4 hours to about 8 hours. The solution of the catalyst compound is then contacted with the  
30 isolated support/activator. In an embodiment of the invention, the supported catalyst system is generated in situ. In alternate embodiment of the invention, the slurry of the support material is first contacted with the catalyst compound for a period of time in

the range of from about 0.5 hours to about 24 hours, or from about 2 hours to about 16 hours, or from about 4 hours to about 8 hours. The slurry of the supported catalyst compound is then contacted with the activator solution.

In an embodiment of the invention, the mixture of the catalyst, activator and support is heated to about 0 °C to about 70 °C, or to about 23 °C to about 60 °C, or to room temperature. Contact times typically range from about 0.5 hours to about 24 hours, or from about 2 hours to about 16 hours, or from about 4 hours to about 8 hours.

Suitable non-polar solvents are materials in which all of the reactants used herein, i.e., the activator and the catalyst compound are at least partially soluble and which are liquid at reaction temperatures. Suitable non-polar solvents include alkanes, such as isopentane, hexane, n-heptane, octane, nonane, and decane, although a variety of other materials including cycloalkanes, such as cyclohexane, aromatics, such as benzene, toluene, and ethylbenzene, may also be employed.

#### 15 **POLYMERIZATION PROCESSES**

In an embodiment of the invention, a polymerization process includes contacting monomers (such as ethylene and propylene), and optionally comonomers, with a catalyst system comprising an activator and at least one catalyst compound, as described above. In an embodiment of the invention, the catalyst compound and activator may be combined in any order, and may be combined prior to contacting with the monomer. In an embodiment of the invention, the catalyst compound and/or the activator are combined after contacting with the monomer.

Monomers useful herein include substituted or unsubstituted C<sub>2</sub> to C<sub>40</sub> alpha olefins, or C<sub>2</sub> to C<sub>20</sub> alpha olefins, or C<sub>2</sub> to C<sub>12</sub> alpha olefins, or ethylene, propylene, butene, pentene, hexene, heptene, octene, nonene, decene, undecene, dodecene and isomers thereof. In an embodiment of the invention, the monomer comprises propylene and an optional comonomer(s) comprising one or more ethylene or C<sub>4</sub> to C<sub>40</sub> olefins, or C<sub>4</sub> to C<sub>20</sub> olefins, or C<sub>6</sub> to C<sub>12</sub> olefins. The C<sub>4</sub> to C<sub>40</sub> olefin monomers may be linear, branched, or cyclic. The C<sub>4</sub> to C<sub>40</sub> cyclic olefins may be strained or unstrained, monocyclic or polycyclic, and may optionally include heteroatoms and/or one or more functional groups. In an embodiment of the invention, the monomer comprises ethylene or ethylene and a comonomer comprising

one or more C<sub>3</sub> to C<sub>40</sub> olefins, or C<sub>4</sub> to C<sub>20</sub> olefins, or C<sub>6</sub> to C<sub>12</sub> olefins. The C<sub>3</sub> to C<sub>40</sub> olefin monomers may be linear, branched, or cyclic. The C<sub>3</sub> to C<sub>40</sub> cyclic olefins may be strained or unstrained, monocyclic or polycyclic, and may optionally include heteroatoms and/or one or more functional groups.

5 Exemplary C<sub>2</sub> to C<sub>40</sub> olefin monomers and optional comonomers include ethylene, propylene, butene, pentene, hexene, heptene, octene, nonene, decene, undecene, dodecene, norbornene, norbornadiene, dicyclopentadiene, cyclopentene, cycloheptene, cyclooctene, cyclooctadiene, cyclododecene, 7-oxanorbornene, 7-oxanorbornadiene, substituted derivatives thereof, and isomers thereof, or hexene,  
10 heptene, octene, nonene, decene, dodecene, cyclooctene, 1,5-cyclooctadiene, 1-hydroxy-4-cyclooctene, 1-acetoxy-4-cyclooctene, 5-methylcyclopentene, cyclopentene, dicyclopentadiene, norbornene, norbornadiene, and their respective homologs and derivatives, or norbornene, norbornadiene, and dicyclopentadiene.

In an embodiment of the invention one or more dienes are present in the  
15 polymer produced herein at up to 10 weight %, or at 0.00001 to 1.0 weight %, or 0.002 to 0.5 weight %, or 0.003 to 0.2 weight %, based upon the total weight of the composition. In an embodiment of the invention 500 ppm or less of diene is added to the polymerization, or 400 ppm or less, or 300 ppm or less. In an embodiment of the invention at least 50 ppm of diene is added to the polymerization, or 100 ppm or  
20 more, or 150 ppm or more.

Diolefin monomers useful in this invention include any hydrocarbon structure, or C<sub>4</sub> to C<sub>30</sub>, having at least two unsaturated bonds, wherein at least two of the unsaturated bonds are readily incorporated into a polymer by either a stereospecific or a non-stereospecific catalyst(s). In an embodiment of the invention, the diolefin  
25 monomers may be selected from alpha, omega-diene monomers (i.e. di-vinyl monomers). Preferably, the diolefin monomers are linear di-vinyl monomers, most or those containing from 4 to 30 carbon atoms. Examples of dienes include butadiene, pentadiene, hexadiene, heptadiene, octadiene, nonadiene, decadiene, undecadiene, dodecadiene, tridecadiene, tetradecadiene, pentadecadiene, hexadecadiene,  
30 heptadecadiene, octadecadiene, nonadecadiene, icosadiene, heneicosadiene, docosadiene, tricosadiene, tetracosadiene, pentacosadiene, hexacosadiene, heptacosadiene, octacosadiene, nonacosadiene, triacontadiene, 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). Cyclic dienes include cyclopentadiene, vinylnorbornene, norbornadiene, ethylidene norbornene, divinylbenzene, dicyclopentadiene or higher ring containing diolefins with or without substituents at various ring positions.

In an embodiment of the invention, where butene is the comonomer, the butene source may be a mixed butene stream comprising various isomers of butene. The 1-butene monomers are expected to be preferentially consumed by the polymerization process. Use of such mixed butene streams will provide an economic benefit, as these mixed streams are often waste streams from refining processes, for example, C<sub>4</sub> raffinate streams, and can therefore be substantially less expensive than pure 1-butene.

Polymerization processes according to the instant disclosure may be carried out in any manner known in the art. Any suspension, homogeneous, bulk, solution, slurry, or gas phase polymerization process known in the art can be used. Such processes can be run in a batch, semi-batch, or continuous mode. Homogeneous polymerization processes and slurry processes are suitable for use herein, wherein a homogeneous polymerization process is defined to be a process where at least 90 wt% of the product is soluble in the reaction media. A bulk homogeneous process is suitable for use herein, wherein a bulk process is defined to be a process where monomer concentration in all feeds to the reactor is 70 volume % or more. In an embodiment of the invention, no solvent or diluent is present or added in the reaction medium, (except for the small amounts used as the carrier for the catalyst system or other additives, or amounts typically found with the monomer; e.g., propane in propylene). In an embodiment of the invention, the process is a slurry process. As used herein the term "slurry polymerization process" means a polymerization process where a supported catalyst is employed and monomers are polymerized on the supported catalyst particles. At least 95 wt% of polymer products derived from the supported catalyst are in granular form as solid particles (not dissolved in the diluent).

Suitable diluents/solvents for polymerization include non-coordinating, inert liquids. Examples include straight and branched-chain hydrocarbons, such as isobutane, butane, pentane, isopentane, hexanes, isohexane, heptane, octane,

dodecane, and mixtures thereof; cyclic and alicyclic hydrocarbons, such as cyclohexane, cycloheptane, methylcyclohexane, methylcycloheptane, and mixtures thereof, such as can be found commercially (Isopar™); perhalogenated hydrocarbons, such as perfluorinated C<sub>4-10</sub> alkanes, chlorobenzene, and aromatic and alkyl substituted aromatic compounds, such as benzene, toluene, mesitylene, and xylene. Suitable solvents also include liquid olefins which may act as monomers or comonomers including ethylene, propylene, 1-butene, 1-hexene, 1-pentene, 3-methyl-1-pentene, 4-methyl-1-pentene, 1-octene, 1-decene, and mixtures thereof. In an embodiment of the invention, aliphatic hydrocarbon solvents are used as the solvent, such as isobutane, butane, pentane, isopentane, hexanes, isohexane, heptane, octane, dodecane, and mixtures thereof; cyclic and alicyclic hydrocarbons, such as cyclohexane, cycloheptane, methylcyclohexane, methylcycloheptane, and mixtures thereof. In an embodiment of the invention, the solvent is not aromatic, or aromatics are present in the solvent at less than 1 wt%, or less than 0.5 wt%, or less than 0.0 wt% based upon the weight of the solvents.

