# FAQ: Ice, Oceans & Atmosphere

December 2019

During the *Summer Meeting In Lausanne Europe* (SMILE, 05.-09.08.2019), young activists from Fridays for Future asked questions about the climate crisis. These were collected and then answered by experts who attended the meeting and others who are engaged with Scientists for Future. At the end of the document, you find a list of the people who were involved.

The questions have been organized in different documents by topic. This document answers questions about Ice, the oceans and the Atmosphere.

Feel free to read, reuse and share them with friends, parents, teachers, neighbours, colleagues.

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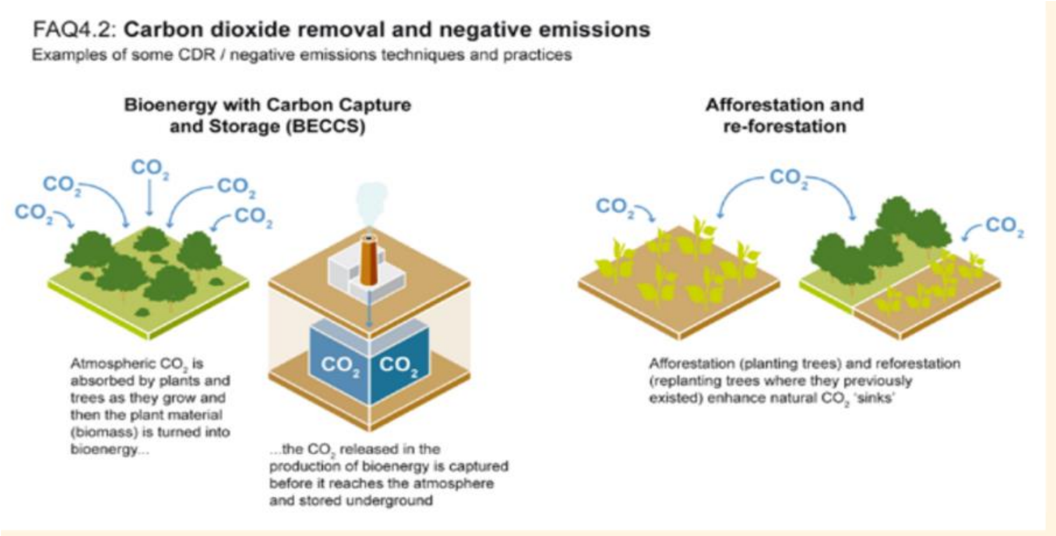
## Which mechanisms take CO2 out of the atmosphere?

A simple overview can be obtained from the FAQ section in IPCC SR 1.5: "Carbon dioxide removal (CDR) refers to the process of removing $CO_2$ from the atmosphere. Since this is the opposite of emissions, practices or technologies that remove $CO_2$ are often described as achieving 'negative emissions'. The process is sometimes referred to more broadly as greenhouse gas removal if it involves removing gases other than $CO_2$. There are two main types of CDR: either *enhancing existing natural processes* that remove carbon from the atmosphere (e.g., by increasing its uptake by trees, soil, or other 'carbon sinks') or *using chemical processes* to, for example, capture $CO_2$ directly from the ambient air and store it elsewhere (e.g., underground). All CDR methods are at different stages of development and some are more conceptual than others, as they have not been tested at scale."




**FAQ 4.2, Figure 1 | Carbon dioxide removal (CDR) refers to the process of removing $CO_2$ from the atmosphere.** There are a number of CDR techniques, each with different potential for achieving 'negative emissions', as well as different associated costs and side effects.

*Fig. 1: $CO_2$ removal and ‚negative emissions' (left) and ‚enhancing existing natural processes' (right)*

*Natural processes* largely result from changes in land use (afforestation or re-forestation) because trees have a long lifetime. If a forest is newly established, the growing (living) trees will uptake $CO_2$ via photosynthesis. If the forest is removed (burned, for example), the previously stored $CO_2$ is released back to the atmosphere (if the wood is used, e.g. for construction) the 'storage time' is extended.

*Chemical processes:* $CO_2$ can be removed from the atmosphere through chemical processes. These mostly require energy – hence, with respect to mitigation of greenhouse gas concentrations in the atmosphere, they only make sense if renewable energy is used.

The (engineered) chemical processes may either extract $CO_2$ directly from the air or through *Bioenergy through Carbon Capture and Storage* (BECCS), in which $CO_2$ is absorbed by plants and trees as they grow (the natural part) and then the dead plant material is burned to produce biofuel (IPCC SR 1.5). Alternatively, the so obtained CO2 may also be stored (in the deep soil, for example) or used in other industrial processes which require carbon.

