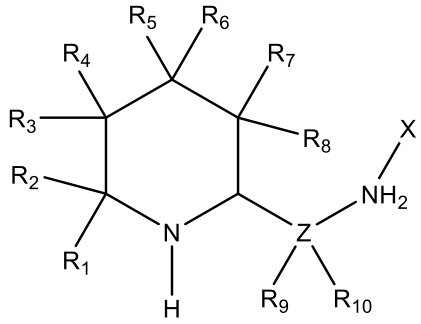
Claims

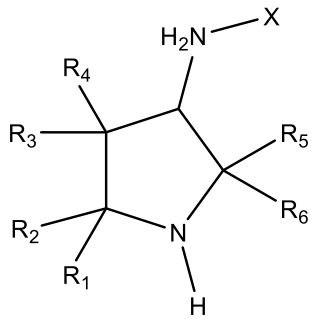
1. An adsorption material, comprising:

a metal–organic framework comprising a plurality of metal ions and a plurality of polytopic organic linkers, wherein each polytopic organic linker in the plurality of polytopic organic linker is connected to at least two metal ions in the plurality of metal ions; and

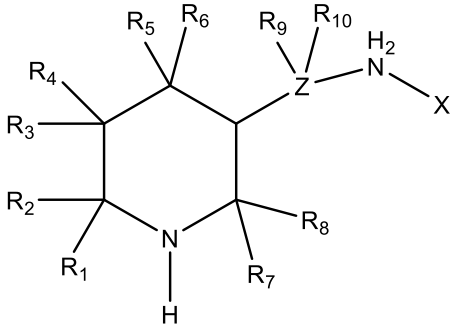
a plurality of ligands, wherein each respective ligand in the plurality of ligands is amine appended to a metal ion in the plurality of metal ions of the metal–organic framework, each respective ligand in the plurality of ligands has the formula:



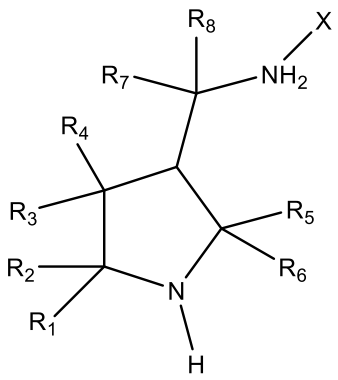
or



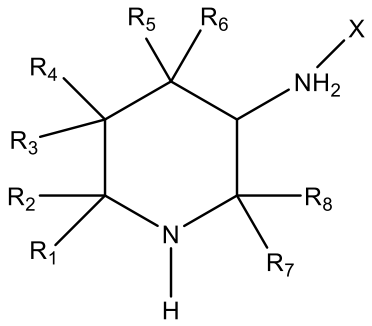
or



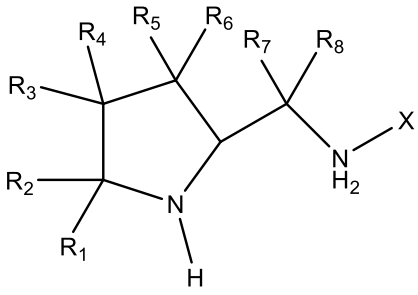
or



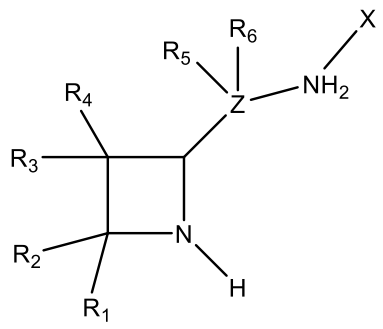
or



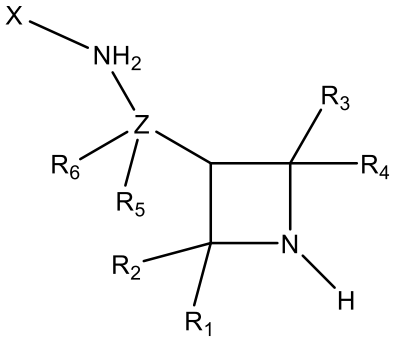
or



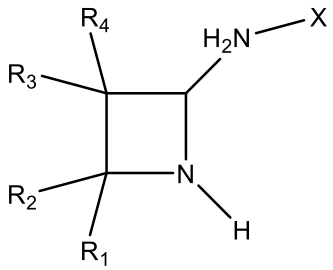
or



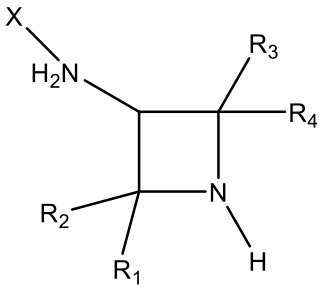
or



or



or



,

wherein,

X is a metal ion in the plurality of metal ions of the metal–organic framework,

Z is carbon, silicon, germanium, sulfur, or selenium, and

R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8, R_9, and R_{10}, are each independently selected from H, halogen, methyl, halogen substituted methyl, and hydroxyl.

