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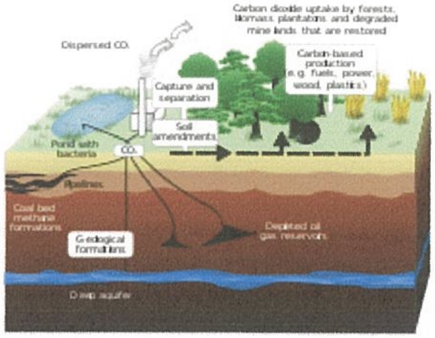
Carbon sequestration



Schematic showing both terrestrial and geological sequestration of carbon dioxide emissions from a coal-fired plant.

Carbon sequestration is the process involved in carbon capture and the long-term storage of atmospheric carbon dioxide[1] or other forms of carbon to mitigate or defer global warming. It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels.[2]

Carbon dioxide (CO_2) is naturally captured from the atmosphere through biological, chemical, and physical processes.[3] Artificial processes have been devised to produce similar effects,[3] including large-scale, artificial capture and sequestration of industrially produced CO_2 using subsurface saline aquifers, reservoirs, ocean water, aging oil fields, or other carbon sinks.

Contents

Description

Carbon sequestration is the process involved in carbon capture and the long-term storage of atmospheric carbon dioxide (CO_2)[1] and may refer specifically to:

- "The process of removing carbon from the atmosphere and depositing it in a reservoir."[4] When carried out deliberately, this may also be referred to as carbon dioxide removal, which is a form of geoengineering.
- Carbon capture and storage, where carbon dioxide is removed from flue gases (e.g., at power stations) before being stored in underground reservoirs.
- Natural biogeochemical cycling of carbon between the atmosphere and reservoirs, such as by chemical weathering of rocks.

Carbon dioxide may be captured as a pure by-product in processes related to petroleum refining or from flue gases from power generation.[5] CO_2 sequestration includes the storage part of carbon capture and storage, which refers to large-scale, artificial capture and sequestration of industrially produced CO_2 using subsurface saline aquifers, reservoirs, ocean water, aging oil fields, or other carbon sinks.

Carbon sequestration describes long-term storage of carbon dioxide or other forms of carbon to either mitigate or defer global warming and avoid dangerous climate change. It has been proposed as a way to slow the atmospheric and marine accumulation of greenhouse gases, which are released by burning fossil fuels.[2]

Carbon dioxide is naturally captured from the atmosphere through biological, chemical or physical processes. Some artificial sequestration techniques exploit these natural processes,[3] while some use entirely artificial processes.

There are three ways that this sequestration can be carried out; post-combustion capture, pre-combustion capture, and oxy-combustion. A wide variety of separation techniques are being pursued, including gas phase separation, absorption into a liquid, and adsorption on a solid, as well as hybrid processes, such as adsorption/membrane systems. These above processes basically will capture carbon emitting from power plants, factories, fuel burning industries and so on.

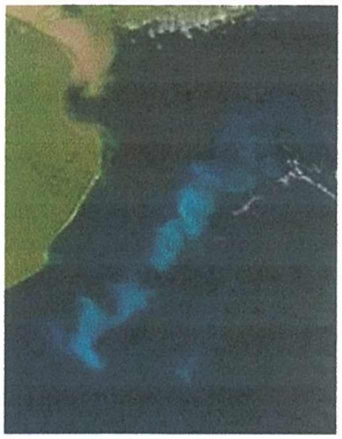
Biological processes

Biosequestration or carbon sequestration through biological processes affects the global carbon cycle. Examples include major climatic fluctuations, such as the Azolla event, which created the current Arctic climate. Such processes created fossil fuels, as well as clathrate and limestone. By manipulating such processes, geoengineers seek to enhance sequestration.

Peat production

Peat bogs act as a sink for carbon due to the accumulation of partially decayed biomass that would otherwise continue to decay completely. There is a variance on how much the peatlands act as a carbon sink or carbon source that can be linked to varying climates in different areas of the world and different times of the year.[6] By creating new bogs, or enhancing existing ones, the amount of carbon that is sequestered by bogs would increase.[7]

Forestry



An oceanic phytoplankton bloom in the South Atlantic Ocean, off the coast of Argentina. Encouraging such blooms with iron fertilization could lock up carbon on the seabed.