Chemical processes essentially differ by their land use (how much land would be required to,remove a certain amount of Co2/year'), energy and water consumption and cost. A comparison can be found at Climeworks (Ref below). As a specific example, a collection unit for $CO_2$ with the size of 1 $m^2$ sweep area and a wind velocity 3 m/s based on a calcination process (a particular chemical reaction chain) could collect 3.6 kg of $CO_2$ per hour, assuming an extraction efficiency of 50 %, and would cost around 22 $/t of $CO_2$ (based on estimates in the year 2002; Dubey et al. 2002).

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***References:***


- *Dubey MK, H. Ziock, G. Rueff, S. Elliott, W.S. Smith, Am. Chem. Soc. – Division of Fuel Chemistry Reprints, 47(1), 2002, 81-84*
- *IPCC SR 1.5: https://www.ipcc.ch/site/assets/uploads/sites/2/2018/12/SR15_FAQ_Low_Res.pdf*
- Climeworks: http://www.climeworks.com/co2-removal/ (private company website, which advertises their method!)


## How to get $CO_2$ out of the ocean?

The overall global carbon cycle (IPCC AR5) shows the 'big picture' and the relative amounts of C involved. The concentration in the atmosphere and (dissolved) in the oceans – more precisely the concentration difference relative to equilibrium conditions - determine how much of the atmospheric (additional) $CO_2$ is effectively dissolved in the oceans. It is important to note that $CO_2$ reacts with water to Carbonic acid and thus increases acidification of the sea. Also, it is important to note that in this equilibrium, $CO_2$ degasses from the ocean back into the atmosphere if water warms up, because $CO_2$ gets less soluble with temperature. This is a so-called 'positive feedback' of global warming.

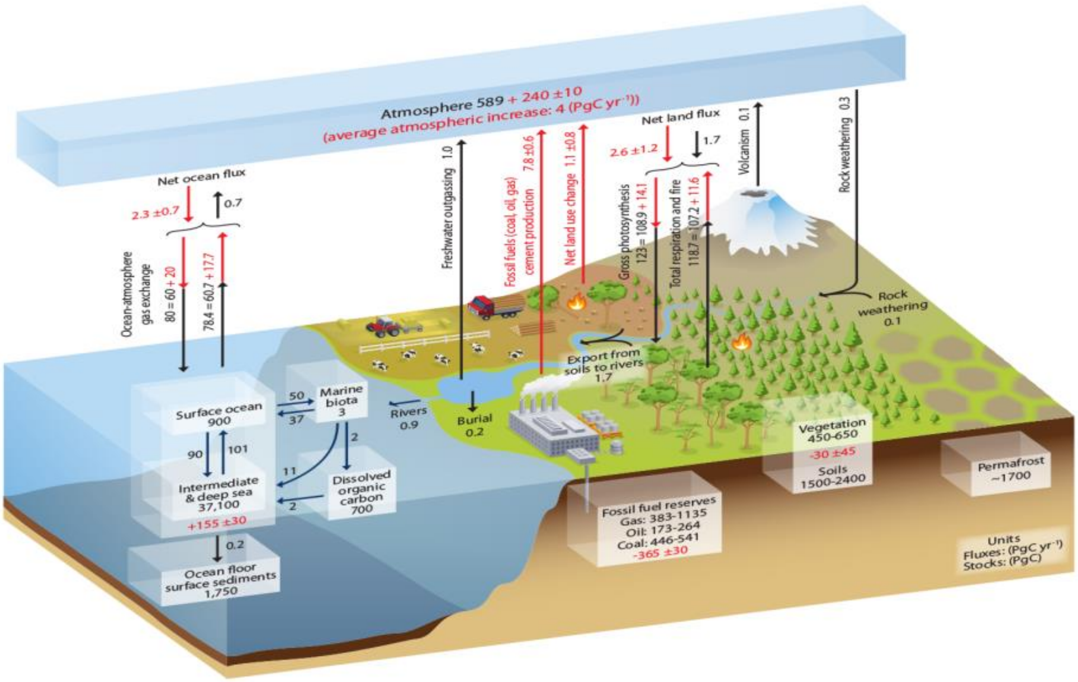


*Fig. 2: Carbon Cycle (from IPCC AR5). Additional detail can be found in KhanAcademy (ref below)*

Once dissolved in the ocean water, carbon is subject to marine photosynthesis (mostly in the upper ocean layers) and thus taken up by water plants (e.g. algae, and through the food chain in other organisms) and eventually deposited at the ground and included in the formation of sediments.

If mixed down to deep ocean layers, $CO_2$ is also exchanged by geo-morphological interaction with the seabed. For example, it can react with the basaltic seafloor to produce secondary minerals that incorporate carbon. Such reactions are also in discussion for permanent $CO_2$ storage in the underground, including waste as starting materials). See, e.g. IPCC (2005).

