CLAIMS

We claim:

1. A process comprising:
   a) contacting
      i) ethylene,
      ii) a catalyst system comprising
         1) a zirconium compound having the formula $ZrX^1_mY^1_q$, where each X^1 independently is a halide, each Y^1 independently is a hydrocarboxide, a dihydrocarbylazanide, a hydrocarbylcarboxylate, a hydrocarbylsulfonate, or a β-diketonate, m is in a range from 0 to 4, q is in a range from 0 to 4, and m + q is an integer from 2 to 4, and
         2) a hydrocarbylmetal compound,
      iii) a chain transfer agent comprising a compound having a hydrogen silicon bond, a compound having a hydrogen sulfur bond, a compound having a hydrogen phosphorus bond, or any combination thereof, and
      iv) optionally, an organic reaction medium; and
   b) forming an oligomer product in a reaction zone; and
   wherein the oligomer product has a Schulz-Flory K value from 0.4 to 0.8.

2. The process of claim 1, wherein the chain transfer agent comprises a compound having the formula $R^{31}SiH_3$, $(R^{31})_2SiH_2$, $(R^{31})_3SiH$, $R^{31}OSiH3$, $(R^{31}O)_2SiH_2$, $(R^{31}O)_3SiH$, $R^{32}SH$, $R^{32}CO_2CH_2SH$, $R^{32}CO_2CH_2CH_2SH$, $R^{33}PH_2$, $(R^{33})_2PH$, $R^{33}OPH_2$, $(R^{33}O)_2PH$, or any combination thereof, wherein each R^{31}, R^{32}, and R^{33} independently is a C_1 to C_{15} hydrocarbyl group.

3. The process of claim 1, wherein the reaction zone has a chain transfer agent to ethylene mole ratio in a range from $1x10^{-5}$:1 to $5x10^{-1}$:1.

4. The process of claim 1, wherein the oligomer product comprises (a) less than 1 wt. % of polymer, (b) less than 1 wt. % compounds having a weight average molecular weight of greater than 1000 g/mol, or (c) any combination thereof, wherein the wt. % is based on the total weight of the oligomer product.

5. The process of claim 1, wherein the process produces an oligomer product comprising (a) polymer having a lower Mw, (b) a polymer having a lower Mw maximum peak, (c) a reduced percentage of polymer, (d) a polymer having a reduced percentage of polymer having a Mw greater than 100,000 g/mol, or (e) any combination thereof, relative to the same process not using the chain transfer agent comprising a compound having a hydrogen silicon bond, a compound having a hydrogen sulfur bond, a compound having a hydrogen phosphorus bond, or any combination thereof.

6. The process of claim 1, wherein the hydrocarbylmetal compound has the formula $AlX^2_{3-n}R^1_n$, $Al_2X^2_{6-q}R^1_q$, R^1_2Zn, or any combination thereof, wherein each R^1 independently is a C_1 to C_{10} alkyl group, each X^2 independently is chloride, bromide, or iodide, n is an integer from 0 to 3, and q is an integer for 0 to 6.

7. The process of claim 1, wherein the catalyst system further comprises a neutral non-ionic organic modifier.

8. The process of claim 7, wherein the neutral non-ionic organic modifier comprises an ether, an ester, a ketone, an aldehyde, an alcohol, an anhydride, an acid chloride, a nitrile, a sulfide, a disulfide, a phosphine, an amine, or an amide.

9. The process of claim 1, wherein the zirconium compound has the formula ZrX^1_m where each X^1 independently is chloride or bromide and m is 4, and wherein the hydrocarbylmetal compound has the formula $AlX^2_nR^1_{3-n}$, $Al_2X^2_3R^1_3$, R^1_2Zn, or any combination thereof, wherein each X^2 independently is a halide and each R^1 independently is C_2 to C_4 alkyl group.

10. The process of claim 9, wherein the catalyst system further comprises a C_2 to C_{20} ester, a C_2 to C_{20} ether, or a C_2 to C_{20} sulfide as a neutral non-ionic organic modifier.

11. The process of claim 1, wherein the zirconium compound has the formula ZrY^1_q where each Y^1 independently is $^-OR^2$, wherein R^2 is a C_1 to C_{10} alkyl group or $^-OC(=O)R^3$, wherein R^3 is a C_1 to C_{10} alkyl group and q is an integer from 2 to 4, and wherein the hydrocarbylmetal compound has the formula $AlX^3_nR^1_{3-n}$, $Al_2X^3_3R^1_3$, or any combination

thereof, wherein each X^2 independently is a halide and each R^1 independently is C_2 to C_4 alkyl group.