Reforestation is the replanting of trees on marginal crop and pasture lands to incorporate carbon from atmospheric CO_2 into biomass.[8] For this process to succeed the carbon must not return to the atmosphere from mass burning or rotting when the trees die.[9] To this end, land allotted to the trees must not be converted to other uses and management of the frequency of disturbances might be necessary in order to avoid extreme events. Alternatively, the wood from them must itself be sequestered, e.g., via biochar, bio-energy with carbon storage (BECS), landfill or 'stored' by use in e.g. construction. Short of growth in perpetuity, however, reforestation with long-lived trees (>100 years) will sequester carbon for a more graduated release, minimizing impact during the expected carbon crisis of the 21st century.

Urban forestry

Urban forestry increases the amount of carbon taken up in cities by adding new tree sites and the sequestration of carbon occurs over the lifetime of the tree.[10] It is generally practiced and maintained on smaller scales, like in cities. The results of urban forestry can have different results depending on the type of vegetation that is being used, so it can function as a sink but can also function as a source of emissions.[11] Along with sequestration by the plants which is difficult to measure but seems to have little effect on the overall amount of carbon dioxide that is uptaken, the vegetation can have indirect effects on carbon by reducing need for energy consumption.[11]

Wetland restoration

Wetland soil is an important carbon sink; 14.5% of the world's soil carbon is found in wetlands, while only 6% of the world's land is composed of wetlands.[12]

Agriculture

Compared to natural vegetation, cropland soils are depleted in soil organic carbon (SOC). When a soil is converted from natural land or semi natural land, such as forests, woodlands, grasslands, steppes and savannas, the SOC content in the soil reduces with about 30–40%.[13] This loss is due to the removal of plant material containing carbon, in terms of harvests. When the land use changes, the carbon in the soil will either increase or decrease, this change will continue until the soil reaches a new equilibrium. Deviations from this equilibrium can also be affected by variated climate .[14] The decreasing of SOC content can be counteracted by increasing the carbon input, this can be done with several strategies, e.g. leave harvest residues on the field, use manure as fertiliser or include perennial crops in the rotation. Perennial crops have larger below ground biomass fraction, which increases the SOC content.[13] Globally, soils are estimated to contain approximately 1,500 gigatons of organic carbon to 1 m depth, more than the amount in vegetation and the atmosphere.[15][16]

Modification of agricultural practices is a recognized method of carbon sequestration as soil can act as an effective carbon sink offsetting as much as 20% of 2010 carbon dioxide emissions annually.[17] (See No-till)

Carbon emission reduction methods in agriculture can be grouped into two categories: reducing and/or displacing emissions and enhancing carbon removal. Some of these reductions involve increasing the efficiency of farm operations (e.g. more fuel-efficient equipment) while some involve interruptions in the natural carbon cycle. Also, some effective techniques (such as the elimination of stubble burning) can negatively impact other environmental concerns (increased herbicide use to control weeds not destroyed by burning).

Deep soil

Soils hold four times the amount of carbon stored in the atmosphere.[18] About half of this is found deep within soils.[19] About 90% of this deep soil C is stabilized by mineral-organic associations.[20]

Reducing emissions

Increasing yields and efficiency generally reduces emissions as well, since more food results from the same or less effort. Techniques include more accurate use of fertilizers, less soil disturbance, better irrigation, and crop strains bred for locally beneficial traits and increased yields.

Replacing more energy intensive farming operations can also reduce emissions. Reduced or no-till farming requires less machine use and burns correspondingly less fuel per acre. However, no-till usually increases use of weed-control chemicals and the residue now left on the soil surface is more likely to release its CO_2 to the atmosphere as it decays, reducing the net carbon reduction.

In practice, most farming operations that incorporate post-harvest crop residues, wastes and byproducts back into the soil provide a carbon storage benefit. This is particularly the case for practices such as field burning of stubble – rather than releasing almost all of the stored CO_2 to the atmosphere, tillage incorporates the biomass back into the soil.

