CLAIMS

WHAT IS CLAIMED IS:

1. A method for intermittently delivering a dose carbon dioxide in solid and gaseous form to a destination comprising

(i) transporting liquid carbon dioxide from a source of liquid carbon dioxide to an orifice via a first conduit, wherein

(a) the first conduit comprises material that can withstand the temperature and pressure of the liquid carbon dioxide, and

(~~B~~b) the pressure drop through the orifice and the configuration of the orifice are such that solid and gaseous carbon dioxide are produced as the carbon dioxide exits the orifice;

(ii) transporting the solid and gaseous carbon dioxide through a second conduit, wherein the ratio of the length of the second conduit to the length of the first conduit is at least 1:-1;

(iii) directing the solid and gaseous carbon dioxide from the end of the second conduit into a third conduit, wherein the third conduit comprises a portion configured to slow the flow of the carbon dioxide through the portion of third conduit sufficiently to cause the solid carbon dioxide to clump before it exits the third conduit through an opening; and

(~~iii~~iv) directing the carbon dioxide that exits the ~~second~~ third conduit to a destination.

2. The method of claim 1 further wherein the length, diameter, and material of the first conduit are such that, after a transition period, the liquid carbon dioxide entering the first conduit arrives at the orifice as at least 90% liquid carbon dioxide when the ambient temperature is less than 30 °C.

3. The method of claim 1 further wherein the second conduit has a smooth bore.

4. The method of claim 1 wherein the first conduit is not insulated.

~~5. The method of claim 1 further comprising directing the solid and gaseous carbon dioxide from the end of the second conduit into a third conduit, wherein the third conduit comprises a portion configured to slow the flow of the carbon dioxide through the portion of third conduit sufficiently to cause the solid carbon dioxide to clump before it exits the third conduit through an opening.~~

5~~6~~. The method of claim ~~5~~ 1 wherein the portion of the third conduit configured to slow the flow of carbon dioxide is an expanded portion compared to the second conduit.

~~7~~6. The method of claim ~~5~~ 1 wherein the ratio of the length of the third conduit to the length of the second conduit is less than 0.1:1.

~~8~~7. The method of claim ~~5~~ 1 wherein the third conduit has a length between 1 and 10 feet.

~~9~~8. The method of claim ~~5~~ 1 wherein the third conduit has an inner diameter between 1 inch and 3 inches.

~~10~~9. The method of claim 1 wherein the ratio of the length of the second conduit to that of the first conduit is at least 2:1.

~~11~~10. The method of claim 1 wherein the first conduit has a length of less than 15 feet.

~~12~~11. The method of claim 1 wherein the first conduit has an inner diameter between 0.25 and 0.75 inches.

~~13~~12. The method of claim 1 wherein the first conduit comprises inner material of braided stainless steel.

~~14~~13. The method of claim 1 wherein the second conduit has a length of at least 30 feet.

~~15~~14. The method of claim 1 wherein the second conduit has an inner diameter between 0.5 and 0.75 inch.

~~16~~15. The method of claim 1 wherein the second conduit comprises inner material of PTFE.

~~17~~16. The method of claim ~~5~~ 1 wherein the third conduit comprises rigid material, and is operably connected to a fourth conduit comprising flexible material.

~~18~~17. The method of claim ~~17~~ 16 wherein the combined length of the third and fourth conduits is between 2 and 10 feet.

~~19~~18. The method of claim 1 wherein the first conduit comprises a valve for regulating the flow of carbon dioxide, wherein the method further comprising determining a pressure and a temperature between the valve and the orifice, and determining a flow rate for the carbon dioxide based on the temperature and the pressure.

~~20~~19. The method of claim ~~19~~ 18 wherein the flow rate is determined by comparing the pressure and temperature to a set of calibration curves for flow rates at a plurality of temperatures and pressures.

~~21~~20. The method of claim 1 wherein the destination to which the carbon dioxide is directed is within a mixer.

~~22~~21. The method of claim ~~21~~ 20 wherein the mixer is a concrete mixer.

~~23~~22. The method of claim ~~22~~ 21 wherein the carbon dioxide is directed to a place in the mixer where, when the mixer is mixing a concrete mix, a wave of concrete folds over onto the mixing concrete.

~~24~~23. The method of claim ~~22~~ 21 wherein the concrete mixer is a stationary mixer.

~~25~~24. The method of claim ~~22~~ 21 wherein the mixer is a transportable mixer.

~~26~~25. The method of claim ~~25~~ 24 wherein the mixer is a drum of a ready-mix truck.