All these processes are extremely slow, so that they are only relevant at scales of thousands to millions of years. For active anthropogenic carbon removal, one would have to accelerate these reactions (see above) - and this costs energy.


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*References:*

- *IPCC AR5: p.159 in:* https://www.ipcc.ch/site/assets/uploads/2018/03/WG1AR5_SummaryVolume_FINAL.pdf
- *IPCC, 2005, Special Report on Carbon Storage and Sequestration (including short summaries)* https://www.ipcc.ch/report/carbon-dioxide-capture-and-storage/
- *KhanAcademy:* https://www.khanacademy.org/science/biology/ecology/biogeochemical-cycles/a/the-carbon-cycle
- *Takahashi et al., 2002, Deep-Sea Research II* https://www.ldeo.columbia.edu/~csweeney/papers/taka2002.pdf


## How to separate C and $O_2$ from $CO_2$?

In principle, it is possible to separate C and O from $CO_2$. However, this may not be the most effective way reducing $CO_2$ concentrations in the atmosphere. 'Most effective' here refers to energy efficiency. And it is constrained by fundamental laws of thermodynamics (energy conservation). $CO_2$ (i.e., the man-made portion) is formed by burning fossil fuels – and the purpose of this was to produce energy. To split it up again, it first must be 'recovered' and then chemically be transformed. An illustrative example (Pfennig 2019) can be given as follows.

400 kJ per mol of $CO_2$ can be obtained as electricity from a coal-fired power plant.

A power plant has an efficiency of some 40% (on average slightly less). In other words, the energy 'stored in the fossil fuel' (coal as an example, numbers from Wang et al. 2011) was 1000 kJ per mol of $CO_2$.

recovering the $CO_2$ will cost 50 to 200 kJ per mol of $CO_2$ (we continue the example with 100 kJ per mol of $CO_2$).

Conversion of $CO_2$ back into C and Oxygen would cost energy as well. Due to energy conservation, this has to be the 100% of energy contained in the coal.

We therefore end up with 400 kJ per mol of $CO_2$ gained energy and 1000+100 kJ per mol of $CO_2$ for back conversion (incl. capturing).

Thus with 100% of coal as starting material, we obtain only 40% of electricity. Thus, converting $CO_2$ back into coal requires some 2.75 times the energy that was originally obtained as electricity by burning the coal in a coal-fired power plant.

This is why transferring the $CO_2$ back to Oxygen and Carbon and storing the Carbon back into the ground as artificial coal is not among the more frequently considered measures to reduce climate impact (see also: Which mechanisms take $CO_2$ out of the atmosphere?).

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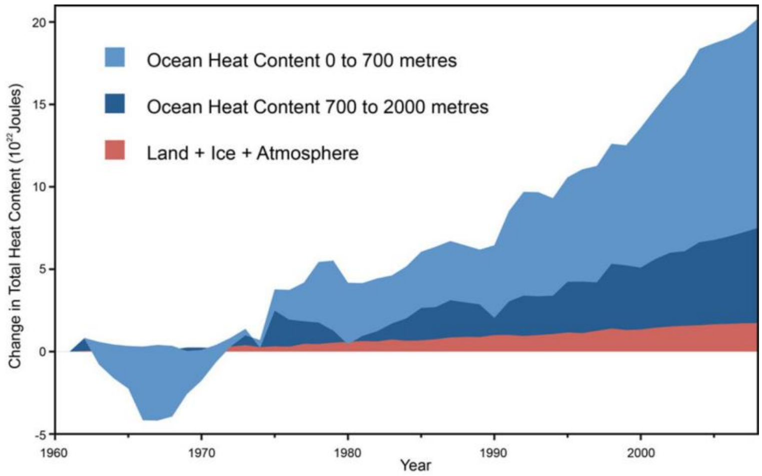
References:

*Wang T, K. S. Lackner, A. Wright, Environ. Sci. Technol. 2011, 45, 6670–6675.* https://doi.org/10.1021/es201180v

*Pfennig A: 2019,* https://doi.org/10.1002/cben.201900006

## Understanding a figure about ocean heat content:

Here is a figure, I would like to understand. What does this negative part in the sixties mean?




*source:*https://skepticalscience.com/warming-oceans-rising-sea-level-energy-imbalance-consistent.html
*Figure by:* Nuccitelli et al. (2012)

In climate sciences time series are often shown as *anomalies*, i.e. the difference between the value at a certain time and a baseline situation (for example, temperatures are shown as temperature increase since the period 1980-2000, or the pre-industrial level). In the above graph, we see the total heat content of the ocean in two layers (0-700 m, and 700-2000 m, respectively) and that of 'land, ice and the atmosphere'. It starts 'at zero' because only the anomaly (i.e. the change) as compared to the beginning of the data base is displayed.