Enhancing carbon removal

All crops absorb CO_2 during growth and release it after harvest. The goal of agricultural carbon removal is to use the crop and its relation to the carbon cycle to permanently sequester carbon within the soil. This is done by selecting farming methods that return biomass to the soil and enhance the conditions in which the carbon within the plants will be reduced to its elemental nature and stored in a stable state. Methods for accomplishing this include:

- Use cover crops such as grasses and weeds as temporary cover between planting seasons
- Concentrate livestock in small paddocks for days at a time so they graze lightly but evenly. This encourages roots to grow deeper into the soil. Stock also till the soil with their hooves, grinding old grass and manures into the soil.[21]
- Cover bare paddocks with hay or dead vegetation. This protects soil from the sun and allows the soil to hold more water and be more attractive to carbon-capturing microbes.[21]
- Restore degraded land, which slows carbon release while returning the land to agriculture or other use.

Agricultural sequestration practices may have positive effects on soil, air, and water quality, be beneficial to wildlife, and expand food production. On degraded croplands, an increase of 1 ton of soil carbon pool may increase crop yield by 20 to 40 kilograms per hectare of wheat, 10 to 20 kg/ ha for maize, and 0.5 to 1 kg/ha for cowpeas.

The effects of soil sequestration can be reversed. If the soil is disrupted or tillage practices are abandoned, the soil becomes a net source of greenhouse gases. Typically after 15 to 30 years of sequestration, soil becomes saturated and ceases to absorb carbon. This implies that there is a global limit to the amount of carbon that soil can hold.[22]

Many factors affect the costs of carbon sequestration including soil quality, transaction costs and various externalities such as leakage and unforeseen environmental damage. Because reduction of atmospheric CO_2 is a long-term concern, farmers can be reluctant to adopt more expensive agricultural techniques when there is not a clear crop, soil, or economic benefit. Governments such as Australia and New Zealand are considering allowing farmers to sell carbon credits once they document that they have sufficiently increased soil carbon content.[21][23][24][25][26][27]

Ocean-related

Iron fertilization

Ocean iron fertilization is an example of such a geoengineering technique.[28] Iron fertilization[29] attempts to encourage phytoplankton growth, which removes carbon from the atmosphere for at least a period of time.[30][31] This technique is controversial due to limited understanding of its complete effects on the marine ecosystem,[32] including side effects and possibly large deviations from expected behavior. Such effects potentially include release of nitrogen oxides,[33] and disruption of the ocean's nutrient balance.[28]

Natural iron fertilisation events (e.g., deposition of iron-rich dust into ocean waters) can enhance carbon sequestration. Sperm whales act as agents of iron fertilisation when they transport iron from the deep ocean to the surface during prey consumption and defecation. Sperm whales have been shown to increase the levels of primary production and carbon export to the deep ocean by depositing iron rich feces into surface waters of the Southern Ocean. The iron rich feces causes phytoplankton to grow and take up more carbon from the atmosphere. When the phytoplankton dies, some of it sinks to the deep ocean and takes the atmospheric carbon with it. By reducing the abundance of sperm whales in the Southern Ocean, whaling has resulted in an extra 200,000 tonnes of carbon remaining in the atmosphere each year.[34]

Urea fertilization

Ian Jones proposes fertilizing the ocean with urea, a nitrogen rich substance, to encourage phytoplankton growth.[35]

Australian company Ocean Nourishment Corporation (ONC) plans to sink hundreds of tonnes of urea into the ocean to boost CO_2-absorbing phytoplankton growth as a way to combat climate change. In 2007, Sydney-based ONC completed an experiment involving 1 tonne of nitrogen in the Sulu Sea off the Philippines.[36]

Mixing layers

Encouraging various ocean layers to mix can move nutrients and dissolved gases around, offering avenues for geoengineering.[37] Mixing may be achieved by placing large vertical pipes in the oceans to pump nutrient rich water to the surface, triggering blooms of algae, which store carbon when they grow and export carbon when they die.[37][38][39] This produces results somewhat similar to iron fertilization. One side-effect is a short-term rise in CO_2, which limits its attractiveness.[40]