~~27~~26. The method of claim 1 wherein the total heat capacity of the first and/or second conduit is no more than that which would cool to the ambient temperature in less than 30 seconds when liquid carbon dioxide flows through the conduit~~X~~.

~~28~~27. The method of claim 1 wherein the configuration of the orifice and are such that solid and gaseous carbon dioxide exits the orifice in a mixture that comprises at least 40% solid carbon dioxide ~~when the dose of carbon dioxide through the orifice is less than X weight/mass and the first conduit has reached a temperature of at least Y degrees centigrade prior to introduction of liquid carbon dioxide into the first conduit~~.

~~29~~28. The method of claim ~~17~~ 16 wherein the conduits are directed to add carbon dioxide to a concrete mixer, and wherein cement is added to the mixer through a cement conduit comprising a first portion comprising a rigid chute connected to a second portion comprising a flexible boot configured to allow a ready -mix truck to move a hopper on the ready -mix into the boot so that the boot flops into the hopper, allowing cement and other ingredients to fall into a drum of the ready- mix truck through the boot, wherein the third conduit is positioned alongside the first portion of the cement conduit and the fourth conduit is positioned to move and direct itself with the second portion of the cement conduit.

~~30~~29. The method of claim ~~29~~ 28 wherein aggregate is added to the mixer through an aggregate chute adjacent to the cement chute, and where the first portion of the third conduit is positioned to reduce contact with aggregate as it exits the aggregate chute.

~~31~~30. The method of claim ~~29~~ 28 wherein the first portion of the third conduit extends to the bottom of the first portion of the cement chute and the fourth conduit is attached to the end of the

third conduit, and extends from the end of the third conduit to the bottom of the rubber boot or near the bottom of the rubber boot when the rubber boot is positioned within the hopper of the ready -mix truck.

~~32~~31. The method of claim ~~29~~ 28 wherein the fourth conduit is positioned within x cm of the center of the rubber boot, on average, where x = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 20, 25, 30, 35, 40, 45,
50, 60, 70, 80, or 90 cm when the rubber boot is positioned to load concrete materials into the drum of the ready--mix truck.

32. A method for intermittently delivering a dose carbon dioxide in solid and gaseous form to a destination comprising

(i) transporting liquid carbon dioxide from a source of liquid carbon dioxide to an orifice via a first conduit, wherein

(a) the first conduit comprises material that can withstand the temperature and pressure of the liquid carbon dioxide,

(b) the pressure drop through the orifice and the configuration of the orifice are such that solid and gaseous carbon dioxide are produced as the carbon dioxide exits the orifice, and

(c) the first conduit comprises a valve for regulating the flow of carbon dioxide;

(ii) transporting the solid and gaseous carbon dioxide through a second conduit,
wherein the ratio of the length of the second conduit to the length of the first conduit is at least 1: 1; and

(iii) directing the carbon dioxide that exits the second conduit to a destination;
wherein the method further comprising determining a pressure and a temperature between the valve and the orifice, and determining a flow rate for the carbon dioxide based on the temperature and the pressure, and the flow rate is determined by comparing the pressure and temperature to a set of calibration curves for flow rates at a plurality of temperatures and pressures.

33. The method of claim 32 further wherein the length, diameter, and material of the first conduit are such that, after a transition period, the liquid carbon dioxide entering the first conduit arrives at the orifice as at least 90% liquid carbon dioxide when the ambient temperature is less than 30 °C.

34. The method of claim 32 further wherein the second conduit has a smooth bore.

35. The method of claim 32 wherein the first conduit is not insulated.

36. The method of claim 32 further comprising directing the solid and gaseous carbon dioxide from the end of the second conduit into a third conduit, wherein the third conduit comprises a

portion configured to slow the flow of the carbon dioxide through the portion of third conduit sufficiently to cause the solid carbon dioxide to clump before it exits the third conduit through an opening.

37. The method of claim 36 wherein the portion of the third conduit configured to slow the flow of carbon dioxide is an expanded portion compared to the second conduit.

38. The method of claim 36 wherein the ratio of the length of the third conduit to the length of the second conduit is less than 0.1:1.

39. The method of claim 36 wherein the third conduit has a length between 1 and 10 feet.

40. The method of claim 36 wherein the third conduit has an inner diameter between 1 inch and 3 inches.

41. The method of claim 32 wherein the ratio of the length of the second conduit to that of the first conduit is at least 2:1.