In an embodiment of the invention, the feed concentration of the monomers and comonomers for the polymerization is 60 vol% solvent or less, or 40 vol% or less, or 20 vol% or less, based on the total volume of the feedstream. The polymerization may also be run in a bulk process.

Polymerizations can be run at any temperature and/or pressure suitable to obtain the desired ethylene polymers. Suitable temperatures and/or pressures include a temperature in the range of from about 0 °C to about 300 °C, or about 20 °C to about 200 °C, or about 35 °C to about 150 °C, or from about 40 °C to about 120 °C, or from about 45 °C to about 80 °C; and at a pressure in the range of from about 0.35 MPa to about 10 MPa, or from about 0.45 MPa to about 6 MPa, or from about 0.5 MPa to about 4 MPa.

In an embodiment of the invention, the run time of the reaction is from about 0.1 minutes to about 24 hours, or up to 16 hours, or in the range of from about 5 to 250 minutes, or from about 10 to 120 minutes.

In an embodiment of the invention, hydrogen is present in the polymerization reactor at a partial pressure of 0.001 to 50 psig (0.007 to 345 kPa), or from 0.01 to 25 psig (0.07 to 172 kPa), or 0.1 to 10 psig (0.7 to 70 kPa).

In an embodiment of the invention, the activity of the catalyst is at least 50 g/mmol/hour, or 500 or more g/mmol/hour, or 5000 or more g/mmol/hr, or 50,000 or more g/mmol/hr. In an alternate embodiment of the invention, the conversion of olefin monomer is at least 10%, based upon polymer yield and the weight of the monomer entering the reaction zone, or 20% or more, or 30% or more, or 50% or more, or 80% or more.

In an embodiment of the invention, the polymerization conditions include one or more of the following: 1) temperatures of 0 to 300 °C (or 25 to 150 °C, or 40 to 120 °C, or 45 to 80 °C); 2) a pressure of atmospheric pressure to 10 MPa (or 0.35 to 10 MPa, or from 0.45 to 6 MPa, or from 0.5 to 4 MPa); 3) the presence of an aliphatic hydrocarbon solvent (such as isobutane, butane, pentane, isopentane, hexanes, isohexane, heptane, octane, dodecane, and mixtures thereof; cyclic and alicyclic hydrocarbons, such as cyclohexane, cycloheptane, methylcyclohexane, methylcycloheptane, and mixtures thereof; or where aromatics are or present in the solvent at less than 1 wt%, or less than 0.5 wt%, or at 0 wt% based upon the weight of the solvents); 4) wherein the catalyst system used in the polymerization comprises less than 0.5 mol%, or 0 mol% alumoxane, or the alumoxane is present at a molar ratio of aluminum to transition metal less than 500:1, or less than 300:1, or less than 100:1, or less than 1:1; 5) the polymerization or occurs in one reaction zone; 6) the productivity of the catalyst compound is at least 80,000 g/mmol/hr (or at least 150,000 g/mmol/hr, or at least 200,000 g/mmol/hr, or at least 250,000 g/mmol/hr, or at least 300,000 g/mmol/hr); 7) scavengers (such as trialkyl aluminum compounds) are absent (e.g., present at zero mol%) or the scavenger is present at a molar ratio of scavenger to transition metal of less than 100:1, or less than 50:1, or less than 15:1, or less than 10:1; and/or 8) optionally hydrogen is present in the polymerization reactor at a partial pressure of 0.007 to 345 kPa (0.001 to 50 psig) (or from 0.07 to 172 kPa (0.01 to 25 psig), or 0.7 to 70 kPa (0.1 to 10 psig)).

In an embodiment of the invention, the catalyst system used in the polymerization comprises no more than one catalyst compound. A "reaction zone" also referred to as a "polymerization zone" is a vessel where polymerization takes place, for example a batch reactor. When multiple reactors are used in either series or parallel configuration, each reactor is considered as a separate polymerization zone.



For a multi-stage polymerization in both a batch reactor and a continuous reactor, each polymerization stage is considered as a separate polymerization zone. In an embodiment of the invention, the polymerization occurs in one reaction zone.

### **POLYOLEFIN PRODUCTS**

5           The instant disclosure also relates to compositions of matter produced by the methods described herein.

          In an embodiment of the invention, the process described herein produces propylene homopolymers or propylene copolymers, such as propylene-ethylene and/or propylene- $\alpha$ -olefin (or C<sub>3</sub> to C<sub>20</sub>) copolymers (such as propylene-hexene copolymers or propylene-octene copolymers) having a Mw/Mn of greater than 1 to 4 (or greater than 1 to 3).

          Likewise, the process of this invention produces olefin polymers, or polyethylene and polypropylene homopolymers and copolymers. In an embodiment of the invention, the polymers produced herein are homopolymers of ethylene or propylene, are copolymers of ethylene or having from 0 to 25 mole% (or from 0.5 to 20 mole%, or from 1 to 15 mole%, or from 3 to 10 mole%) of one or more C<sub>3</sub> to C<sub>20</sub> olefin comonomer (or C<sub>3</sub> to C<sub>12</sub> alpha-olefin, or propylene, butene, hexene, octene, decene, dodecene, or propylene, butene, hexene, octene), or are copolymers of propylene or having from 0 to 25 mole% (or from 0.5 to 20 mole%, or from 1 to 15 mole%, or from 3 to 10 mole%) of one or more of C<sub>2</sub> or C<sub>4</sub> to C<sub>20</sub> olefin comonomer (or ethylene or C<sub>4</sub> to C<sub>12</sub> alpha-olefin, or ethylene, butene, hexene, octene, decene, dodecene, or ethylene, butene, hexene, octene).

          In an embodiment of the invention, the polymers produced herein have an Mw of 5,000 to 1,000,000 g/mol (e.g., 25,000 to 750,000 g/mol, or 50,000 to 500,000 g/mol), and/or an Mw/Mn of greater than 1 to 40, or 1.2 to 20, or 1.3 to 10, or 1.4 to 5, or 1.5 to 4, or 1.5 to 3.

          In an embodiment of the invention, the polymer produced herein has a unimodal or multimodal molecular weight distribution as determined by Gel Permeation Chromatography (GPC). By "unimodal" is meant that the GPC trace has one peak or inflection point. By "multimodal" is meant that the GPC trace has at least two peaks or inflection points. An inflection point is that point where the second derivative of the curve changes in sign (e.g., from negative to positive or vice versa).

Unless otherwise indicated Mw, Mn, MWD are determined by GPC as described in US 2006/0173123 page 24-25, paragraphs [0334] to [0341].

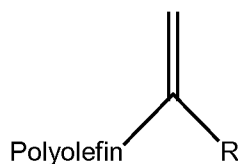
In an embodiment of the invention, the instant catalyst is used to produce vinyl terminated propylene polymers having unsaturated chain end or terminus. The unsaturated chain end of the vinyl terminated macromonomer comprises an “allyl chain end”, a vinylidene chain end, or a “3-alkyl” chain end.

An allyl chain end is represented by  $\text{CH}_2\text{CH}=\text{CH}_2$ -, as shown in the formula:



where M represents the polymer chain. “Allylic vinyl group,” “allyl chain end,” “vinyl chain end,” “vinyl termination,” “allylic vinyl group,” and “vinyl terminated” are used interchangeably in the following description. The number of allyl chain ends, vinylidene chain ends, vinylene chain ends, and other unsaturated chain ends is determined using  $^1\text{H}$  NMR at  $120^\circ\text{C}$  using deuterated tetrachloroethane as the solvent on an at least 250 MHz NMR spectrometer, and in selected cases, confirmed by  $^{13}\text{C}$  NMR. Resconi has reported proton and carbon assignments (neat perdeuterated tetrachloroethane used for proton spectra, while a 50:50 mixture of normal and perdeuterated tetrachloroethane was used for carbon spectra; all spectra were recorded at  $100^\circ\text{C}$  on a BRUKER spectrometer operating at 500 MHz for proton and 125 MHz for carbon) for vinyl terminated oligomers in *J. American Chemical Soc.*, 114, 1992, pp. 1025-1032 that are useful herein. Allyl chain ends are reported as a molar percentage of the total number of moles of unsaturated groups (that is, the sum of allyl chain ends, vinylidene chain ends, vinylene chain ends, and the like).

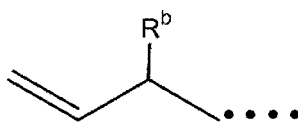
A vinylidene chain end is represented by the formula:



where R can be H, alkyl, aryl alkyl, or alkaryl.