Seaweed

Seaweed grows very fast and can theoretically be harvested and processed to generate biomethane, via Anaerobic Digestion to generate electricity, via Cogeneration/CHP or as a replacement for natural gas. One study suggested that if seaweed farms covered 9% of the ocean they could produce enough biomethane to supply Earth's equivalent demand for fossil fuel energy, remove 53 gigatonnes of CO_2 per year from the atmosphere and sustainably produce 200 kg per year of fish, per person, for 10 billion people.[41] Ideal species for such farming and conversion include *Laminaria digitata*, *Fucus serratus* and *Saccharina latissima*.[42]

Physical processes

Biomass-related

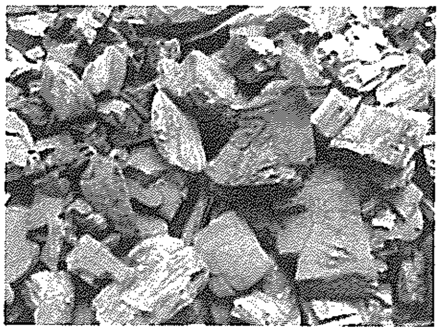
Bio-energy with carbon capture and storage

Bio-energy with carbon capture and storage (BECCS) refers to biomass in power stations and boilers that use carbon capture and storage.[43][44] The carbon sequestered by the biomass would be captured and stored, thus removing carbon dioxide from the atmosphere.[45]

This technology is sometimes referred to as bio-energy with carbon storage, BECS, though this term can also refer to the carbon sequestration potential in other technologies, such as biochar.

Burial

Burying biomass (such as trees)[46] directly, mimics the natural processes that created fossil fuels.[47] Landfills also represent a physical method of sequestration.



Biochar can be landfilled, used as a soil improver or burned using carbon capture and storage

Biochar burial

Biochar is charcoal created by pyrolysis of biomass waste. The resulting material is added to a landfill or used as a soil improver to create terra preta.[48][49] Addition of pyrogenic organic carbon (biochar) is a novel strategy to increase the soil-C stock for the long-term and to mitigate global-warming by offsetting the atmospheric C (up to 9.5 Pg C annually).[50]

In the soil, the carbon is unavailable for oxidation to CO_2 and consequential atmospheric release. This is one technique advocated by scientist James Lovelock, creator of the Gaia hypothesis.[51] According to Simon Shackley, "people are talking more about something in the range of one to two billion tonnes a year."[52]

The mechanisms related to biochar are referred to as bio-energy with carbon storage, BECS.

Ocean storage

If CO_2 were to be injected to the ocean bottom, the pressures would be great enough for CO_2 to be in its liquid phase. The idea behind ocean injection would be to have stable, stationary pools of CO_2 at the ocean floor. The ocean could potentially hold over a thousand billion tons of CO_2. However, this avenue of sequestration isn't being as actively pursued because of concerns about the impact on ocean life, and concerns about its stability.[53]

River mouths bring large quantities of nutrients and dead material from upriver into the ocean as part of the process that eventually produces fossil fuels. Transporting material such as crop waste out to sea and allowing it to sink exploits this idea to increase carbon storage.[54] International regulations on marine dumping may restrict or prevent use of this technique.

Geological sequestration

Geological sequestration refers to the storage of CO_2 underground in depleted oil and gas reservoirs, saline formations, or deep, un-minable coal beds.

Once CO_2 is captured from a gas or coal-fired power plant, it would be compressed to ≈100 bar so that it would be a supercritical fluid. In this fluid form, the CO_2 would be easy to transport via pipeline to the place of storage. The CO_2 would then be injected deep underground, typically around 1 km, where it would be stable for hundreds to millions of years.[53] At these storage conditions, the density of supercritical CO_2 is 600 to 800 kg / m^3.[55] For consumers, the cost of electricity from a coal-fired power plant with carbon capture and storage (CCS) is estimated to be 0.01–0.05 $ / kWh higher than without CCS. For reference, the average cost of electricity in the US in 2004 was 0.0762 $ / kWh. In other terms, the cost of CCS would be 20–70 $/ton of CO_2 captured. The transportation and injection of CO_2 is relatively cheap, with the capture costs accounting for 70–80% of CCS costs.[55]