12. A process comprising:
    a) contacting
        i) ethylene,
        ii) a catalyst system comprising
            1) a zirconium compound having the formula $ZrX^1_mY^1_q$, wherein each X^1 independently is a halide, each Y^1 independently is a hydrocarboxide, a dihydrocarbylazanide, a hydrocarbylcarboxylate, a hydrocarbylsulfonate, or a β-diketonate, m is in a range from 0 to 4, q is in a range from 0 to 4, and m + q is an integer from 2 to 4, and
            2) a hydrocarbylmetal compound,
        iii) hydrogen, and
        iv) optionally, an organic reaction medium; and
    b) forming an oligomer product in a reaction zone; and
    wherein the oligomer product has a Schulz-Flory K value from 0.4 to 0.8.

13. The process of claim 12, wherein the reaction zone has a hydrogen to ethylene mass ratio in range from (0.05 g hydrogen)/(kg ethylene) to (5 g hydrogen)/(kg ethylene).

14. The process of claim 12, wherein the oligomer product comprises (a) less than 1 wt. % of polymer, (b) less than 1 wt. % compounds having a weight average molecular weight of greater than 1000 g/mol, or (c) any combination thereof, wherein the wt. % is based on the total weight of the oligomer product.

15. The process of claim 12, wherein the process produces an oligomer product comprising (a) polymer having a lower Mw, (b) a polymer having a lower Mw maximum peak, (c) a reduced percentage of polymer, (d) a polymer having a reduced percentage of polymer having a Mw greater than 100,000 g/mol, or (e) any combination thereof, relative to the same process not using hydrogen.

16. The process of claim 12, wherein the hydrocarbylmetal compound has the formula $AlX^2_{3-n}R^1_n$, $Al_2X^2_{6-q}R^1_q$, R^1_2Zn, or any combination thereof, wherein each R^1

independently is a C_1 to C_{10} alkyl group, each X^2 independently is chloride, bromide, or iodide, n is an integer from 0 to 3, and q is an integer for 0 to 6.

17. The process of claim 12, wherein the catalyst system further comprises a neutral non-ionic organic modifier.

18. The process of claim 17, wherein the neutral non-ionic organic modifier comprises an ether, an ester, a ketone, an aldehyde, an alcohol, an anhydride, an acid chloride, a nitrile, a sulfide, a disulfide, a phosphine, an amine, or an amide.

19. The process of claim 12, wherein the zirconium compound has the formula ZrX^1_m, wherein each X^1 independently is chloride or bromide and m is 4, and wherein the hydrocarbylmetal compound has the formula $AlX^2_nR^1_{3-n}$, $Al_2X^2_3R^1_3$, R^1_2Zn, or any combination thereof, wherein each X^2 independently is a halide and each R^1 independently is C_2 to C_4 alkyl group.

20. The process of claim 19, wherein the catalyst system further comprises a C_2 to C_{20} ester, a C_2 to C_{20} ether, or a C_2 to C_{20} sulfide as a neutral non-ionic organic modifier.

21. The process of claim 12, wherein the zirconium compound has the formula ZrY^1_q where each Y^1 independently is $^-OR^2$, wherein R^2 is a C_1 to C_{10} alkyl group or $^-OC(=O)R^3$, wherein R^3 is a C_1 to C_{10} alkyl group and q is an integer from 2 to 4, and wherein the hydrocarbylmetal compound has the formula $AlX^3_nR^1_{3-n}$, $Al_2X^3_3R^1_3$, or any combination thereof, wherein each X^3 independently is a halide and each R^1 independently is C_2 to C_4 alkyl group.

22. A process comprising:
    a) contacting
        i) ethylene,
        ii) a catalyst system comprising
            1) a zirconium compound having the formula $ZrX^1_mY^1_q$, where each X^1 independently is a halide, each Y^1 independently is a hydrocarboxide, a dihydrocarbylazanide, a hydrocarbylcarboxylate, a

hydrocarbylsulfonate, or a β-diketonate, m is in a range from 0 to 4, q is in a range from 0 to 4, and m + q is an integer from 2 to 4, and

2) a hydrocarbylmetal compound,

iii) a transition metal compound chain transfer agent, and

iv) optionally, an organic reaction medium; and

b) forming an oligomer product in a reaction zone; and

wherein the oligomer product has a Schulz-Flory K value from 0.4 to 0.8.