A 3-alkyl chain end (where the alkyl is a  $\text{C}_1$  to  $\text{C}_{38}$  alkyl), also referred to as a “3-alkyl vinyl end group” or a “3-alkyl vinyl termination”, is represented by the

formula:



3-alkyl vinyl end group

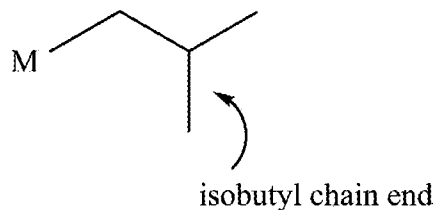
where “••••” represents the polyolefin chain and R<sup>b</sup> is a C<sub>1</sub> to C<sub>38</sub> alkyl group, or a C<sub>1</sub> to C<sub>20</sub> alkyl group, such as methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl,  
 5 nonyl, decyl, undecyl, dodecyl, and the like. The amount of 3-alkyl chain ends is determined using <sup>13</sup>C NMR as set out below.

<sup>13</sup>C NMR data is collected at 120°C at a frequency of at least 100 MHz, using a BRUKER 400 MHz NMR spectrometer. A 90 degree pulse, an acquisition time adjusted to give a digital resolution between 0.1 and 0.12 Hz, at least a 10 second  
 10 pulse acquisition delay time with continuous broadband proton decoupling using swept square wave modulation without gating is employed during the entire acquisition period. The spectra is acquired with time averaging to provide a signal to noise level adequate to measure the signals of interest. Samples are dissolved in tetrachloroethane-d<sub>2</sub> at concentrations between 10 wt% to 15 wt% prior to being  
 15 inserted into the spectrometer magnet. Prior to data analysis spectra are referenced by setting the chemical shift of the TCE solvent signal to 74.39 ppm. Chain ends for quantization were identified using the signals shown in the table below. N-butyl and n-propyl were not reported due to their low abundance (less than 5%) relative to the chain ends shown in the table below.

Chain End	<sup>13</sup> C NMR Chemical Shift
P~i-Bu	23.5 to 25.5 and 25.8 to 26.3 ppm
E~i-Bu	39.5 to 40.2 ppm
P~Vinyl	41.5 to 43 ppm
E~Vinyl	33.9 to 34.4 ppm

20 The “allyl chain end to vinylidene chain end ratio” is defined to be the ratio of the percentage of allyl chain ends to the percentage of vinylidene chain ends. The “allyl chain end to vinylidene chain end ratio” is defined to be the ratio of the percentage of allyl chain ends to the percentage of vinylene chain ends. Vinyl terminated macromonomers typically also have a saturated chain end. In

polymerizations where propylene is present, the polymer chain may initiate growth in a propylene monomer, thereby generating an isobutyl chain end. An “isobutyl chain end” is defined to be an end or terminus of a polymer, represented as shown in the formula below:



where M represents the polymer chain. Isobutyl chain ends are determined according to the procedure set out in WO 2009/155471. The “isobutyl chain end to allylic vinyl group ratio” is defined to be the ratio of the percentage of isobutyl chain ends to the percentage of allyl chain ends. The “isobutyl chain end to alpha bromo carbon ratio” is defined to be the ratio of the percentage of isobutyl chain ends to the percentage of brominated chain ends (at about 34 ppm).

In an embodiment of the invention, the propylene polymer produced using the instant catalyst comprises at least 50% vinyl or unsaturated chain ends. In an embodiment of the invention, at least 90%, or at least 95%, or at least 99% vinylidene chain ends.

In an embodiment of the invention, the polyolefins produced using the instant catalyst may be isotactic, highly isotactic, syndiotactic, or highly syndiotactic propylene polymer. As used herein, “isotactic” is defined as having at least 10% isotactic pentads, preferably having at least 40% isotactic pentads of methyl groups derived from propylene according to analysis by  $^{13}\text{C}$ -NMR. As used herein, “highly isotactic” is defined as having at least 60% isotactic pentads according to analysis by  $^{13}\text{C}$ -NMR. In a desirable embodiment, the vinyl terminated polyolefin (preferably polypropylene) has at least 85% isotacticity. As used herein, “syndiotactic” is defined as having at least 10% syndiotactic pentads, preferably at least 40%, according to analysis by  $^{13}\text{C}$ -NMR. As used herein, “highly syndiotactic” is defined as having at least 60% syndiotactic pentads according to analysis by  $^{13}\text{C}$ -NMR. In another embodiment, the vinyl terminated polyolefin (preferably polypropylene) has at least 85% syndiotacticity.

In an embodiment of the invention, the polymers may be linear in character, which may be determined by elution fractionation, wherein non-linear polymers have a CDBI of less than 45%, whereas linear polyethylene types refer to polyethylene having a CDBI of greater than 50%, the CDBI being determined as described in  
5 WO93/03093 (US5206075). In an embodiment of the invention the polymer produced herein has a composition distribution breadth index (CDBI) of 50% or more, or 60% or more, or 70 % or more. CDBI is a measure of the composition distribution of monomer within the polymer chains and is measured by the procedure described in PCT publication WO 93/03093, published February 18, 1993, specifically columns 7  
10 and 8 as well as in Wild et al, *J. Poly. Sci., Poly. Phys. Ed.*, Vol. 20, p. 441 (1982) and U.S. Patent No. 5,008,204, including that fractions having a weight average molecular weight (Mw) below 15,000 are ignored when determining CDBI.

Polymers with an Mw/Mn of 4.5 or less may include a significant level of long chain branching. The long chain branching is understood to be the result of the  
15 incorporation of terminally unsaturated polymer chains (formed by the specific termination reaction mechanism encountered with single site catalysts) into other polymer chains in a manner analogous to monomer incorporation. The branches are hence believed to be linear in structure and may be present at a level where no peaks can be specifically attributed to such long chain branches in the <sup>13</sup>C NMR spectrum.  
20 In an embodiment of the invention, the polymers produced according to the instant disclosure comprise a significant amount of long chain branching, defined as having a ratio of long chain branching of at least 7 carbons per 1000 carbon atoms as determined according to the <sup>13</sup>C NMR spectrum of greater than 0.5. In an embodiment of the invention, the ratio of long chain branching with branches having  
25 at least 7 carbons, per 1000 carbon atoms as determined according to the <sup>13</sup>C NMR spectrum is greater than 1, or greater than 1.5, or greater than 2.

In an embodiment of the invention, the polymers produced according to the instant disclosure include a significant amount of vinyl termination, defined as a ratio of vinyl groups per molecule of greater than or equal to 0.2. In an embodiment of the  
30 invention, the polymers according to the instant disclosure comprise a ratio of vinyl groups per molecule of greater than or equal to 0.5, or 0.7, or 0.8, or 0.9, or 0.95, when determined according to the description provided in the *J. American Chemical*

*Soc.*, 114,1992, pp. 1025-1032, or an equivalent thereof.

### **BLENDS**

In an embodiment of the invention, the polymer (or the polyethylene or polypropylene) produced herein is combined with one or more additional polymers prior to being formed into a film, molded part or other article. Other useful polymers include polyethylene, isotactic polypropylene, highly isotactic polypropylene, syndiotactic polypropylene, random copolymer of propylene and ethylene, and/or butene, and/or hexene, polybutene, ethylene vinyl acetate, LDPE, LLDPE, HDPE, ethylene vinyl acetate, ethylene methyl acrylate, copolymers of acrylic acid, polymethylmethacrylate or any other polymers polymerizable by a high-pressure free radical process, polyvinylchloride, polybutene-1, isotactic polybutene, ABS resins, ethylene-propylene rubber (EPR), vulcanized EPR, EPDM, block copolymer, styrenic block copolymers, polyamides, polycarbonates, PET resins, cross linked polyethylene, copolymers of ethylene and vinyl alcohol (EVOH), polymers of aromatic monomers such as polystyrene, poly-1 esters, polyacetal, polyvinylidene fluoride, polyethylene glycols, and/or polyisobutylene.

In an embodiment of the invention, the polymer (or the polyethylene or polypropylene) is present in the above blends, at from 10 to 99 wt%, based upon the weight of the polymers in the blend, or 20 to 95 wt%, or at least 30 to 90 wt%, or at least 40 to 90 wt%, or at least 50 to 90 wt%, or at least 60 to 90 wt%, or at least 70 to 90 wt%.

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

The blends may be formed using conventional equipment and methods, such as by dry blending the individual components and subsequently melt mixing in a mixer, or by mixing the components together directly in a mixer, such as, for example, a Banbury mixer, a Haake mixer, a Brabender internal mixer, or a single or twin-screw extruder, which may include a compounding extruder and a side-arm extruder used directly downstream of a polymerization process, which may include blending

powders or pellets of the resins at the hopper of the film extruder. Additionally, additives may be included in the blend, in one or more components of the blend, and/or in a product formed from the blend, such as a film, as desired. Such additives are well known in the art, and can include, for example: fillers; antioxidants (e.g., hindered phenolics such as IRGANOX 1010 or IRGANOX 1076 available from Ciba-Geigy); phosphites (e.g., IRGAFOS 168 available from Ciba-Geigy); anti-cling additives; tackifiers, such as polybutenes, terpene resins, aliphatic and aromatic hydrocarbon resins, alkali metal and glycerol stearates, and hydrogenated rosins; UV stabilizers; heat stabilizers; anti-blocking agents; release agents; anti-static agents; pigments; colorants; dyes; waxes; silica; fillers; talc; and the like.