The important parameters in determining a good site for carbon storage are: rock porosity, rock permeability, absence of faults, and geometry of rock layers. The medium in which the CO_2 is to be stored ideally has a high porosity and permeability, such as sandstone or limestone. Sandstone can have a permeability ranging from 1 to 10^{-5} Darcy, and can have a porosity as high as ≈30%. The porous rock must be capped by a layer of low permeability which acts as a seal, or caprock, for the CO_2. Shale is an example of a very good caprock, with a permeability of 10^{-5} to 10^{-9} Darcy. Once injected, the CO_2 plume will rise via buoyant forces, since it is less dense than its surroundings. Once it encounters a caprock, it will spread laterally until it encounters a gap. If there are fault planes near the injection zone, there is a possibility the CO_2 could migrate along the fault to the surface, leaking into the atmosphere, which would be potentially dangerous to life in the surrounding area. Another danger related to carbon sequestration is induced seismicity. If the injection of CO_2 creates pressures that are too high underground, the formation will fracture, causing an earthquake.[56]

While trapped in a rock formation, CO_2 can be in the supercritical fluid phase or dissolve in groundwater/brine. It can also react with minerals in the geologic formation to precipitate carbonates. See CarbFix.

Worldwide storage capacity in oil and gas reservoirs is estimated to be 675–900 Gt CO_2, and in un-minable coal seams is estimated to be 15–200 Gt CO_2. Deep saline formations have the largest capacity, which is estimated to be 1,000–10,000 Gt CO_2.[55] In the US, there is an estimated 160 Gt CO_2 storage capacity.[56]

There are a number of large-scale carbon capture and sequestration projects that have demonstrated the viability and safety of this method of carbon storage, which are summarized here [57] by the Global CCS Institute. The dominant monitoring technique is seismic imaging, where vibrations are generated that propagate through the subsurface. The geologic structure can be imaged from the refracted/reflected waves.[56]

The first large-scale CO_2 sequestration project which began in 1996 is called Sleipner, and is located in the North Sea where Norway's StatoilHydro strips carbon dioxide from natural gas with amine solvents and disposed of this carbon dioxide in a deep saline aquifer. In 2000, a coal-fueled synthetic natural gas plant in Beulah, North Dakota, became the world's first coal-using plant to capture and store carbon dioxide, at the Weyburn-Midale Carbon Dioxide Project.[58]

CO_2 has been used extensively in enhanced crude oil recovery operations in the United States beginning in 1972.[2] There are in excess of 10,000 wells that inject CO_2 in the state of Texas alone. The gas comes in part from anthropogenic sources, but is principally from large naturally occurring geologic formations of CO_2. It is transported to the oil-producing fields through a large network of over 5,000 kilometres (3,100 mi) of CO_2 pipelines. The use of CO_2 for enhanced oil recovery (EOR) methods in heavy oil reservoirs in the Western Canadian Sedimentary Basin (WCSB) has also been proposed.[59] However, transport cost remains an important hurdle. An extensive CO_2 pipeline system does not yet exist in the WCSB. Athabasca oil sands mining that produces CO_2 is hundreds of kilometers north of the subsurface Heavy crude oil reservoirs that could most benefit from CO_2 injection.

Chemical processes

Developed in the Netherlands, an electrocatalysis by a copper complex helps reduce carbon dioxide to oxalic acid;[60] This conversion uses carbon dioxide as a feedstock to generate oxalic acid.

Mineral carbonation

Carbon, in the form of CO_2 can be removed from the atmosphere by chemical processes, and stored in stable carbonate mineral forms. This process is known as 'carbon sequestration by mineral carbonation' or mineral sequestration. The process involves reacting carbon dioxide with abundantly available metal oxides–either magnesium oxide (MgO) or calcium oxide (CaO)–to form stable carbonates. These reactions are exothermic and occur naturally (e.g., the weathering of rock over geologic time periods).[61][62]

$$CaO + CO_2 \rightarrow CaCO_3$$

$$MgO + CO_2 \rightarrow MgCO_3$$

Calcium and magnesium are found in nature typically as calcium and magnesium silicates (such as forsterite and serpentinite) and not as binary oxides. For forsterite and serpentine the reactions are:

$$Mg_2SiO_4 + 2\ CO_2 \rightarrow 2\ MgCO_3 + SiO_2$$

$$Mg_3Si_2O_5(OH)_4 + 3\ CO_2 \rightarrow 3\ MgCO_3 + 2\ SiO_2 + 2\ H_2O$$

The following table lists principal metal oxides of Earth's crust. Theoretically up to 22% of this mineral mass is able to form carbonates.

