CLAIMS

1. A method for recovering organic heteroatom compounds from a hydrocarbon feedstock, the method comprising:

feeding a hydrocarbon feedstock into at least one contactor, the hydrocarbon feedstock comprising at least one hydrocarbon and at least one organic heteroatom compound;

feeding an aqueous solvent into the contactor to form an extraction mixture of the aqueous solvent with the hydrocarbon feedstock, the aqueous solvent comprising an ionic liquid formed from pressurized carbon dioxide and water;

establishing a contactor pressure and a contactor temperature of the extraction mixture in the contactor that together tune the aqueous solvent to selectively form a solvent complex with the at least one organic heteroatom compound, the contactor temperature being from greater than the critical temperature of carbon dioxide to 100 °C;

extracting the solvent complex to a recovery vessel from the extraction mixture in the contactor;

adjusting a recovery temperature of the recovery vessel, a recovery pressure of the recovery vessel, or both, to decompose the solvent complex in the recovery vessel into carbon dioxide and the at least one organic heteroatom compound; and

recovering the at least one organic heteroatom compound from the recovery vessel.

2. The method of claim 1, wherein the hydrocarbon feedstock is crude oil or a crude oil fraction.

3. The method of claim 1 or claim 2, wherein the at least one heteroatom compound is chosen from nitrogen-containing heterocyclic compounds, sulfur-containing heterocyclic compounds, porphyrins, organometallic compounds, and combinations thereof.

4. The method of ~~any of claims 1-3~~claim 1 or claim 2, wherein the at least one organic heteroatom compound is chosen from pyrrole, pyridine, quinoline, isoquinoline, acridine, benzocarbazole, carbazole, indole, nickel-tetraphenyl-porphyrin, vanadyl-tetraphenyl-porphyrin, thiophene, benzothiophene, dibenzothiophene, and 7,8,9,10-tetrahydro-benzo[b]naphtho[2,3-d]thiophene, and combinations thereof.

5. The method of ~~any of claims 1-4~~claim 1 or claim 2, wherein the contactor comprises electrical plates, the method further comprising activating the electrical plates to align ions of the ionic liquid and ions of the at least one organic heteroatom compound.

~~6. The method of any of claims 1-5, wherein the pressurized carbon dioxide in the aqueous solvent comprises supercritical CO_2, subcritical CO_2, or both.~~

~~7~~6. The method of ~~any of claims 1-6~~claim 1 or claim 2, wherein the contactor pressure is from about 2 bar to about 300 bar~~, from about 20 bar to about 275 bar, from about 50 bar to about 250 bar, from about 75 bar to about 225 bar, from about 100 bar to about 200 bar, or from about 125 bar to about 175 bar, and preferably about 150 bar~~.

~~8~~7. The method of ~~any of claims 1-7~~claim 1 or claim 2, wherein the contactor pressure is greater than or equal to the critical pressure of CO_2.

~~9. The method of any of claims 1-8, wherein the contactor temperature is greater than or equal to the critical temperature of carbon dioxide.~~

~~10. The method of any of claims 1-9, wherein the contactor temperature is about 20 °C greater than the critical temperature of carbon dioxide, greater than or equal to about 40 °C above the critical temperature of carbon dioxide, or about 60 °C greater than the critical temperature of carbon dioxide.~~

~~11. The method of any of claims 1-10, wherein the temperature in the contactor is less than or equal to about 100 °C, and preferably less than or equal to about 80 °C.~~

~~12. The method of claim 11, wherein the contactor temperature is from greater than the critical temperature of carbon dioxide to about 100 °C.~~

~~13. The method of any of claims 1-12, wherein the hydrocarbon feedstock and the aqueous solvent are fed into the contactor such that the hydrocarbon feedstock and aqueous solvent are in counter-flow in the contactor.~~

~~14. The method of any of claims 1-13, wherein the hydrocarbon feedstock and the aqueous solvent are fed into opposing ends of the contactor.~~