### **FILMS**

In an embodiment of the invention, any of the foregoing polymers, such as the foregoing polypropylenes or blends thereof, may be used in a variety of end-use applications.

Applications include, for example, mono- or multi-layer blown, extruded, and/or shrink films. These films may be formed by any number of well known extrusion or coextrusion techniques, such as a blown bubble film processing technique, wherein the composition can be extruded in a molten state through an annular die and then expanded to form a uni-axial or biaxial orientation melt prior to being cooled to form a tubular, blown film, which can then be axially slit and unfolded to form a flat film. Films may be subsequently unoriented, uniaxially oriented, or biaxially oriented to the same or different extents. One or more of the layers of the film may be oriented in the transverse and/or longitudinal directions to the same or different extents. The uniaxial orientation can be accomplished using typical cold drawing or hot drawing methods. Biaxial orientation can be accomplished using tenter frame equipment or a double bubble processes and may occur before or after the individual layers are brought together. For example, a polyethylene layer can be extrusion coated or laminated onto an oriented polypropylene layer or the polyethylene and polypropylene can be coextruded together into a film then oriented. Likewise, oriented polypropylene could be laminated to oriented polyethylene or oriented polyethylene could be coated onto polypropylene then optionally the combination could be oriented even further. Typically the films are oriented in the machine direction (MD) at a ratio of up to 15,

or between 5 and 7, and in the transverse direction (TD) at a ratio of up to 15, or 7 to 9. However, In an embodiment of the invention the film is oriented to the same extent in both the MD and TD directions.

The films may vary in thickness depending on the intended application; however, films of a thickness from 1 to 50  $\mu\text{m}$  are usually suitable. Films intended for packaging are usually from 10 to 50  $\mu\text{m}$  thick. The thickness of the sealing layer is typically 0.2 to 50  $\mu\text{m}$ . There may be a sealing layer on both the inner and outer surfaces of the film or the sealing layer may be present on only the inner or the outer surface.

In an embodiment of the invention, one or more layers may be modified by corona treatment, electron beam irradiation, gamma irradiation, flame treatment, or microwave. In an embodiment of the invention, one or both of the surface layers is modified by corona treatment.

### **MOLDED PRODUCTS**

The compositions described herein (or polypropylene compositions) may also be used to prepare molded products in any molding process, including but not limited to, injection molding, gas-assisted injection molding, extrusion blow molding, injection blow molding, injection stretch blow molding, compression molding, rotational molding, foam molding, thermoforming, sheet extrusion, and profile extrusion. The molding processes are well known to those of ordinary skill in the art.

Further, the compositions described herein (or polypropylene compositions) may be shaped into desirable end use articles by any suitable means known in the art. Thermoforming, vacuum forming, blow molding, rotational molding, slush molding, transfer molding, wet lay-up or contact molding, cast molding, cold forming matched-die molding, injection molding, spray techniques, profile co-extrusion, or combinations thereof are typically used methods.

Thermoforming is a process of forming at least one pliable plastic sheet into a desired shape. Typically, an extrudate film of the composition of this invention (and any other layers or materials) is placed on a shuttle rack to hold it during heating. The shuttle rack indexes into the oven which pre-heats the film before forming. Once the film is heated, the shuttle rack indexes back to the forming tool. The film is then vacuumed onto the forming tool to hold it in place and the forming



tool is closed. The tool stays closed to cool the film and the tool is then opened. The shaped laminate is then removed from the tool. The thermoforming is accomplished by vacuum, positive air pressure, plug-assisted vacuum forming, or combinations and variations of these, once the sheet of material reaches thermoforming temperatures, typically of from 140 °C to 185 °C or higher. A pre-stretched bubble step is used, especially on large parts, to improve material distribution.

Blow molding is another suitable forming means for use with the compositions of this invention, which includes injection blow molding, multi-layer blow molding, extrusion blow molding, and stretch blow molding, and is especially suitable for substantially closed or hollow objects, such as, for example, gas tanks and other fluid containers. Blow molding is described in more detail in, for example, CONCISE ENCYCLOPEDIA OF POLYMER SCIENCE AND ENGINEERING, pp. 90-92 (Jacqueline I. Kroschwitz, ed., John Wiley & Sons 1990).

Likewise, molded articles may be fabricated by injecting molten polymer into a mold that shapes and solidifies the molten polymer into desirable geometry and thickness of molded articles. Sheets may be made either by extruding a substantially flat profile from a die, onto a chill roll, or by calendaring. Sheets are generally considered to have a thickness of from 254 µm to 2540 µm (10 mils to 100 mils), although any given sheet may be substantially thicker.

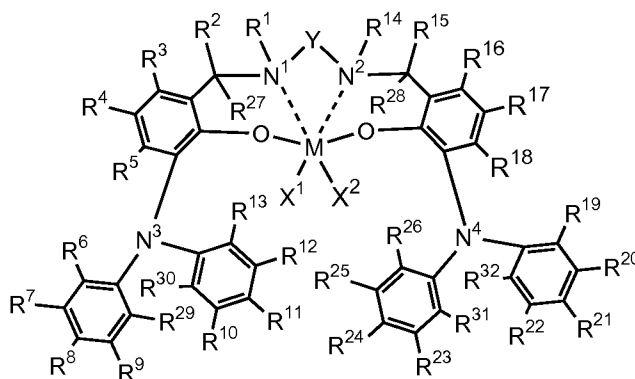
#### **NON-WOVENS AND FIBERS**

The polyolefin compositions described above may also be used to prepare nonwoven fabrics and fibers of this invention in any nonwoven fabric and fiber making process, including but not limited to, melt blowing, spunbonding, film aperturing, and staple fiber carding. A continuous filament process may also be used. A spunbonding process may also be used. The spunbonding process is well known in the art. Generally it involves the extrusion of fibers through a spinneret. These fibers are then drawn using high velocity air and laid on an endless belt. A calender roll is generally then used to heat the web and bond the fibers to one another although other techniques may be used such as sonic bonding and adhesive bonding.

#### **EMBODIMENTS LISTING**

Accordingly, the instant disclosure relates to the following embodiments:

A. A catalyst compound represented by the formula:



wherein each solid line represents a covalent bond and each dashed line represents a bond having varying degrees of covalency and a varying degree of coordination;

5

M is a Group 3, 4, 5 or 6 transition metal;

N<sup>1</sup>, N<sup>2</sup>, N<sup>3</sup> and N<sup>4</sup> are nitrogen;

each of X<sup>1</sup> and X<sup>2</sup> is, independently, a univalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical, a functional group comprising elements from Groups 13 – 17 of the periodic table of the elements, or X<sup>1</sup> and X<sup>2</sup> join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure, provided however when M is trivalent X<sup>2</sup> is not present;

10

Y is a divalent hydrocarbyl radical covalently bonded to and bridging between both of the nitrogen atoms N<sup>1</sup> and N<sup>2</sup>; and

15

each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> is, independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of R<sup>1</sup> to R<sup>32</sup> may independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure, or a combination thereof.

20

B. The catalyst compound of embodiment A wherein M is Hf, Ti, or Zr.

C. The catalyst compound of embodiment A or embodiment B wherein each X is, independently, a halogen or a C<sub>1</sub> to C<sub>7</sub> hydrocarbyl radical, preferably methyl, ethyl, propyl, butyl, pentyl, hexyl, benzyl, heptyl, chloro, benzo, iodo, and the like.

25

D. The catalyst compound of any one of embodiments A to C wherein each X is a

benzyl radical.

