Below Zero

Carbon Removal and the Climate Challenge

THERE'S NO SILVER BULLET WITH CLIMATE CHANGE. A BROAD SOLUTIONS MIX IS NEEDED.

CHANGING OUR PATH TO STEER CLEAR OF 2°C

Early warning signs

Early signs of climate change are being seen across the world: the 11 hottest years on record have occurred since 2000, glaciers worldwide are losing ice, and we are witnessing the effects of increasingly frequent and severe droughts and floods. The Intergovernmental Panel on Climate Change (IPCC) and other authorities warn that emissions need to be falling significantly by 2020 to avoid the most dangerous impacts of climate change,[1] with the global economy reaching *net zero emissions* by 2050.[2]

In 2011, the threat of climate change was recognised by 190 countries who committed to restrict the global average temperature increase to below 2°C above pre-industrial levels. While this is an important global commitment, 2°C is certainly not a target to aim for; it is a guardrail to steer clear of.

Action is needed across all sectors and by all major-emitting countries.

The foundation to steer clear of two-degrees exists: all major economies are implementing policies including regulation and carbon pricing to encourage renewable energy and energy efficiency.

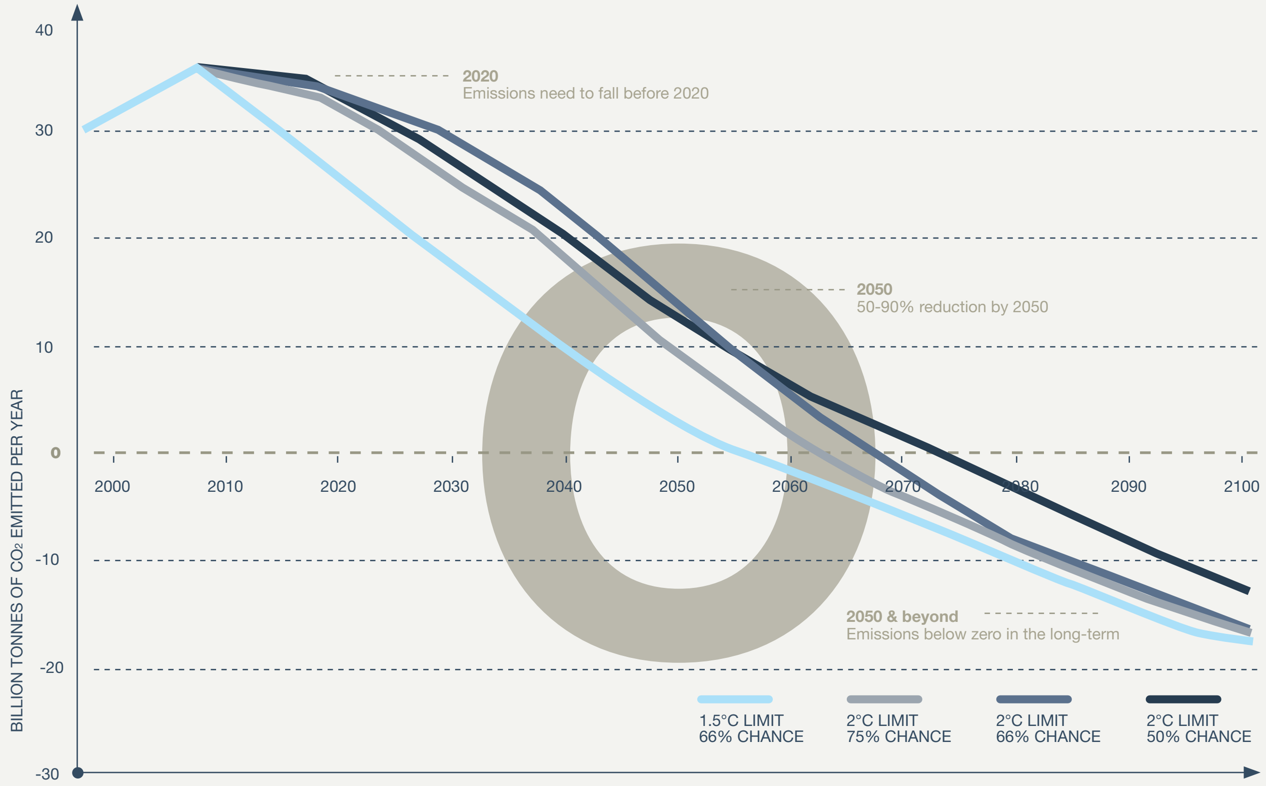
However, despite these positive steps, the global temperature is on course to rise by 4°C or more even if current policy commitments are met.[3] There is a growing gap between the path that is being carved out by government action and the path that is in the interest of their population: jeopardising their future prosperity.

