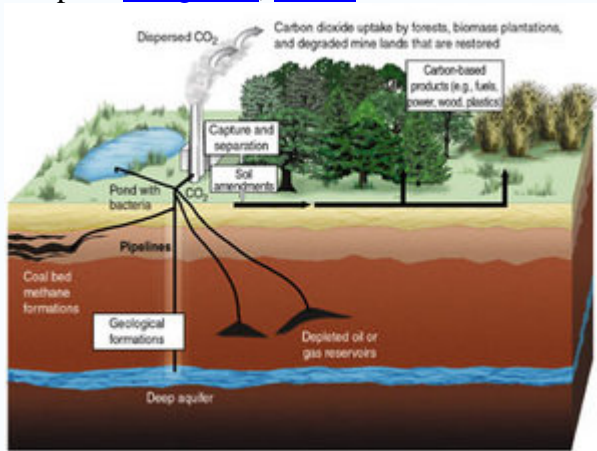



Carbon dioxide sink

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(Redirected from [CO2 sink](#))

Jump to: [navigation](#), [search](#)



 Carbon sequestration from a fossil-fuel power station

A **carbon dioxide sink** or **CO₂ sink** is a carbon reservoir that is increasing in size, and is the opposite of a carbon "source". The main sinks are the [oceans](#) and growing [vegetation](#). The concept has become more widely known through its application by the [Kyoto Protocol](#).

Carbon sequestration is the term describing processes that removes carbon from the [biosphere](#). A variety of means of artificially capturing and storing carbon, as well as of enhancing natural sequestration processes, are being explored. This is intended to support the [mitigation of global warming](#).

Natural sinks

Forests

The idea of carbon sinks based on growing trees rests on an understanding of the [carbon cycle](#). Enormous amounts of carbon are naturally stored in trees. As part of [photosynthesis](#) trees absorb carbon dioxide from the [atmosphere](#) and store it as carbon while [oxygen](#) is released back into the atmosphere. Rapidly growing trees absorb a larger amount of carbon dioxide. Mature trees grow less rapidly and thus have a lower intake of

carbon dioxide. Trees are about 20 per cent carbon by weight. While individual trees die and decay, releasing most stored carbon back to the atmosphere, the forest as a whole continues to store carbon as dying or harvested trees are replaced by natural regeneration.

The dead trees, plants, and moss in [peat](#) bogs undergo slow anaerobic decomposition below the surface of the bog. This process is slow enough that in many cases the bog grows faster and fixes more carbon from the atmosphere than is released. Over time, the peat grows deeper. Peat bogs inter approximately one-quarter of the carbon in land plants and soils [\[1\]](#).

Under some conditions, forests and peat bogs may become sources of CO₂.

Oceans

Oceans are natural carbon dioxide sinks, and as the level of carbon dioxide increases in the atmosphere the oceans also increase creating potentially disastrous [acidic oceans](#). Ocean water can hold a variable amount of dissolved CO₂ depending on temperature and pressure. [Phytoplankton](#) in the oceans, like trees, use photosynthesis to extract carbon from CO₂. They are the starting point of the marine [food chain](#). Plankton and other marine organisms extract CO₂ from the ocean water to build their skeletons and shells of the mineral [calcite](#), CaCO₃. This removes CO₂ from the water and more dissolves in from the atmosphere. These calcite skeletons and shells along with the organic carbon of the organism eventually fall to the bottom of the ocean when the organisms die. The carbon or plankton cells have to sink to the deep water in 2000 to 4000 meter to be sequestered for ca. 1000 years. The sinking can be accelerated orders of magnitude when [zooplankton](#) prey on the cells and produce fast sinking fecal pellets or fecal strings, like the [Antarctic krill](#). This process is called the [biological pump](#). It has been theorized that the organic carbon within the accumulating ocean bottom sediments is how [fossil fuels](#) are created.