- E. The catalyst compound of any one of embodiments A to D wherein Y is -CH<sub>2</sub>CH<sub>2</sub>- or 1,2-cyclohexylene.
- F. The catalyst compound of any one of embodiments A to E wherein Y is -CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>-.
- G. The catalyst compound of any one of embodiments A to F wherein Y is a C<sub>1</sub>-C<sub>40</sub> divalent hydrocarbyl radical comprising a linker backbone comprising from 1 to 18 carbon atoms bridging between nitrogen atoms N<sup>1</sup> and N<sup>2</sup>.
- H. The catalyst compound of any one of embodiments A to G wherein Y is a C<sub>1</sub>-C<sub>40</sub> divalent hydrocarbyl radical comprising O, S, S(O), S(O)<sub>2</sub>, Si(R')<sub>2</sub>, P(R'), N, N(R'), or a combination thereof, wherein each R' is independently a C<sub>1</sub>-C<sub>18</sub> hydrocarbyl radical.
- I. The catalyst compound of any one of embodiments A to H wherein each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> is, independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of R<sup>1</sup> to R<sup>32</sup> may independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure wherein R<sup>6</sup> and R<sup>29</sup> are not directly bridged to R<sup>13</sup> or R<sup>30</sup> and wherein R<sup>26</sup> and R<sup>31</sup> are not directly bridged to R<sup>19</sup> or R<sup>32</sup>, or a combination thereof.
- J. The catalyst compound of any one of embodiments A to I wherein each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> is, independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of R<sup>1</sup> to R<sup>32</sup> may independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure wherein neither R<sup>6</sup> nor R<sup>29</sup> join together with R<sup>13</sup> or R<sup>30</sup> to form direct covalent bonds between the respective aromatic rings and wherein neither R<sup>26</sup> nor R<sup>31</sup> join together with R<sup>19</sup> or R<sup>32</sup> to form direct covalent bonds between the respective aromatic rings.
- K. The catalyst compound of any one of embodiments A to J wherein each

$R^1, R^2, R^3, R^4, R^5, R^7, R^8, R^9, R^{10}, R^{11}, R^{12}, R^{14}, R^{15}, R^{16}, R^{17}, R^{18}, R^{20}, R^{21}, R^{22}, R^{23}, R^{24}, R^{25}, R^{27}$ , and  $R^{28}$  is, independently, a hydrogen, a  $C_1$ - $C_{40}$  hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of  $R^1, R^2, R^3, R^4, R^5, R^7, R^8, R^9, R^{10}, R^{11}, R^{12}, R^{14}, R^{15}, R^{16}, R^{17}, R^{18}, R^{20}, R^{21}, R^{22}, R^{23}, R^{24}, R^{25}, R^{27}$  and  $R^{28}$  may independently join together to form a  $C_4$  to  $C_{62}$  cyclic or polycyclic ring structure, or a combination thereof; and each  $R^6, R^{13}, R^{19}, R^{26}, R^{29}, R^{30}, R^{31}$  and  $R^{32}$  is, independently, a hydrogen, a  $C_1$ - $C_{40}$  hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or a combination thereof.

L. The catalyst compound of any one of embodiments A to K wherein each  $R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8, R^9, R^{10}, R^{11}, R^{12}, R^{13}, R^{14}, R^{15}, R^{16}, R^{17}, R^{18}, R^{19}, R^{20}, R^{21}, R^{22}, R^{23}, R^{24}, R^{25}, R^{26}, R^{27}, R^{28}, R^{29}, R^{30}, R^{31}$ , and  $R^{32}$  is, independently, hydrogen, a halogen, or a  $C_1$  to  $C_{30}$  hydrocarbyl radical.

M. The catalyst compound of any one of embodiments A to L wherein each  $R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8, R^9, R^{10}, R^{11}, R^{12}, R^{13}, R^{14}, R^{15}, R^{16}, R^{17}, R^{18}, R^{19}, R^{20}, R^{21}, R^{22}, R^{23}, R^{24}, R^{25}, R^{26}, R^{27}, R^{28}, R^{29}, R^{30}, R^{31}$ , and  $R^{32}$  is, independently, hydrogen, a halogen, or a  $C_1$  to  $C_{10}$  hydrocarbyl radical.

N. The catalyst compound of any one of embodiments A to M, wherein one or more of  $R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8, R^9, R^{10}, R^{11}, R^{12}, R^{13}, R^{14}, R^{15}, R^{16}, R^{17}, R^{18}, R^{19}, R^{20}, R^{21}, R^{22}, R^{23}, R^{24}, R^{25}, R^{26}, R^{27}, R^{28}, R^{29}, R^{30}, R^{31}$ , and  $R^{32}$  is a methyl radical, a fluoride, or a combination thereof.

O. The catalyst compound of any one of embodiments A to N wherein:  
 M is Zr;  
 $X^1$  and  $X^2$  are benzyl radicals;  
 $R^1$  and  $R^{14}$  are methyl radicals;  
 $R^2$  through  $R^{13}$  and  $R^{15}$  through  $R^{32}$  are hydrogen; and  
 Y is  $-CH_2CH_2-$ .

P. The catalyst compound of any one of embodiments A to O wherein:  
 M is Zr;  
 $X^1$  and  $X^2$  are benzyl radicals;  
 $R^1, R^4, R^{14}$  and  $R^{17}$  are methyl radicals;

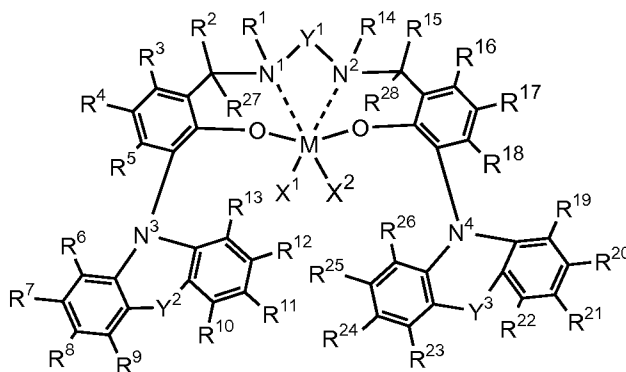
$R^2, R^3, R^5$  through  $R^{13}, R^{15}, R^{16}$ , and  $R^{18}$  through  $R^{32}$  are hydrogen; and

Y is  $-\text{CH}_2\text{CH}_2-$ .

Q. The catalyst compound of any one of embodiments A to J wherein  $R^{29}$  and  $R^{30}$  join together to form a divalent  $C_1$  to  $C_{20}$  hydrocarbyl radical, a divalent functional group comprising elements from Group 13 – 16 of the periodic table of the elements, or a combination thereof.

R. The catalyst compound of any one of embodiments A to J and Q wherein  $R^{31}$  and  $R^{32}$  join together to form a divalent  $C_1$  to  $C_{20}$  hydrocarbyl radical, a divalent functional group comprising elements from Group 13 – 16 of the periodic table of the elements, or a combination thereof.

S. The catalyst compound of any one of embodiments A to J and Q to R wherein the catalyst compound is represented by the formula:



wherein each solid line represents a covalent bond and each dashed line represents a bond having varying degrees of covalency and a varying degree of coordination;

$Y^1$  is Y (a divalent  $C_1$  to  $C_{20}$  hydrocarbyl radical);

$Y^2$  and  $Y^3$  are independently a divalent  $C_1$  to  $C_{20}$  hydrocarbyl radical, a divalent functional group comprising elements from Group 13 – 16 of the periodic table of the elements, or a combination thereof; and

each  $R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8, R^9, R^{10}, R^{11}, R^{12}, R^{13}, R^{14}, R^{15}, R^{16}, R^{17}, R^{18}, R^{19}, R^{20}, R^{21}, R^{22}, R^{23}, R^{24}, R^{25}, R^{26}, R^{27}$ , and  $R^{28}$  is, independently, a hydrogen, a  $C_1$ - $C_{40}$  hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of  $R^1$  to  $R^{28}$  may independently join together to form a  $C_4$  to  $C_{62}$  cyclic or polycyclic ring structure.

T. The catalyst compound according to embodiment S wherein  $Y^2$  and  $Y^3$  are

independently divalent C<sub>1</sub> to C<sub>10</sub> hydrocarbyl radicals, oxo or a combination thereof.

U. The catalyst compound according to embodiment S or embodiment T wherein Y<sup>2</sup> and Y<sup>3</sup> are methylene, ethylene, propylene, butylene, or oxo.

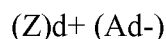
5 V. The catalyst compound of any one of embodiments S to U wherein Y<sup>2</sup> and Y<sup>3</sup> are nonconjugated.

W. A catalyst system comprising an activator and the catalyst compound of any one of embodiments A to V.

10 X. The catalyst system of embodiment W, wherein the activator comprises alumoxane, a non-coordinating anion activator, or a combination thereof.

Y. The catalyst system of embodiment W or embodiment X, wherein the activator comprises alumoxane and the alumoxane is present at a ratio of 1 mole aluminum or more to mole of catalyst compound.

15 Z. The catalyst system of any one of embodiments W to Y, wherein the activator is represented by the formula:



wherein Z is (L-H), or a reducible Lewis Acid, wherein L is a neutral Lewis base;

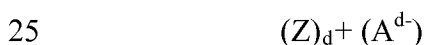
H is hydrogen;

20 (L-H)<sup>+</sup> is a Bronsted acid;

Ad<sup>-</sup> is a non-coordinating anion having the charge d<sup>-</sup>; and

d is an integer from 1 to 3.

A1. The catalyst system of any one of embodiments W to Z wherein the activator is represented by the formula:



wherein A<sup>d-</sup> is a non-coordinating anion having the charge d<sup>-</sup>;

d is an integer from 1 to 3, and

Z is a reducible Lewis acid represented by the formula: (Ar<sub>3</sub>C<sup>+</sup>), where Ar is aryl radical, an aryl radical substituted with a heteroatom, an aryl radical substituted with one or more C<sub>1</sub> to C<sub>40</sub> hydrocarbyl radicals, an aryl radical substituted with one or more functional groups comprising elements from Groups 13 – 17 of the periodic table of the elements, or

30

a combination thereof.