Earthen Oxide	Percent of Crust	Carbonate	Enthalpy change (kJ/mol)
SiO_2	59.71		
Al_2O_3	15.41		
CaO	4.90	$CaCO_3$	−179
MgO	4.36	$MgCO_3$	−117
Na_2O	3.55	Na_2CO_3	
FeO	3.52	$FeCO_3$	
K_2O	2.80	K_2CO_3	
Fe_2O_3	2.63	$FeCO_3$	
	21.76	All Carbonates	

These reactions are slightly more favorable at low temperatures.[61] This process occurs naturally over geologic time frames and is responsible for much of the Earth's surface limestone. The reaction rate can be made faster however, by reacting at higher temperatures and/or pressures, although this method requires some additional energy. Alternatively, the mineral could be milled to increase its surface area, and exposed to water and constant abrasion to remove the inert Silica as could be achieved naturally by dumping Olivine in the high energy surf of beaches.[63] Experiments suggest the weathering process is reasonably quick (one year) given porous basaltic rocks.[64][65]

CO_2 naturally reacts with peridotite rock in surface exposures of ophiolites, notably in Oman. It has been suggested that this process can be enhanced to carry out natural mineralisation of CO_2.[66][67]

When CO_2 is dissolved in water and injected into hot basaltic rocks underground it has been shown that the CO_2 reacts with the basalt to form solid carbonate minerals.[68] A test plant in Iceland started up in October 2017, extracting up to 50 tons of CO_2 a year from the atmosphere and storing it underground in basaltic rock.[69]

Researchers from British Columbia, developed a low cost process for the production of magnesite, also known as magnesium carbonate, which can sequester CO_2 from the air, or at the point of air pollution, e.g. at a power plant. The crystals are naturally occurring, but accumulation is usually very slow.[70]

Electrochemical method

Another method uses a liquid metal catalyst and an electrolyte liquid into which CO_2 is dissolved. The CO_2 then converts into solid flakes of carbon. This method is done at room temperature.[71][72][73]

Industrial use

Traditional cement manufacture releases large amounts of carbon dioxide, but newly developed cement types from Novacem[74] can absorb CO_2 from ambient air during hardening.[75] A similar technique was pioneered by TecEco, which has been producing "EcoCement" since 2002.[76] A Canadian startup CarbonCure takes captured CO_2 and injects it into concrete as it is being mixed.[77] Carbon Upcycling UCLA is another company that uses CO_2 in concrete. Their concrete product is called CO2NCRETE™, a concrete that hardens faster and is more eco-friendly than traditional concrete.[78]

In Estonia, oil shale ash, generated by power stations could be used as sorbents for CO_2 mineral sequestration. The amount of CO_2 captured averaged 60 to 65% of the carbonaceous CO_2 and 10 to 11% of the total CO_2 emissions.[79]

Chemical scrubbers

Various carbon dioxide scrubbing processes have been proposed to remove CO_2 from the air, usually using a variant of the Kraft process. Carbon dioxide scrubbing variants exist based on potassium carbonate, which can be used to create liquid fuels, or on sodium hydroxide.[80][81][82] These notably include artificial trees proposed by Klaus Lackner to remove carbon dioxide from the atmosphere using chemical scrubbers.[83][84]

Ocean-related

Basalt storage

Carbon dioxide sequestration in basalt involves the injecting of CO_2 into deep-sea formations. The CO_2 first mixes with seawater and then reacts with the basalt, both of which are alkaline-rich elements. This reaction results in the release of Ca^{2+} and Mg^{2+} ions forming stable carbonate minerals.[85]