The 'negative part in the sixties' is likely due to observational difficulties:

Not very much data until at least the 1970's: Warming is not the same everywhere and to estimate the 'heat content of the ocean' requires many data points to reduce statistical uncertainty. Also, there were systematic differences between the sensors used to measure the ocean temperatures at different times.

A recent analysis (Cheng et al. 2019), taking all the best knowledge into account, shows that the 'dip' in the 1960ies is essentially a measurement artifact, meaning it does not refelct what was actually happening.

_Contributions:_

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Reference:

*Cheng et al. 2019, Science, doi: 10.1126/science.aav7619.*
[http://159.226.119.60/cheng/images_files/GlobalOHC_anomaly_bar_plot_2018all.png](http://159.226.119.60/cheng/images_files/GlobalOHC_anomaly_bar_plot_2018all.png)

## Is it true that only 25% of the arctic ice mass Is left?

This is good example for a question that needs 'refinement' before it can be answered.

If only the 'arctic sea ice at the end of summer' is concerned, this is roughly true for the *sea ice volume* (see, for example, a short youtube clip, based on PIOMAS (refs), Zhang and Rothrock (2003): [https://www.youtube.com/watch?v=Xh3oakgxZ9w](https://www.youtube.com/watch?v=Xh3oakgxZ9w)). If the *total ice extent* (this is the *area covered by ice*) in the Arctic (this includes 'sea ice' and 'land ice' [Ice sheet(s) + arctic mountain glaciers]) is concerned, we get a different answer (Figure 1 below): The total *annual Arctic ice extent* is about 20% reduced when compared to pre-industrial levels.

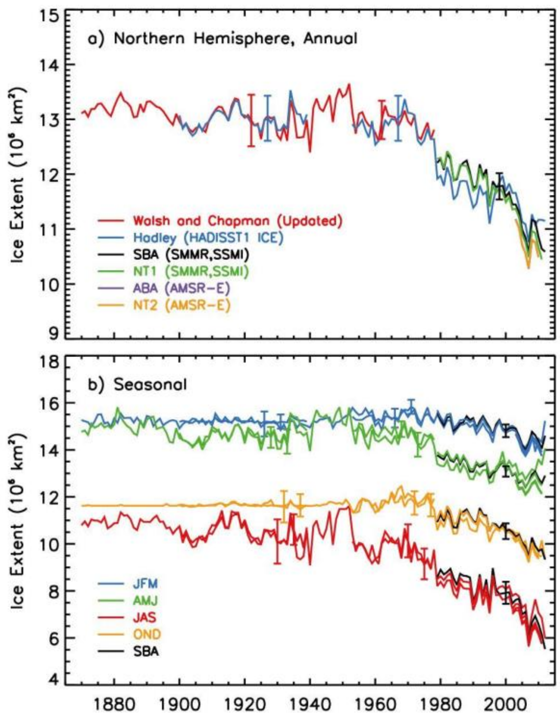


*Fig. 1:* (from IPCC AR5): *Ice extent in the Arctic from 1870 to 2011. (a) Annual ice extent and (b) seasonal ice extent using averages of mid-month values derived from in situ and other sources including observations from [see IPCC AR5]*

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*References:*


- *IPCC AR5: https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter04_FINAL.pdf*
- *PIOMAS: https://mpas-analysis.readthedocs.io/en/master/obs/piomass_ice_volume.html*
- Zhang and Rothrock, 2003: *https://doi.org/10.1175/15200493(2003)131<0845:MGSIWA>2.0.CO;2*


## If ice is melting, does this help to take CO2 out of the atmosphere because there would be more water then? Oceans are more capable to hold CO2 than the atmosphere.

This is only a relatively minor effect. If all remaining ice on land would melt, sea level rise would be around 65 m (e.g., Rohling, 2019). The upper ocean level, which is responsible for taking up roughly half the emitted $CO_2$ until equilibrium is reached, has a depth of around 700 m. Thus, the effect of the 65 meters is comparably small. This is an estimate relevant for us and the coming few generations.

The average depth of the oceans is 3700m, i.e. the long-term effect of the 65 m is even less. The latter is relevant only on time scales of centuries and millennia.

**These effects are small and far outweighed by albedo changes**: once the ice has melted, the surface is no longer white but dark (water instead of ice). Dark surfaces absorb much more heat than brighter ones. This is also one of the reasons why the polar regions have been warming much faster than the rest of the world.

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References:


- Rohling EJ: The climate question, Oxford University Press, 2019
- https://global.oup.com/academic/product/the-climate-question-9780190910877?cc=at&lang=en&
- https://www.nature.com/articles/s41558-018-0339-y

## Contributing experts and scientists

Please note that the responsibility for the content of the answers lies solely with the listed authors and not with the whole scientists for future community. However, all answers have been reviewed and edited by experts in the field.

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