42. The method of claim 32 wherein the first conduit has a length of less than 15 feet.

43. The method of claim 32 wherein the first conduit has an inner diameter between 0.25 and 0.75 inches.

44. The method of claim 32 wherein the first conduit comprises inner material of braided stainless steel.

45. The method of claim 32 wherein the second conduit has a length of at least 30 feet.

46. The method of claim 32 wherein the second conduit has an inner diameter between 0.5 and 0.75 inch.

47. The method of claim 32 wherein the second conduit comprises inner material of PTFE.

48. The method of claim 36 wherein the third conduit comprises rigid material, and is operably connected to a fourth conduit comprising flexible material.

49. The method of claim 48 wherein the combined length of the third and fourth conduits is between 2 and 10 feet.

50. The method of claim 32 wherein the destination to which the carbon dioxide is directed is within a mixer.

51. The method of claim 50 wherein the mixer is a concrete mixer.

52. The method of claim 51 wherein the carbon dioxide is directed to a place in the mixer where, when the mixer is mixing a concrete mix, a wave of concrete folds over onto the mixing concrete.

53. The method of claim 51 wherein the concrete mixer is a stationary mixer.

54. The method of claim 51 wherein the mixer is a transportable mixer.

55. The method of claim 54 wherein the mixer is a drum of a ready-mix truck.

56. The method of claim 32 wherein the total heat capacity of the first and/or second conduit is no more than that which would cool to the ambient temperature in less than 30 seconds when liquid carbon dioxide flows through the conduit.

57. The method of claim 32 wherein the configuration of the orifice and are such that solid and gaseous carbon dioxide exits the orifice in a mixture that comprises at least 40% solid carbon dioxide.

58. The method of claim 48 wherein the conduits are directed to add carbon dioxide to a concrete mixer, and wherein cement is added to the mixer through a cement conduit comprising a first portion comprising a rigid chute connected to a second portion comprising a flexible boot configured to allow a ready -mix truck to move a hopper on the ready -mix into the boot so that the boot flops into the hopper, allowing cement and other ingredients to fall into a drum of the ready- mix truck through the boot, wherein the third conduit is positioned alongside the first portion of the cement conduit and the fourth conduit is positioned to move and direct itself with the second portion of the cement conduit.

59. The method of claim 58 wherein aggregate is added to the mixer through an aggregate chute adjacent to the cement chute, and where the first portion of the third conduit is positioned to reduce contact with aggregate as it exits the aggregate chute.

60. The method of claim 58 wherein the first portion of the third conduit extends to the bottom of the first portion of the cement chute and the fourth conduit is attached to the end of the third conduit, and extends from the end of the third conduit to the bottom of the rubber boot or near

the bottom of the rubber boot when the rubber boot is positioned within the hopper of the ready-mix truck.

61. The method of claim 58 wherein the fourth conduit is positioned within x cm of the center of the rubber boot, on average, where x = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, or 90 cm when the rubber boot is positioned to load concrete materials into the drum of the ready-mix truck.

~~33. An apparatus for delivering solid and gaseous carbon dioxide comprising~~
~~(i) a source of liquid carbon dioxide;~~
~~(ii) a first conduit, wherein the first conduit comprises a proximal end operably connected to the source of liquid carbon dioxide, and a distal end operably connected to an orifice, wherein the first conduit is configured to transport liquid carbon dioxide under pressure to the orifice, and wherein the orifice is open to atmospheric pressure, or close to atmospheric pressure, and is configured to convert the liquid carbon dioxide to a mixture of solid and gaseous carbon dioxide as it passes through the orifice;~~
~~(iii) a second conduit operably connected to the orifice for directing the mixture of gaseous and solid carbon dioxide to a desired destination, wherein the second conduit has a smooth bore, and wherein the ratio of the length of the first conduit to the length of the second conduit is less than 1:1.~~

~~34. The apparatus of claim 33 wherein the ratio of the length of the first conduit to the length of the second conduit is less than 1:2.~~

~~35. The apparatus of claim 33 wherein the ratio of the length of the first conduit to the length of the second conduit is less than 1:5.~~

~~36. The apparatus of claim 33 wherein the first conduit is less than 20 feet long.~~

~~37. The apparatus of claim 33 wherein the first conduit is less than 15 feet long.~~

~~38. The apparatus of claim 33 wherein the first conduit is less than 12 feet long.~~

~~39. The apparatus of claim 33 wherein the first conduit is less than 5 feet long.~~

~~40. The apparatus of claim 33 wherein the first conduit comprises a valve prior to the orifice to regulate the flow of the liquid carbon dioxide.~~

41. The apparatus of claim 40 further comprising a first pressure sensor between the valve and the orifice.

42. The apparatus of claim 40 further comprising a second pressure sensor between the source of liquid carbon dioxide and the valve.