23. The process of claim 22, wherein the transition metal compound chain transfer agent is a transition metal compound chain transfer agent having the formula MX^4_p, wherein M is a transition metal, X^4 is a mono anion, and p is an integer from 2 to 4.

24. The process of claim 23, wherein M is iron, cobalt, or nickel.

25. The process of claim 23, wherein X^4 is a C_4 to C_{19} carboxylate.

26. The process of claim 23, wherein the reaction zone has a metal of the chain transfer agent to ethylene mole ratio in a range of from 1×10^{-8} to 1×10^{-3}.

27. The process of claim 22, wherein the oligomer product comprises (a) less than 1 wt. % of polymer, (b) less than 1 wt. % compounds having a weight average molecular weight of greater than 1000 g/mol, or (c) any combination thereof, wherein the wt. % is based on the total weight of the oligomer product.

28. The process of claim 22, wherein the process produces an oligomer product comprising (a) polymer having a lower Mw, (b) a polymer having a lower Mw maximum peak, (c) a reduced percentage of polymer, (d) a polymer having a reduced percentage of polymer having a Mw greater than 100,000 g/mol, or (e) any combination thereof, relative to the same process not using the transition metal compound chain transfer agent.

29. The process of claim 22, wherein the hydrocarbylmetal compound has the formula $AlX^2_{3-n}R^1_n$, $Al_2X^2_{6-q}R^1_q$, R^1_2Zn, or any combination thereof, wherein each R^1 independently is a C_1 to C_{10} alkyl group, each X^2 independently is chloride, bromide, or iodide, n is an integer from 0 to 3, and q is an integer for 0 to 6.

30. The process of claim 22, wherein the catalyst system further comprises a neutral non-ionic organic modifier.

31. The process of claim 30, wherein the neutral non-ionic organic modifier comprises an ether, an ester, a ketone, an aldehyde, an alcohol, an anhydride, an acid chloride, a nitrile, a sulfide, a disulfide, a phosphine, an amine, or an amide.

32. The process of claim 22, wherein the zirconium compound has the formula ZrX^1_m, wherein each X^1 independently is chloride or bromide and m is 4, and wherein the hydrocarbylmetal compound has the formula $AlX^2_nR^1_{3-n}$, $Al_2X^2_3R^1_3$, R^1_2Zn, or any combination thereof, wherein each X^2 independently is a halide and each R^1 independently is C_2 to C_4 alkyl group.

33. The process of claim 32, wherein the catalyst system further comprises a C_2 to C_{20} ester, a C_2 to C_{20} ether, or a C_2 to C_{20} sulfide as a neutral non-ionic organic modifier.

34. The process of claim 22, wherein the zirconium compound has the formula ZrY^1_q, wherein each Y^1 independently is $^-OR^2$, wherein R^2 is a C_1 to C_{10} alkyl group or $^-OC(=O)R^3$, wherein R^3 is a C_1 to C_{10} alkyl group and q is an integer from 2 to 4, and wherein the hydrocarbylmetal compound has the formula $AlX^3_nR^1_{3-n}$, $Al_2X^3_3R^1_3$, or any combination thereof, wherein each X^2 independently is a halide and each R^1 independently is C_2 to C_4 alkyl group.

35. The process of claim 22, wherein the hydrocarbylmetal compound comprises a trialkylaluminum, an alkylaluminum halide, or any combination thereof.

36. The process of claim 22, wherein the transition metal compound chain transfer agent comprises iron(II) chloride, iron(III) chloride, iron(II) acetate, iron(III) acetate, an iron(II) octanoate, an iron(III) octanoate, iron(II) acetylacetonate, iron(III) acetylacetonate, cobalt(II) chloride, cobalt(III) chloride, cobalt(II) acetate, cobalt(III) acetate, an cobalt(II) octanoate, a cobalt(III) octanoate, cobalt(II) acetylacetonate, cobalt(III) acetylacetonate, nickel(II) chloride, nickel(II) acetate, a nickel(II) octanoate, nickel(II) acetylacetonate, or any combination thereof.