air separation process that involves cryogenically cooling air into liquid form and distilling pure oxygen from nitrogen in the liquid air.

[0007] Given the reliance on fossil fuels, widespread adoption of CCS is imperative for reduction of greenhouse gases and control of global warming. Although some companies are focused on finding alternative CCS processes, a significant amount of research is focused on increasing the efficiency of current carbon dioxide-capture processes.

## SUMMARY

[0008] It is an object of the present disclosure to provide a method for the absorption and separation of carbon dioxide that overcomes many of the disadvantages of the prior art. The inventor has identified methods for the production of mineral ion salts that can be used to sequester carbon dioxide in the form of mineral ion carbonate salts. The mineral ion salts can be obtained from different sources, including industrial waste materials and various geological silicate minerals.

[0009] The disclosure is directed to a method of employing a waste material to sequester carbon dioxide. The method comprises the steps of reacting a magnesium chloride hydrate-containing material with steam to generate hydrochloric acid and magnesium hydroxide, contacting the magnesium hydroxide with a gas stream comprising carbon dioxide to provide a partially or fully carbonated stream, contacting waste material with the hydrochloric acid and optionally water to leach mineral ion salts from the waste material into a brine or slurry, recovering the mineral ion salts from the brine or slurry, and reacting the mineral ions salts with the partially or fully carbonated stream to sequester carbon dioxide in the form of mineral ion carbonate salts. In some examples, the partially or fully carbonated stream comprises $Mg(OH)_x(HCO_3)_y$, where $x+y = 2$. In some examples, the mineral ion carbonate salts comprise precipitated calcium carbonate (PCC). In some examples, the mineral ion carbonate salts further comprise lesser value, mixed carbonates.

[0009a] In one aspect, the disclosure is directed to a method of employing a waste material to sequester carbon dioxide, the method comprising: reacting a magnesium chloride hydrate-containing material with steam to generate HCl and $Mg(OH)_2$; contacting the $Mg(OH)_2$ with a gas stream comprising carbon dioxide to provide a partially or fully carbonated stream; contacting waste material with the HCl and optionally water to leach mineral ion salts from the waste material into a brine or slurry; recovering the mineral ion salts from the brine or slurry;

and reacting the mineral ions salts with the partially or fully carbonated stream to sequester carbon dioxide in the form of mineral ion carbonate salts.

[0010] The disclosure is directed to a method of employing a geological silicate mineral to sequester carbon dioxide. The method comprises the steps of reacting a magnesium chloride hydrate-containing material with steam to generate hydrochloric acid and magnesium hydroxide, contacting the magnesium hydroxide with a gas stream comprising carbon dioxide to provide a partially or fully carbonated stream, contacting the geological silicate mineral with the hydrochloric acid and optionally water to

leach mineral ion salts from the geological silicate mineral into a brine or slurry, recovering the mineral ion salts from the brine or slurry, reacting the mineral ions salts with the partially or fully carbonated stream to sequester carbon dioxide in the form of mineral ion carbonate salts. In some examples, the partially or fully carbonated stream comprises $Mg(OH)_x(HCO_3)_y$, where x+y = 2. In some examples, the mineral ion carbonate salts comprise precipitated calcium carbonate. In some examples, the mineral ion carbonate salts further comprise lesser value, mixed carbonates.

[0010a] In another aspect, the disclosure is directed to a method of employing a geological silicate mineral to sequester carbon dioxide, the method comprising: reacting a magnesium chloride hydrate-containing material with steam to generate HCl and $Mg(OH)_2$; contacting the $Mg(OH)_2$ with a gas stream comprising carbon dioxide to provide a partially or fully carbonated stream; contacting the geological silicate mineral with the HCl and optionally water to leach mineral ion salts from the geological silicate mineral into a brine or slurry; recovering the mineral ion salts from the brine or slurry; and reacting the mineral ions salts with the partially or fully carbonated stream to sequester carbon dioxide in the form of mineral ion carbonate salts.

[0011] In some examples, the mineral ion salts comprise at least one Group II metal cation. In some examples, the Group II metal cation is a calcium cation. In some examples, the Group II metal cation is a magnesium cation. In some examples, the waste material is an industrial waste material. In some examples, the industrial waste material is selected from the group consisting of masonry, concrete, steel furnace slag, bio-mass fuel production slag, and waste coal fly ash.

[0012] In some examples, the carbon dioxide is a component of a flue gas stream. In some examples, the carbon dioxide is atmospheric carbon dioxide. In some examples, the step of contacting the waste material with the hydrochloric acid is performed at ambient temperature. In some examples, the step of contacting the waste material with the hydrochloric acid is performed at greater-than-ambient temperature. In some examples, the step of contacting the waste material with the hydrochloric acid is performed at ambient pressure.