- B1. A process to polymerize olefins comprising contacting one or more olefins with the catalyst system of any one of embodiments W to A1 at a temperature, a pressure, and for a period of time sufficient to produce a polyolefin.
- 5 C1. The process of embodiment B1 wherein the conditions comprise a temperature of from about 0 °C to about 300 °C, a pressure from about 0.35 MPa to about 10 MPa, and a time from about 0.1 minutes to about 24 hours.
- D1. The process of embodiment B1 or embodiment C1, wherein the one or more olefins comprise propylene.
- 10 E1. The process of any one of embodiments B1 to D1 wherein the polyolefin comprises at least 50 mole% propylene.

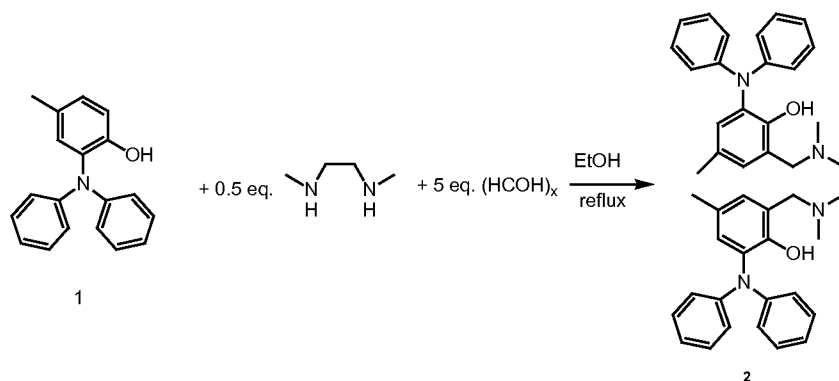
### EXAMPLES

The foregoing discussion can be further described with reference to the following non-limiting examples. Thirteen illustrative catalyst compounds (A through

15 M), each according to one or more embodiments described, were synthesized and used to polymerize olefins. 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

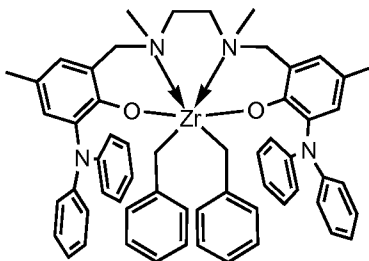
20 Aldrich and purified prior to use or prepared according to procedures known to those skilled in the art. Comparative catalyst compound C1 was synthesized as described in WO 03/091292A2.

#### Synthesis of Compounds A - M:



- 25 Synthesis of 2: In a 100 mL round bottom flask, 1(0.566 g, 2.056 mmol), N,N'-dimethylethylenediamine (0.111 g, 1.259 mmol), and paraformaldehyde (0.309 g,

10.290 mmol) were slurried in 30 mL of ethanol. The flask was then placed in an oil bath. The reaction was stirred and heated to reflux overnight, during which all reactants dissolved. Solvent was removed under a N<sub>2</sub> stream while heating leaving an orange oily residue. Residue was purified using a Biotage silica column with a dual solvent system - Run A: 20— 100% CH<sub>2</sub>Cl<sub>2</sub>/hexanes; Run B: 5% MeOH/CH<sub>2</sub>Cl<sub>2</sub>. NMR of the fraction from Biotage run A shows the presence of 1. The fraction from Biotage run B shows pure 2. Yield of 2 was 0.331 g.



3

Synthesis of 3: In a nitrogen purged drybox, 2 and tetrabenzylzirconium were weighed out into separate vials and either slurried or dissolved in 5 mL of toluene. The solution of ZrBn<sub>4</sub> was then slowly added to the stirring slurry of 2. The reaction was left to stir for 3 hours. The mixture was filtered through an Acro-disc (0.2 micron) into another vial. The volatiles were removed under N<sub>2</sub> stream. The resulting residue was slurried in pentane for 20 minutes. The slurry was filtered through a fit and the solids washed with pentane. The solids were then dried under vacuum. NMR of the dried solids shows pure 3. Yield of 3 was 0.166 g.

#### Example 1

A PARR bomb equipped with a glass bottle was chilled to -85°C. To this was added MAO(s) (361.1mg, 6.225mmol) and 3 (11.9mg, 0.0127mmol). Propylene (l) (24.4g, 580 mmol) was poured into the bottle. The PARR bomb was sealed over the bottle and heated to 70°C for 1 hr. The reactor was vented. The product was washed out of the PARR bomb with toluene. The toluene was blown down under N<sub>2</sub> overnight. Collected 4.860g of a greenish liquid. Activity: 382 g polymer/(mmol Catalyst\*hr) NMR: (C<sub>6</sub>D<sub>6</sub>): δ 0.9-1.8 (mn, 168.38H), 4.79(d, 2.00H). 100% vinylidene, Mn 1179g/mol

#### Example 2

In a 20mL vial 3 (9.1 mg, 0.0097mmol) and (C<sub>6</sub>H<sub>5</sub>)<sub>3</sub>C<sup>+</sup>B(C<sub>6</sub>F<sub>5</sub>)<sub>4</sub><sup>-</sup> (9.2mg, 0.010 mmol) were combined together in ~2mL of toluene for 30min. A PARR bomb



equipped with a glass bottle was chilled to -85°C. Tri-n-octyl aluminum (71mg, 0.19mmol) was added to the bottle followed by propylene (l) (24.5g, 582mmol). The catalyst solution was then added to the glass bottle and the PARR bomb was sealed over the bottle and heated to 70°C for 1 hr. The reactor was vented. The product was washed out of the PARR bomb with toluene. The toluene was blown down under N<sub>2</sub> overnight. Collected 7.880g of a greenish liquid. Activity: 809 g polymer/(mmol Catalyst\*hr) NMR: (C<sub>6</sub>D<sub>6</sub>): δ 0.9-1.8 (mn, 226.47H), 4.78(d, 2.00 H) 100% vinylidene, Mn = 1585g/mol

### Example 3

A PARR bomb equipped with a glass bottle was chilled to -85°C. To this was added MAO(s) (348.0mg, 5.999mmol) and 3 (10.3mg, 0.0110 mmol). Propylene (l) (25.0g, 594mmol) was poured into the bottle. The PARR bomb was sealed over the bottle and allowed to warm up to RT and stir overnight. The reactor was vented. The product was washed out of the PARR bomb with toluene. The toluene was blown down under N<sub>2</sub>. Collected 7.785g of a greenish liquid. Activity: 706 g polymer/(mmol Catalyst\*hr) NMR: (C<sub>6</sub>D<sub>6</sub>): δ 0.9-1.8 (mn, 155.55H), 4.78(d, 2.00H) 100% vinylidene, Mn 1089g/mol. The data are shown in Table 1.

**Table 1**

Propylene	Temp. °C	Mn	Rxn Time (hr)	Yield (g)	Conversion (%)
Example 1	70	1179	1	4.86	19.9
Example 2	70	1585	1	7.88	32.2
Example 3	20	1089	16	7.78	31.0

As the data show, the catalyst compounds, catalyst systems, and polymerization processes disclosed herein provide novel and improved catalyst and systems for the polymerization of olefins, which produce polymers having improved properties, such as high polymer melting point, high polymer molecular weights, an increased conversion and/or comonomer incorporation, which may further include a significant amount of long chain branching and/or a significant amount of vinyl termination.

The catalysts in an embodiment of the invention provide improvement in catalyst activity, produce polymers with improved properties or both. Crystallographic techniques indicate that the appended ring system or systems are oriented transversely, e.g., perpendicular, to the phenol rings. These catalysts have a

structure to provide a broad corridor for the polymeryl moiety to reside and for the monomer to insert during the polymerization process. As such, catalysts according to one embodiment of the instant disclosure provide for an ability to control one or more characteristics of polymerization, tacticity, comonomer insertion, and the like.