Underwater basalt offers a good alternative to other forms of oceanic carbon storage because it has a number of trapping measures to ensure added protection against leakage. These measures include "geochemical, sediment, gravitational and hydrate formation." Because CO_2 hydrate is denser than CO_2 in seawater, the risk of leakage is minimal. Injecting the CO_2 at depths greater than 2,700 meters (8,900 ft) ensures that the CO_2 has a greater density than seawater, causing it to sink.[86]

One possible injection site is Juan de Fuca plate. Researchers at the Lamont-Doherty Earth Observatory found that this plate at the western coast of the United States has a possible storage capacity of 208 gigatons. This could cover the entire current U.S. carbon emissions for over 100 years.[86]

This process is undergoing tests as part of the CarbFix project, resulting in 95% of the injected 250 tonnes of CO_2 to solidify into calcite in 2 years, using 25 tonnes of water per tonne of CO_2.[65][87]

Acid neutralisation

Carbon dioxide forms carbonic acid when dissolved in water, so ocean acidification is a significant consequence of elevated carbon dioxide levels, and limits the rate at which it can be absorbed into the ocean (the solubility pump). A variety of different bases have been suggested that could neutralize the acid and thus increase CO_2 absorption.[88][89][90][91][92] For example, adding crushed limestone to oceans enhances the absorption of carbon dioxide.[93] Another approach is to add sodium hydroxide to oceans which is produced by electrolysis of salt water or brine, while eliminating the waste hydrochloric acid by reaction with a volcanic silicate rock such as enstatite, effectively increasing the rate of natural weathering of these rocks to restore ocean pH.[94][95][96]

Obstruction

Danger of leaks

Carbon dioxide may be stored deep underground. At depth, hydrostatic pressure acts to keep it in a liquid state. Reservoir design faults, rock fissures and tectonic processes may act to release the gas stored into the ocean or atmosphere.

Financial costs

The use of the technology would add an additional 1–5 cents of cost per kilowatt hour, according to estimate made by the Intergovernmental Panel on Climate Change. The financial costs of modern coal technology would nearly double if use of CCS technology were to be required by regulation.[97] The cost of CCS technology differs with the different types of capture technologies being used and with the different sites that it is implemented in, but the costs tend to increase with CCS capture implementation.[98] One study conducted predicted that with new technologies these costs could be lowered but would remain slightly higher than prices without CCS technologies.[99]

Energy requirements

The energy requirements of sequestration processes may be significant. In one paper, sequestration consumed 25 percent of the plant's rated 600 megawatt output capacity.[100]

> *After adding CO_2 capture and compression, the capacity of the coal-fired power plant is reduced to 457 MW.*

See also

- Bio-energy with carbon capture and storage
- Blue carbon
- CarbonFix Standard
- Carbon capture and storage
- Carbon carousel
- Woodland Carbon Code

Notes

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External links

- GA Mansoori, N Enayati, LB Agyarko (2016), Energy: Sources, Utilization, Legislation, Sustainability, Illinois as Model State (http://www.worldscientific.com/worldscibooks/10.1142/9699), World Sci. Pub. Co., ISBN 978-9814704007
- Carbon Sequestration Leadership Forum (http://www.cslforum.org/) International carbon capture and storage initiative.
- UK Carbon Capture and Storage Consortium (https://web.archive.org/web/20091117231051/http://www.co2storage.org.uk/) Overview of the UK academic consortium focused on researching issues related to Carbon Capture and Storage.
- Sieves put a lid on greenhouse gas (http://www.physorg.com/news65284632.html)
- The capture, utilization and disposal of carbon dioxide from fossil fuel-fired power plants. (http://www.osti.gov/bridge/servlets/purl/10192734-xc1wDZ/webviewable/10192734.pdf)
- Carbon Capture and Storage Information Center (Chinese + English) (http://www.captureready.com/)
- Carbon Sequestration: Science, Technology, and Policy (http://web.mit.edu/professional/short-programs/courses/geological_carbon_sequestration.html) MIT program covers carbon capture and storage (CCS)
- Link to video, *UK Looks for Natural Products in Kentucky's Unique Environments* (https://www.youtube.com/watch?v=VglEEjMviVA/)

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