2. The adsorption material of claim 1, wherein each metal ion (X) in the plurality of metal ions is Mg, Ca, Mn, Cr, Fe, Co, Ni, Cu, or Zn.

3. The adsorption material of claim 1, wherein R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8, R_9, and R_{10} are each hydrogen.

4. The adsorption material of claim 1, wherein Z is carbon.

5. The adsorption material of claim 1, wherein each metal ion (X) in the plurality of metal ions is Mg.

6. The adsorption material of claim 1, wherein the polytopic organic linker is 4,4′-dioxidobiphenyl-3,3′-dicarboxylate ($dobpdc^{4-}$).

7. The adsorption material of claim 1, wherein the polytopic organic linker is 4,4''-dioxido-[1,1':4',1''-terphenyl]-3,3''-dicarboxylate ($dotpdc^{4-}$).

8. The adsorption material of claim 1, wherein the polytopic organic linker is dioxidobiphenyl-4,4′-dicarboxylate (para-carboxylate-$dobpdc^{4-}$, also referred to as pc-$dobpdc^{4-}$).

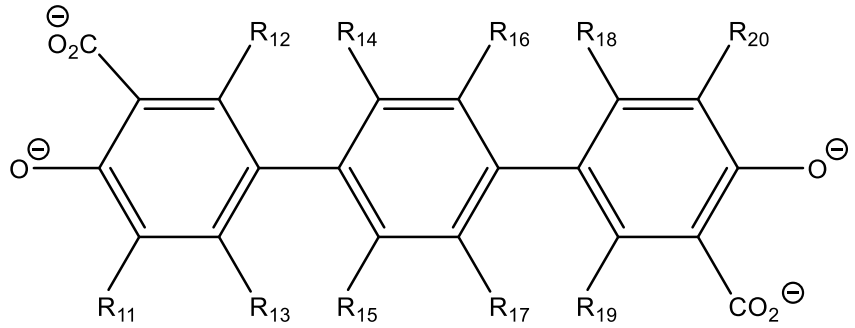
9. The adsorption material of claim 1, wherein the adsorption material exhibits a plurality of CO_2 adsorption steps upon CO_2 adsorption.

10. The adsorption material of claim 1, wherein the adsorption material exhibits a plurality of CO_2 desorption steps upon CO_2 desorption.

11. The adsorption material of claim 1, wherein the adsorption material exhibits a single CO_2 adsorption step upon CO_2 adsorption.

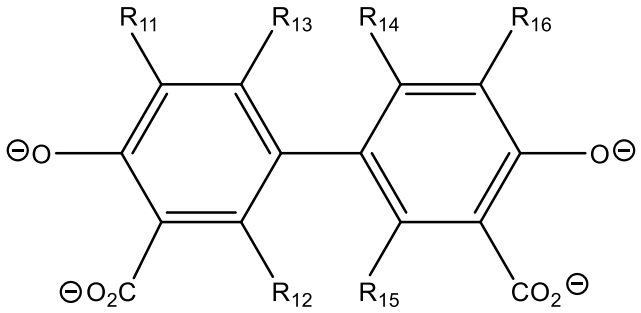
12. The adsorption material of claim 1, wherein the adsorption material exhibits a single CO_2 desorption step upon CO_2 desorption.

13. The adsorption material of claim 1, wherein the polytopic organic linker has the formula:



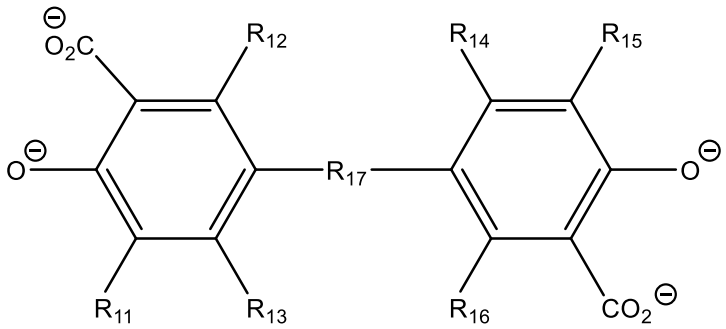
wherein, R_{11}, R_{12}, R_{13}, R_{14}, R_{15}, R_{16}, R_{17}, R_{18}, R_{19}, and R_{20} are each independently selected from H, halogen, hydroxyl, methyl, and halogen substituted methyl.