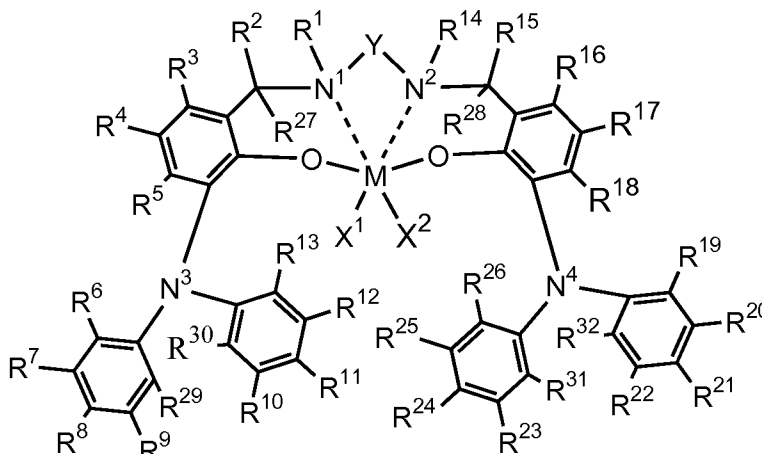
5 All documents described herein are incorporated by reference herein, including any priority documents and/or testing procedures to the extent they are not inconsistent with this text, provided however that any priority document not named in the initially filed application or filing documents is NOT incorporated by reference herein. As is apparent from the foregoing general description and the specific  
10 embodiments of the invention, 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. Likewise whenever a composition, an  
15 element or a group of elements is preceded with the transitional phrase "comprising", it is understood that we also contemplate the same composition or group of elements with transitional phrases "consisting essentially of," "consisting of", "selected from the group of consisting of," or "is" preceding the recitation of the composition, element, or elements and vice versa.

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**CLAIMS:**

What is claimed is:

1. A catalyst compound represented by the formula:



- 5 wherein each solid line represents a covalent bond and each dashed line represents a bond having varying degrees of covalency and a varying degree of coordination;
- M is a Group 3, 4, 5 or 6 transition metal;
- N<sup>1</sup>, N<sup>2</sup>, N<sup>3</sup> and N<sup>4</sup> are nitrogen;
- 10 each of X<sup>1</sup> and X<sup>2</sup> is, independently, a univalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical, a functional group comprising elements from Groups 13 – 17 of the periodic table of the elements, or X<sup>1</sup> and X<sup>2</sup> join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure, provided however when M is trivalent X<sup>2</sup> is not present;
- 15 Y is a divalent hydrocarbyl radical covalently bonded to and bridging between both of the nitrogen atoms N<sup>1</sup> and N<sup>2</sup>; and
- each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> is, independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a
- 20 functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of R<sup>1</sup> to R<sup>32</sup> may independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure wherein neither R<sup>6</sup> nor R<sup>29</sup> join together with R<sup>13</sup> or R<sup>30</sup> to form direct covalent bonds between the respective aromatic rings and wherein neither R<sup>26</sup> nor R<sup>31</sup> join together with R<sup>19</sup> or R<sup>32</sup> to form
- 25

direct covalent bonds between the respective aromatic, or a combination thereof.

2. The catalyst compound of claim 1 wherein M is Hf, Ti, or Zr.
- 5
3. The catalyst compound of claim 1 wherein each X is, independently, a halogen or a C<sub>1</sub> to C<sub>7</sub> hydrocarbyl radical.
4. The catalyst compound of claim 1 wherein each X is a benzyl radical.
- 10
5. The catalyst compound of claim 1 wherein Y is -CH<sub>2</sub>CH<sub>2</sub>- or 1,2-cyclohexylene.
6. The catalyst compound of claim 1 wherein Y is -CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>-.
- 15
7. The catalyst compound of claim 1 wherein Y is a C<sub>1</sub>-C<sub>40</sub> divalent hydrocarbyl radical comprising a linker backbone comprising from 1 to 18 carbon atoms bridging between nitrogen atoms N<sup>1</sup> and N<sup>2</sup>.
- 20
8. The catalyst compound of claim 1, wherein Y is a C<sub>1</sub>-C<sub>40</sub> divalent hydrocarbyl radical comprising O, S, S(O), S(O)<sub>2</sub>, Si(R')<sub>2</sub>, P(R'), N, N(R'), or a combination thereof, wherein each R' is independently a C<sub>1</sub>-C<sub>18</sub> hydrocarbyl radical.
- 25
9. The catalyst compound of claim 1 wherein each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>27</sup> and R<sup>28</sup> is, independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>27</sup> and R<sup>28</sup> may independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure, or a combination thereof; and each R<sup>6</sup>, R<sup>13</sup>, R<sup>19</sup>, R<sup>26</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup> and R<sup>32</sup> is,
- 30

independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or a combination thereof.

- 5 10. The catalyst compound of claim 1 wherein each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> is, independently, hydrogen, a halogen, or a C<sub>1</sub> to C<sub>30</sub> hydrocarbyl radical.
- 10 11. The catalyst compound of claim 1 wherein each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> is, independently, hydrogen, a halogen, or a C<sub>1</sub> to C<sub>10</sub> hydrocarbyl radical.
- 15 12. The catalyst compound of claim 1 wherein one or more of R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> is a methyl radical, a fluoride, or a combination thereof.
- 20 13. The catalyst compound of claim 1, wherein R<sup>29</sup> and R<sup>30</sup> join together to form a divalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical, a divalent functional group comprising elements from Group 13 – 16 of the periodic table of the elements, or a combination thereof, and wherein R<sup>31</sup> and R<sup>32</sup> join together to form a divalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical, a divalent functional group comprising  
25 elements from Group 13 – 16 of the periodic table of the elements, or a combination thereof.
14. The catalyst compound of claim 1 wherein:  
M is Zr;  
30 X<sup>1</sup> and X<sup>2</sup> are benzyl radicals;  
R<sup>1</sup> and R<sup>14</sup> are methyl radicals;  
R<sup>2</sup> through R<sup>13</sup> and R<sup>15</sup> through R<sup>32</sup> are hydrogen; and

Y is  $-\text{CH}_2\text{CH}_2-$ .

15. The catalyst compound of claim 1 wherein:

M is Zr;

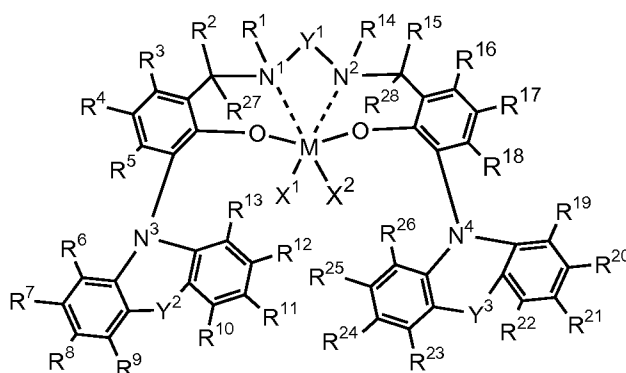
5  $X^1$  and  $X^2$  are benzyl radicals;

$R^1$ ,  $R^4$ ,  $R^{14}$  and  $R^{17}$  are methyl radicals;

$R^2$ ,  $R^3$ ,  $R^5$  through  $R^{13}$ ,  $R^{15}$ ,  $R^{16}$ , and  $R^{18}$  through  $R^{32}$  are hydrogen; and

Y is  $-\text{CH}_2\text{CH}_2-$ .

10 16. A catalyst compound represented by the formula:



wherein each solid line represents a covalent bond and each dashed line represents a bond having varying degrees of covalency and a varying degree of coordination;

15 M is a Group 3, 4, 5 or 6 transition metal;

$N^1$ ,  $N^2$ ,  $N^3$  and  $N^4$  are nitrogen;

each of  $X^1$  and  $X^2$  is, independently, a univalent  $C_1$  to  $C_{20}$  hydrocarbyl radical, a functional group comprising elements from Groups 13 – 17 of the periodic table of the elements, or  $X^1$  and  $X^2$  join together to form a  $C_4$  to  $C_{62}$  cyclic or polycyclic ring structure, provided however when M is trivalent  $X^2$  is not present;

$Y^1$  is a divalent  $C_1$  to  $C_{20}$  hydrocarbyl radical;

$Y^2$  and  $Y^3$  are independently a divalent  $C_1$  to  $C_{20}$  hydrocarbyl radical, a divalent functional group comprising elements from Group 13 – 16 of the periodic table of the elements, or a combination thereof; and

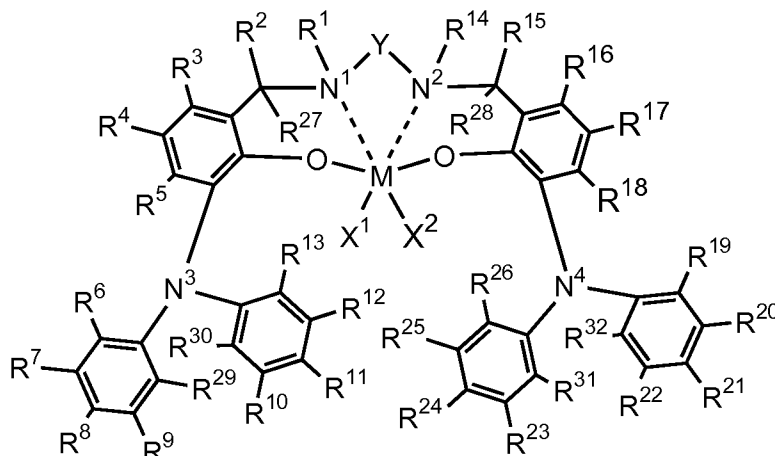
25 each  $R^1$ ,  $R^2$ ,  $R^3$ ,  $R^4$ ,  $R^5$ ,  $R^6$ ,  $R^7$ ,  $R^8$ ,  $R^9$ ,  $R^{10}$ ,  $R^{11}$ ,  $R^{12}$ ,  $R^{13}$ ,  $R^{14}$ ,  $R^{15}$ ,  $R^{16}$ ,  $R^{17}$ ,  $R^{18}$ ,  $R^{19}$ ,  $R^{20}$ ,  $R^{21}$ ,  $R^{22}$ ,  $R^{23}$ ,  $R^{24}$ ,  $R^{25}$ ,  $R^{26}$ ,  $R^{27}$ , and  $R^{28}$  is,

independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of R<sup>1</sup> to R<sup>28</sup> may independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure.