43. The apparatus of claim 40 further comprising a third pressure sensor after the orifice.

44. The apparatus of claim 41 further comprising a temperature sensor between the valve and the orifice.

45. The apparatus of claim 44 further comprising a control system operably connected to the first pressure sensor and the temperature sensor.

46. The apparatus of claim 44 wherein the controller receives a pressure from the first pressure sensor and a temperature from the temperature sensor and calculates a flow rate of carbon dioxide in the system from the pressure and temperature.

47. The apparatus of claim 46 wherein the controller calculates the flow rate based on a set of calibration curves for the apparatus.

48. The apparatus of claim 47 wherein the set of calibration curves is produced with a calibration setup comprising a source of liquid carbon dioxide, a first conduit, an orifice, a valve in the first conduit before the orifice, a pressure sensor between the valve and the orifice, and a temperature sensor between the valve and the orifice, wherein the material of the first conduit, the length and diameter of the first conduit, and the material and configuration of the orifice, are the same as or similar to those of the apparatus.

49. The apparatus of claim 48 wherein the set of calibration curves is produced by determining the flow of carbon dioxide at a plurality of temperatures as measured at the temperature sensor and a plurality of pressures as measured at the pressure sensor.

50. The apparatus of claim 33 further comprising a third conduit, operably attached to the second conduit, wherein the third conduit has a larger inside diameter than the second conduit and wherein the diameter and length of the third conduit are configured to slow the flow of the gaseous and solid carbon dioxide and to cause clumping of the solid carbon dioxide.

51. The apparatus of claim 33 wherein the first conduit is not insulated.

52. A system for delivering solid and gaseous carbon dioxide in an intermittent manner at doses of carbon dioxide of less than 60 pounds, with a time between doses of at least 5 minutes, wherein the system is configured to deliver repeated doses with a ratio of solid to gaseous carbon dioxide of at average of least 1:1.5 in each dose , in less than 60 seconds per dose, at an ambient temperature of 35 °C or less.

53. The system of claim 52 wherein the system is configured to deliver the repeated doses of carbon dioxide with a coefficient of variation of less than 10%.

54. The system of claim 52 wherein the system is configured to deliver repeated doses of carbon dioxide with a coefficient of variation of less than 5%.

55. The system of claim 52 comprising a source of liquid carbon dioxide and a conduit from the source to an apparatus configured to convert the liquid carbon dioxide to solid and gaseous carbon dioxide, wherein the conduit is not required to be insulated.

56. The system of claim 55 wherein the conduit is not insulated.

57. The system of claim 55 further comprising a second conduit connected to the apparatus to convert the liquid carbon dioxide to solid and gaseous carbon dioxide, wherein the second conduit delivers the solid and gaseous carbon dioxide to a desired location.

58. The system of claim 57 wherein the ratio of lengths of the first conduit to the second conduit is less than 1:1.

59. An apparatus for delivering solid and gaseous carbon dioxide in low doses in an intermittent manner of repeated doses of solid and gaseous carbon dioxide comprising -
(i) a source of liquid carbon dioxide;
(ii) a first conduit, wherein the first conduit comprises a proximal end operably connected to the source of liquid carbon dioxide, and a distal end operably connected to an orifice, wherein the first conduit is configured to transport liquid carbon dioxide under pressure to the orifice, and wherein the orifice is open to atmospheric pressure and is configured to convert the liquid carbon dioxide to a mixture of solid and gaseous carbon dioxide as it passes through the orifice;
(iii) a valve in the conduit between the source of carbon dioxide and the orifice, to regulate the flow of liquid carbon dioxide;
(iv) a heat source operable connected to the section of conduit between the valve and the orifice, and to the orifice, wherein the heat source is configured to warm the conduit and orifice between doses to convert liquid or solid carbon dioxide to gas which is vented through the orifice.

~~60. The apparatus of claim 59 further comprising a heat sink operably connected to the heat source.~~

~~61. The apparatus of claim 59 further comprising (v) a second conduit operably connected to the orifice for directing the mixture of gaseous and solid carbon dioxide to a desired destination~~

~~62. The apparatus of claim 61 wherein the second conduit has a smooth bore.~~

~~63. The apparatus of claim 61 wherein the ratio of the length of the first conduit to the length of the second conduit is less than 1:1.~~