~~15. The method of claim 13 or claim 14, wherein the hydrocarbon feedstock is fed into the contactor by a method comprising spraying the hydrocarbon feedstock into a bottom of the contactor; and the aqueous solvent is fed into the contactor by a method comprising spraying the aqueous solvent into a top of the contactor.~~

~~16~~8. The method of ~~any of claims 1-15~~claim 1 or claim 2, wherein adjusting a recovery temperature of the recovery vessel, a recovery pressure of the recovery vessel, or both comprises reducing the recovery pressure to less than the contactor pressure.

~~17~~9. The method of ~~any of claims 1-16~~claim 1 or claim 2, wherein adjusting a recovery temperature of the recovery vessel, a recovery pressure of the recovery vessel, or both comprises lowering the recovery temperature to less than the contactor temperature.

~~18. The method of any of claims 1-17, wherein the density of the aqueous solvent is greater than the density of the hydrocarbon feedstock, whereby the extraction mixture separates into at least an organic phase and an aqueous phase and at least a portion of the solvent complex migrates into the aqueous phase.~~

~~19~~10. The method of ~~any of claims 1-18~~claim 1 or claim 2, wherein extracting the solvent complex comprises removing the at least a portion of the solvent complex from the aqueous phase or from a CO_2 phase that forms above the aqueous phase in the contactor.

~~20~~11. The method of ~~any of claims 1-19~~claim 1 or claim 2, wherein the solvent complex is depressurized in the recovery vessel to decompose the solvent complex to form a mixture comprising one or more heteroatom compound(s), carbon dioxide and water, and recovering the at least one or more heteroatom compound.

~~21~~12. The method of claim ~~20~~11, further comprising recycling at least a portion of the carbon dioxide released during the depressurizing of the solvent complex in the recovery vessel back to the contactor.

~~22~~13. The method of claim ~~21~~-12, wherein the carbon dioxide is used to form the aqueous solvent that is fed to the contactor.

~~23~~14. The method of ~~any of claims 1-22~~claim 1 or claim 2, wherein ~~the~~-the hydrocarbon feedstock is mixed with the aqueous solvent contating supercritical CO_2 and water before feeding into the contactor.

~~24. The method of claim 23, wherein the supercritical carbon dioxide comprises carbon dioxide recycled from the method of claim 21.~~

~~25~~15. The method of ~~any of claims 1-24~~claim 1 or claim 2, wherein recovering the at least one organic heteroatom compound from the recovery vessel comprises mixing an aromatic solvent with the mixture containing one or more heteroatom compound(s) and ionic solvent, ~~and preferably~~ extracting the organic heteroatom compound into the aromatic solvent, ~~followed removal of~~and removing the aromatic solvent.

~~26~~16. The method of ~~any of claims 1-25~~claim 1 or claim 2, wherein recovering the at least one organic heteroatom compound from the recovery vessel comprises filtering the mixture containing one or more heteroatom compound(s) and ionic solvent.

~~27. The method of any of claims 1-26, further comprising extracting and recovering lean hydrocarbon from the contractor.~~

~~28. The method of claim 27, wherein the lean hydrocarbon is recovered from the contractor by depressurizing to produce a mixture containing lean hydrocarbon, carbon dioxide and water, and recovering the lean hydrocarbon..~~

~~29. The method of claim 28, wherein the carbon dioxide and/or water are optionally separated, and used to form the aqueous solvent that is fed to the contactor.~~

~~30. The method of any of claims 1-29, wherein one contactor is employed.~~

~~31~~17. The method of ~~any of claims 1-30~~claim 1 or claim 2, wherein multiple contactors are employed in series, ~~preferably~~ and wherein each contactor is employed to recover different organic heteroatom compounds from the hydrocarbon feedstock.