14. The adsorption material of any one of claim 1, wherein the polytopic organic linker has the formula:



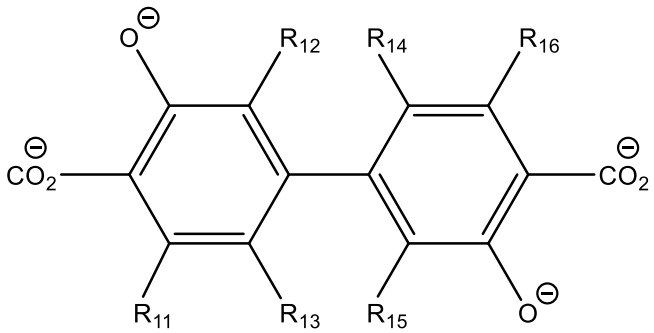
wherein, R_{11}, R_{12}, R_{13}, R_{14}, R_{15}, and R_{16} are each independently selected from H, halogen, hydroxyl, methyl, and halogen substituted methyl.

15. The adsorption material of claim 1, wherein the polytopic organic linker has the formula:



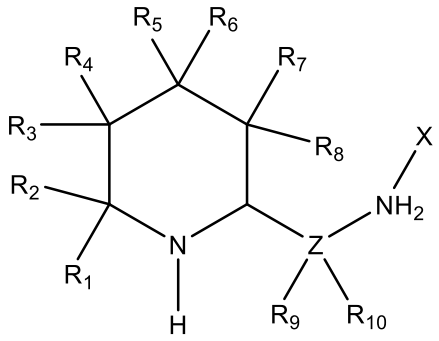
wherein, R_{11}, R_{12}, R_{13}, R_{14}, R_{15}, and R_{16} are each independently selected from H, halogen, hydroxyl, methyl, or halogen substituted methyl, and R_{17} is selected from substituted or unsubstituted aryl, vinyl, alkynyl, and substituted or unsubstituted heteroaryl.

16. The adsorption material of claim 1, wherein the polytopic organic linker has the formula:



wherein, R_{11}, R_{12}, R_{13}, R_{14}, R_{15}, and R_{16} are each independently selected from H, halogen, hydroxyl, methyl, or halogen substituted methyl.

17. The absorption material of claim 1 wherein each respective ligand in the plurality of ligands has the formula:



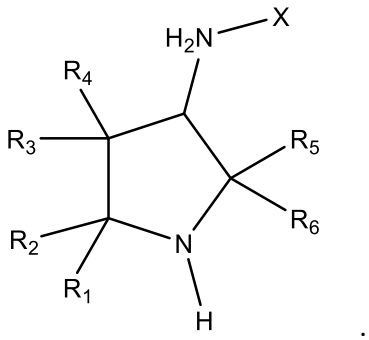
18. The absorption material of claim 17, wherein

R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8, R_9, and R_{10} are each hydrogen,

Z is carbon, and

X is Mg.

19. The absorption material of claim 1 wherein each respective ligand in the plurality of ligands has the formula:



20. The absorption material of claim 19, wherein

R_1, R_2, R_3, R_4, R_5, and R_6 are each hydrogen,

Z is carbon, and

X is Mg, and wherein the diamine also coordinates with the Mg.

21. A method for abating CO_2 from a flue gas, the method comprising:

(a) contacting the flue gas with the adsorption material of claim 1 to reversibly adsorb CO_2 from the flue gas thereby generating an adsorption material enriched for CO_2; and

(b) stripping a major portion of the CO_2 from the adsorption material enriched for CO_2 using a temperature swing adsorption method, a vacuum swing adsorption method, a pressure

swing adsorption method, a concentration swing adsorption method, or a combination thereof.

22. The method of claim 21, wherein flue gas contains ≤4% (40 mbar) CO_2 and wherein the adsorption process removes more than 90% of the CO_2 from flue gas to a concentration ≤ 0.4% (4 mbar).

23. A method for removing CO_2 from a biogas, the method comprising contacting the biogas with the adsorption material of claim 1 to reversibly adsorb CO_2 from the biogas the contacting thereby generating an adsorption material enriched for CO_2 and a residual gas that contains purified methane with ≤2% CO_2.

24. The method of claim 23, the method further comprising adsorption of more than 90 percent of the CO_2 from the target gas stream and stripping the CO_2 from the adsorption material enriched for CO_2 using a temperature swing adsorption method, a vacuum swing adsorption method, a pressure swing adsorption method, a concentration swing adsorption method, or a combination thereof.

25. A method of sequestering carbon dioxide produced by a source, comprising exposing the carbon dioxide to the adsorption material of claim 1, whereby the carbon dioxide is reversibly sequestered into the adsorption material.

26. The method of claim 25, the method further comprising regenerating the adsorption material enriched for CO_2 using a temperature swing adsorption method, vacuum swing adsorption method, a pressure swing adsorption method, a concentration swing adsorption method, or a combination thereof.