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17. A catalyst system comprising:

an activator and a catalyst compound represented by the formula:



wherein each solid line represents a covalent bond and each dashed line represents a bond having varying degrees of covalency and a varying degree of coordination;

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M is a Group 3, 4, 5 or 6 transition metal;

N<sup>1</sup>, N<sup>2</sup>, N<sup>3</sup> and N<sup>4</sup> are nitrogen;

each of X<sup>1</sup> and X<sup>2</sup> is, independently, a univalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical, a functional group comprising elements from Groups 13 – 17 of the periodic table of the elements, or X<sup>1</sup> and X<sup>2</sup> join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure, provided however when M is trivalent X<sup>2</sup> is not present;

15

Y is a divalent hydrocarbyl radical covalently bonded to and bridging between both of the nitrogen atoms N<sup>1</sup> and N<sup>2</sup>; and

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each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> is, independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of R<sup>1</sup> to R<sup>32</sup> may

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independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure wherein neither R<sup>6</sup> nor R<sup>29</sup> join together with R<sup>13</sup> or R<sup>30</sup> to form direct covalent bonds between the respective aromatic rings and wherein neither R<sup>26</sup> nor R<sup>31</sup> join together with R<sup>19</sup> or R<sup>32</sup> to form direct covalent bonds between the respective aromatic rings, or a combination thereof.

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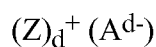
18. The catalyst system of claim 17, wherein the activator comprises alumoxane, a non-coordinating anion activator, or a combination thereof.

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19. The catalyst system of claim 17, wherein the activator comprises alumoxane and the alumoxane is present at a ratio of 1 mole aluminum or more to mole of catalyst compound.

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20. The catalyst system of claim 17, wherein the activator is represented by the formula:



wherein Z is (L-H), or a reducible Lewis Acid, wherein L is a neutral Lewis base;

20

H is hydrogen;

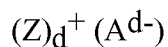
(L-H)<sup>+</sup> is a Bronsted acid;

A<sup>d-</sup> is a non-coordinating anion having the charge d<sup>-</sup>; and

d is an integer from 1 to 3.

25

21. The catalyst system of claim 17 wherein the activator is represented by the formula:



wherein A<sup>d-</sup> is a non-coordinating anion having the charge d<sup>-</sup>;

d is an integer from 1 to 3, and

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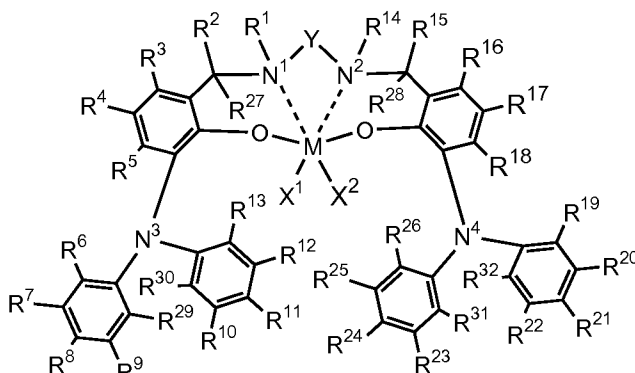
Z is a reducible Lewis acid represented by the formula: (Ar<sub>3</sub>C<sup>+</sup>), where Ar is aryl radical, an aryl radical substituted with a heteroatom, an aryl radical substituted with one or more C<sub>1</sub> to C<sub>40</sub> hydrocarbyl radicals, an



aryl radical substituted with one or more functional groups comprising elements from Groups 13 – 17 of the periodic table of the elements, or a combination thereof.

5 22. A process to polymerize olefins comprising:

contacting one or more olefins with a catalyst system at a temperature, a pressure, and for a period of time sufficient to produce a polyolefin, the catalyst system comprising an activator and a catalyst compound represented by the formula:



10 wherein each solid line represents a covalent bond and each dashed line represents a bond having varying degrees of covalency and a varying degree of coordination;

M is a Group 3, 4, 5 or 6 transition metal;

15 N<sup>1</sup>, N<sup>2</sup>, N<sup>3</sup> and N<sup>4</sup> are nitrogen;

each of X<sup>1</sup> and X<sup>2</sup> is, independently, a univalent C<sub>1</sub> to C<sub>20</sub> hydrocarbyl radical, a functional group comprising elements from Groups 13 – 17 of the periodic table of the elements, or X<sup>1</sup> and X<sup>2</sup> join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure, provided however when M is trivalent X<sup>2</sup> is not present;

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Y is a divalent hydrocarbyl radical covalently bonded to and bridging between both of the nitrogen atoms N<sup>1</sup> and N<sup>2</sup>; and

each R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup>, R<sup>7</sup>, R<sup>8</sup>, R<sup>9</sup>, R<sup>10</sup>, R<sup>11</sup>, R<sup>12</sup>, R<sup>13</sup>, R<sup>14</sup>, R<sup>15</sup>, R<sup>16</sup>, R<sup>17</sup>, R<sup>18</sup>, R<sup>19</sup>, R<sup>20</sup>, R<sup>21</sup>, R<sup>22</sup>, R<sup>23</sup>, R<sup>24</sup>, R<sup>25</sup>, R<sup>26</sup>, R<sup>27</sup>, R<sup>28</sup>, R<sup>29</sup>, R<sup>30</sup>, R<sup>31</sup>, and R<sup>32</sup> is, independently, a hydrogen, a C<sub>1</sub>-C<sub>40</sub> hydrocarbyl radical, a functional group comprising elements from Group 13 – 17 of the periodic table of the elements, or two or more of R<sup>1</sup> to R<sup>32</sup> may

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5 independently join together to form a C<sub>4</sub> to C<sub>62</sub> cyclic or polycyclic ring structure wherein neither R<sup>6</sup> nor R<sup>29</sup> join together with R<sup>13</sup> or R<sup>30</sup> to form direct covalent bonds between the respective aromatic rings and wherein neither R<sup>26</sup> nor R<sup>31</sup> join together with R<sup>19</sup> or R<sup>32</sup> to form direct covalent bonds between the respective aromatic rings, or a combination thereof.

23. The process of claim 22, wherein the one or more olefins comprise propylene.

10 24. The process of claim 22 wherein the polyolefin comprises at least 50 mole% propylene.

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 13/69419

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC(8) - C09B 55/00; C07C 1/00 (2014.01) USPC - 556/32,33,34;585/369, 329,50 According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) IPC (8) - C09B 55/00; C07C 1/00 (2013.01) USPC - 556/32,33,34;585/369, 329,50 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched IPC(8) - C09B 55/00; C07C 1/00 (2013.01) USPC - 556/32,33,34;585/369, 329,50 Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) Minesoft Patbase, Google Scholar, Google: Salan, salen, salalen, metallosalan, metallosalen, metallocene, olefin, carbazol, diphenylamine, amine, catalyst, activator KOL, HOLT CAMP, GIESBRECHT, (Ti or Hf or Zr), (1000 carbon atoms) w25 (long branch, t-butyl, branching w2 index, density.		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2012/098521 A1 (KOL et al.) 26 July 2012 (26.07.2012) page 7, lines 1-5, page 6, Structure II, page 7, lines 1-10; page 13, lines 1-30; page 19, lines 20-23; page 12, lines 19; page 37, lines 17-18, 23-25; page 26, lines 15-20; benzyl; page 15, lines 5-13; Page 12, lines 23-25; page 10, lines 6-10; page 51, lines 10-15.	1-24
Y	US 2013/0030135 A1 (Hagadorn et al.) 31 January 2013 (13.01.2013)	1-15, 17-24
Y	US 2005/0075242 A1 (Holtcamp et al.) 07 April 2005 (07.04.2005)	13, 16
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/>		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 08 February 2014 (08.02.2014)		Date of mailing of the international search report 07 MAR 2014
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201		Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774