~~32~~18. The method according to ~~claim 30 or claim 31~~claim 17, wherein more than one recovery vessel is employed, ~~preferably~~ and wherein each recovery vessel is employed to recover different organic heteroatom compounds from the decomposed solvent complex.

~~33. The method according to any of claims 1-32 wherein the method is a batch or a continuous operation, and preferably a continuous operation.~~

~~34. Use of an ionic liquid formed from pressurized carbon dioxide and water as a complexing agent for recovering at least one organic heteroatom compound from a hydrocarbon feedstock, preferably wherein the hydrocarbon feedstock comprises crude oil or a crude oil fraction.~~

~~35. Use of an ionic liquid formed from pressurized carbon dioxide and water as a agent for removing or reducing at least one organic heteroatom compound from a hydrocarbon feedstock, preferably wherein the hydrocarbon feedstock comprises crude oil or a crude oil fraction.~~

~~36. Use according to Claim 34 or Claim 35 wherein the at least one organic heteroatom compound is selected from the group consisting of nitrogen containing heterocyclic compounds, sulfur containing heterocyclic compounds, porphyrins, organometallic compounds, and combinations thereof.~~

~~37. Use according to claim 36, wherein the at least one organic heteroatom compound is selected from the group consisting of pyrrole, pyridine, quinoline, carbazole, indole, nickel tetraphenyl porphyrin, vanadyl tetraphenyl porphyrin, thiophene, benzothiophene, dibenzothiophene, and 7,8,9,10 tetrahydro-benzo[b]naphtho[2,3-d]thiophene, and combinations thereof.~~

~~38~~19. A method for reducing or removing one or more organic heteroatom compounds from a hydrocarbon feedstock to form a lean hydrocarbon, the method comprising:

feeding a hydrocarbon feedstock into a contactor, the hydrocarbon feedstock comprising at least one hydrocarbon and at least one organic heteroatom compound;

feeding an aqueous solvent into the contactor to form an extraction mixture of the aqueous solvent with the hydrocarbon feedstock, the aqueous solvent comprising an ionic liquid formed from pressurized carbon dioxide and water;

establishing a contactor pressure and a contactor temperature of the extraction mixture in the contactor that together tune the aqueous solvent to selectively form a mixture containing a lean hydrocarbon and a solvent complex with the at least one organic heteroatom compound, the contactor temperature being from greater than the critical temperature of carbon dioxide to 100 °C;

extracting the solvent complex to a recovery vessel from the extraction mixture in the contactor; and

recovering the lean hydrocarbon from the contactor.

~~39. A method according to Claim 38, further comprising recovering the at least one organic heteroatom compound from the solvent complex.~~

~~40. A method according to Claim 39, whereby the organic heteroatom compound is recovered from the solvent complex by adjusting a recovery temperature of the recovery vessel, a recovery pressure of the recovery vessel, or both, to decompose the solvent complex in the recovery vessel into carbon dioxide and the at least one organic heteroatom compound; and recovering the at least one organic heteroatom compound from the recovery vessel.~~

~~41~~20. A method according to ~~any of Claim 38-40~~claim 19, wherein the hydrocarbon feedstock comprises crude oil or a crude oil fraction.

~~42~~21. A method according to ~~any of Claims 38-41~~claim 19 or claim 20, wherein the at least one organic heteroatom compound is selected from the group consisting of nitrogen-containing heterocyclic compounds, sulfur-containing heterocyclic compounds, porphyrins, organometallic compounds, and combinations thereof.

~~43~~22. The method of ~~claim 42~~claim 21, wherein the at least one organic heteroatom compound is selected from the group consisting of pyrrole, pyridine, quinoline, carbazole, indole, nickel-tetraphenyl-porphyrin, vanadyl-tetraphenyl-porphyrin, thiophene, benzothiophene, dibenzothiophene, and 7,8,9,10-tetrahydro-benzo[b]naphtho[2,3-d]thiophene, and combinations thereof.