Enhancing natural sequestration

Forests

Forests are carbon dioxide stores, but the sink effect exists only when they grow in size: it is thus naturally limited. The rate at which forests can sequester carbon, given the available land, is far exceeded by the rate at which it is released by the combustion of fossilised forests (coal, oil and natural gas). It seems clear that the use of forests to curb climate change can only be a temporary measure. Even optimistic estimates come to the conclusion that the planting of new forests is not enough to counter-balance the current level of [greenhouse gas](#) emissions [\[2\]](#). To reduce U.S. carbon emissions by 7 percent, as stipulated in the Kyoto Protocol, would require the planting of "an area the size of Texas every 30 years", according to William H. Schlesinger, dean of the Nicholas School of the environment and earth sciences at Duke University, in Durham, N.C. [\[3\]](#).

Furthermore, forests, particularly new ones, may not be straight-forward carbon sinks. Although a forest is a net CO₂ sink over time, the plantation of new forests may also

initially be a source of carbon dioxide emission when carbon from the soil is released into the atmosphere. Other studies indicate that the cooling effect of removing carbon by forest growth can be counteracted by the effects of the forest on reflection of sunlight, or [albedo](#). Mid-to-high latitude forests have a much lower albedo during snow seasons than flat ground, and this contributes to warming.

Oceans

One of the most promising ways to increase the carbon sequestration efficiency of oceans is to add micron-sized iron particles called [hematite](#) or iron sulfate to the water. This has the effect of stimulating growth of [plankton](#). Iron is an important nutrient for [phytoplankton](#), usually made available via upwelling along the [continental shelves](#), inflows from rivers and streams, as well as deposition of dust suspended in the [atmosphere](#). Natural sources of ocean iron have been declining in recent decades, contributing to an overall decline in ocean productivity (NASA, 2003). Yet in the presence of iron nutrients plankton populations quickly grow, or 'bloom', expanding the base of [biomass](#) productivity throughout the region and removing significant quantities of CO₂ from the atmosphere via [photosynthesis](#). A test in 2002 in the [Southern Ocean](#) around [Antarctica](#) suggests that between 10,000 and 100,000 carbon atoms are sunk for each iron atom added to the water. More recent work in Germany (2005) suggests that any biomass carbon in the oceans, whether exported to depth or recycled in the [euphotic zone](#), represents long term storage of carbon. This means that application of iron nutrients in select parts of the oceans, at appropriate scales, could have the combined effect of restoring ocean productivity while at the same time mitigating the effects of human caused emissions of carbon dioxide to the atmosphere.

Those skeptical of this approach argue that the effect of periodic small scale phytoplankton blooms on ocean ecosystems is unclear, and that more studies would be advantageous. For example, it's known that phytoplankton have a complex effect on cloud formation via the release of substances such as [dimethyl sulfide \(DMS\)](#) which are converted to sulfate aerosols in the atmosphere providing [cloud condensation nuclei](#), or CCN. But the effect of small scale plankton blooms on overall DMS production is unknown.

Soils

The carbon sequestration potential of [soils](#) (by increasing [soil organic matter](#)) is substantial; below ground organic carbon storage is more than twice above-ground storage. Soils' organic carbon levels in many agricultural areas have been severely depleted. Improving the [humus](#) levels of these soils would both improve soil quality and increase the amount of carbon sequestered in these soils.

Grasslands contribute huge quantities of soil organic matter over time, mostly in the form of roots, and much of this organic matter can remain unoxidized for long periods. Since the 1850s, a large proportion of the world's grasslands have been tilled and converted to croplands, allowing the rapid oxidation of large quantities of soil organic carbon. No-till

agricultural systems can increase the amount of carbon stored in soil, and conversion to pastureland, particularly with good management of grazing, can sequester even more carbon in the soil.

Mechanisms to enhance carbon sequestration in soil include conservation tilling; cover cropping; and [crop rotation](#).

Artificial sequestration

For carbon to be sequestered artificially (i.e. not using the natural processes of the carbon cycle) it must first be captured. Thereafter it can be stored in a variety of ways.

[Natural gas](#) purification plants often already have to remove carbon dioxide, either to avoid [dry ice](#) clogging gas tankers or to prevent carbon dioxide concentrations exceeding the 3% maximum permitted on the natural gas distribution grid.