[0013] In some examples, the step of contacting the waste material with the hydrochloric acid does not involve mechanical agitation or abrasion of solids. In some examples, the step of contacting the waste material with the hydrochloric acid involves mechanical agitation or abrasion of solids. In some examples, the step

of contacting the waste material with the hydrochloric acid further comprises recirculating liquids to increase contact between the waste material and the hydrochloric acid.

[0014] In some examples, the step of contacting the geological silicate mineral with the hydrochloric acid is performed at ambient temperature. In some examples, the step of contacting the geological silicate mineral with the HCl is performed at greater-than-ambient temperature. In some examples, the step of contacting the geological silicate mineral with the hydrochloric acid is performed at ambient pressure. In some examples, the step of

contacting the geological silicate mineral with the hydrochloric acid is performed at greater-than-ambient pressure.

[0015] In some examples, the step of contacting the geological silicate mineral with the hydrochloric acid does not involve mechanical agitation or abrasion of solids. In some examples, the step of contacting the geological silicate mineral with the hydrochloric acid involves mechanical agitation or abrasion of solids. In some examples, the step of contacting the geological silicate mineral with the hydrochloric acid further comprises recirculating liquids to increase contact between the geological silicate mineral and the hydrochloric acid.

[0016] In some examples, mineral ion salts present in brine or slurry are recovered. In some examples, the brine or slurry is transferred to a settling tank. In some examples, solids in the brine or slurry are allowed to settle at the bottom of the settling tank. In some examples, the brine or slurry is transferred to an evaporation pond. In some examples, liquid in the brine or slurry is allowed to evaporate. In some examples, solar energy and/or naturally occurring wind are harnessed to increase the rate of evaporation. In some examples, non-renewable energy is not used to increase the rate of evaporation. In some examples, no energy is provided to the evaporation pond to increase the rate of evaporation.

[0017] In some examples, the mineral ion salts comprise at least one Group II metal cation. In some examples, the Group II metal cation is a calcium cation. In some examples, the Group II metal cation is a magnesium cation. In some examples, the geological silicate mineral is selected from the group consisting of olivine, forsterite, pyrope, spessartine, grossular, andradite, uvarovite, hydrogrossular, norbergite, chondrodite, humite, clinohumite, datolite, titanite, chloritoid, lawsonite, axinite, ilvaite, epidote, zoisite, tanzanite, clinozoisite, allanite, dollaseite, vesuvianite, paopgoite, tourmaline, osumilite, cordierite, sekaninaite, eudialyte, milarite, enstatite, pigeonite, diopside, hedenbergite, augite, proxferroite, wollastonite, pectolite, anthophyllite, cummingtonite, tremolite, actinolite, hornblende, glaucophane, arfvedsonite, antigorite, chrysotile, lizardite, talc, illite, montmorillonite, chlorite, vermiculite, sepiolite, palygorskite, biotite, phlogopite, margarite, glauconite, oligoclase, andesine, labradorite, bytownite, anorthite, cancrinite, hauyne, lazurite, erionite, chabazite, heulandite, stilbite, scolecite, mordenite, clinoenstatite, and combinations thereof.

[0018] It is specifically contemplated that any limitation discussed with respect to one example of the disclosure may apply to any other example of the disclosure. Furthermore, any composition of the disclosure may be used in any method of the disclosure, and any method of the disclosure may be used to produce or to utilize any composition of the disclosure.

[0019] Other objects, features and advantages of the present disclosure will become apparent from the following detailed description. It should be understood, however, that the detailed description and the specific examples, while indicating preferred examples of the disclosure, are given by way of illustration only, since various changes and modifications within the spirit and scope of the disclosure will become apparent to those skilled in the art from this detailed description.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0020] **FIG. 1** is a block diagram of a carbon dioxide sequestration process according to some embodiments of the present invention.

## DETAILED DESCRIPTION

[0021] The present invention relates to methods for capturing carbon dioxide and permanently sequestering carbon dioxide in the form of metal carbonates. The invention involves production of HCl by reacting steam with a material that includes a magnesium chloride hydrate. The HCl that is generated from this process is used to leach mineral salts from a variety of different materials, including minerals and industrial waste materials. The leached mineral salts are used to capture carbon dioxide by forming carbonates of mineral salt cations.

[0022] Of the numerous mineral salts that are available, Group II salts are generally employed for $CO_2$ capture. The Group II metals calcium and magnesium are relatively abundant throughout the world in various geological mineral deposits and in industrial waste materials. The abundant calcium and magnesium-containing minerals and waste materials provide a relatively inexpensive feedstock for $CO_2$-sequestering chemicals.

### A. Definitions

[0023] As used herein, the terms “carbonates” or “carbonate products” are generally defined as mineral components containing the carbonate group, $[CO_3]^{2-}$. Thus, the terms encompass both carbonate/bicarbonate mixtures and species containing solely the carbonate