Beyond this, one of the of the most likely early applications of carbon capture is the capture of carbon dioxide from [flue gases](#) at [power stations](#) (in the case of coal, this is known as "[clean coal](#)"). A typical new 1000-MW coal-fired power station produces around 6m tons of carbon dioxide annually. Adding carbon capture to existing plants can add significantly to the costs of energy production; scrubbing costs aside, a 1000-MW coal plant will require the storage of about 50m [barrels](#) of carbon dioxide a year. However, scrubbing is relatively affordable when added to new plants based on coal gasification technology, where it is estimated to raise energy costs for households using only coal-fired electricity sources from 10 cents per kWh to 12 ^[4].

Carbon capture

Currently, capture of carbon dioxide is performed on a large scale by absorption of carbon dioxide onto various amine based solvents. Other techniques are currently being investigated such as pressure and temperature swing absorption, gas separation membranes and cryogenics.

In coal-fired power stations, the main alternatives to retro-fitting amine-based absorbers to existing power stations are two new technologies - [coal gasification](#) combined-cycle and [oxyfuel combustion](#). Gasification first produces a "[syngas](#)" primarily of hydrogen and carbon monoxide, which is burned, with carbon dioxide filtered from the flue gas. Oxyfuel combustion burns the coal in [oxygen](#) instead of air, producing only carbon dioxide and water vapour, which are relatively easily separated. Oxyfuel combustion, however, produces very high temperatures, and the materials to withstand its temperatures are still being developed.

Oceans

Another proposed form of carbon sequestration in the ocean is direct injection. In this method, carbon dioxide is pumped directly into the water at depth, and expected to form

"lakes" of liquid CO₂ at the bottom. Experiments carried out in moderate to deep waters (350 - 3600 meters) indicate that the liquid CO₂ reacts to form solid CO₂ [clathrate hydrates](#) which gradually dissolve in the surrounding waters.

This method, too, has potentially dangerous environmental consequences. The carbon dioxide does react with the water to form [carbonic acid](#), H₂CO₃; however, most (as much as 99%) remains as dissolved molecular CO₂. The equilibrium would no doubt be quite different under the high pressure conditions in the deep ocean. The resulting environmental effects on [benthic](#) life forms of the [bathypelagic](#), [abyssopelagic](#) and [hadopelagic](#) zones are unknown. Even though life appears to be rather sparse in the deep ocean basins, energy and chemical effects in these deep basins could have far reaching implications. Much more work is needed here to define the extent of the potential problems.

It is not clear whether carbon storage in or under oceans is compatible with the [London Convention](#) (*Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter*) [5].

Geological sequestration

Also known as *geo-sequestration*, this method involves injecting carbon dioxide directly into underground geological formations. Such formations may be natural such caverns or porous rock structures. They may also be man-made, such as spent mines and expended petroleum fields.

A major research project examining the geological sequestration of carbon dioxide is currently being performed at an oil field at [Weyburn](#) in southeastern [Saskatchewan](#). In the North Sea, Norway's Statoil natural gas platform Sleipner strips carbon dioxide out of the natural gas with amine solvents and disposes of this carbon dioxide by geological sequestration. Sleipner reduces emissions of carbon dioxide by approximately one million tonnes a year. The cost of geological sequestration is minor relative to the overall running costs. As of April 2005, [BP](#) are considering a trial of large-scale sequestration of carbon dioxide stripped from power plant emissions in the Miller oilfield as its reserves are depleted.

Carbon sinks and the Kyoto Protocol

The protocols hold that, since growing vegetation absorbs [carbon dioxide](#), countries that have large areas of forest (or other vegetation) can deduct a certain amount from their emissions, thus making it easier for them to achieve the desired emission levels. The effectiveness of these provisions is controversial.

Some countries want to be able to trade in emission rights in carbon emission markets, to make it possible for one country to buy the benefit of carbon dioxide sinks in another country. It is said that such a market mechanism will help find cost-effective ways to reduce greenhouse emissions. There is as yet no [carbon audit regime](#) for all such markets

globally, and none is specified in the [Kyoto Protocol](#). Each nation is on its own to verify actual carbon emission reductions, and to account for carbon sequestration using some less formal method.

Notes

1. [^] [Scientific American](#), July 2005, p42