Moving below zero

Carbon dioxide in the air is already at dangerous levels – 40 per cent above pre-industrial quantities, and rising fast. The surplus of carbon in the air is caused by the amount of emissions released minus how much is withdrawn through *carbon sinks* like forests and oceans. Imagine a bath tub overflowing with water. To get atmospheric carbon levels back to manageable levels (lower than they are today) we not only need to turn off the tap by reducing emissions but also pull out the plug by boosting our carbon sinks.[4] We need to find ways to remove that excess carbon from the air.

There is no silver bullet that will stop climate change. The solutions mix requires not only renewables like wind and solar, but also changing the way we behave with more sustainable farming practices and more efficient use of energy. Part of the portfolio will also need to include innovative processes that remove carbon from the air, known as "negative emissions" or "carbon removal".

Biomass - plant materials like wood and crop stalks - will play a key role in removing carbon pollution. The life and death of plants makes up the *natural carbon cycle* – as they grow they breathe in CO_2, but as they die and decay, that CO_2 is slowly released back into the air. There are ways we can harness this CO_2, removing it from the carbon cycle and preventing it from escaping back to the air. This snapshot explores some key technologies that could move us below zero emissions.



ZERO EMISSIONS ARE NOT ENOUGH

The challenge

While it may be possible to avoid a rise in average global temperature of 2°C without carbon removal, relying solely on zero emission technologies such as wind and solar is a higher-risk option. Analysis undertaken since the last IPCC assessment report in 2007 finds that the majority of emission pathways that avoid 2°C require pollution levels to move below zero in the latter half of the century.[5]

For example, the *Global Energy Assessment* models how the global economy can limit temperature increase while complying with energy affordability, health and environment goals.[6] It shows regardless of our temperature goal, emissions will likely need to go below zero.

Importantly, we need to find means of carbon removal that don't create more problems or harm than those they seek to address.

Figure 1 above shows the declining global annual CO_2 emissions required for four temperature pathways: 50, 66, and 75 per cent chance of avoiding 2°C, and 66 per cent chance of limiting to 1.5°C temperature rise.

Vital for managing risk

Carbon removal is needed to manage climate change risks – without it, our options are much more limited. A recent study by the Potsdam Institute shows that we would likely overshoot 2°C by more than 10 per cent if one of the key carbon-removal technologies does not become available.[7] That has the same effect as delaying action for 30 years.

Carbon removal is important in our transition and future economy because it can offset higher-emitting processes, allowing us to reach (and move below) zero emissions overall. Some industries like steel and sectors like agriculture have very limited options for reducing their emissions to zero. In addition, having the ability to remove carbon pollution from the air provides important insurance in the case that either we don't de-carbonise as quickly as planned; or the climate turns out to be more sensitive to carbon pollution than we had anticipated.

Developing these technologies early also helps us avoid a world where potentially high-risk geo-engineering technologies need to be explored.

WHY DOES IT MATTER?

The system is out of balance.

Currently, CO_2 is being released into the atmosphere nearly twice as fast as it is removed by Earth's carbon sinks, like forests and oceans. We are already at dangerous levels – 40 per cent above pre-industrial quantities, and rising fast.

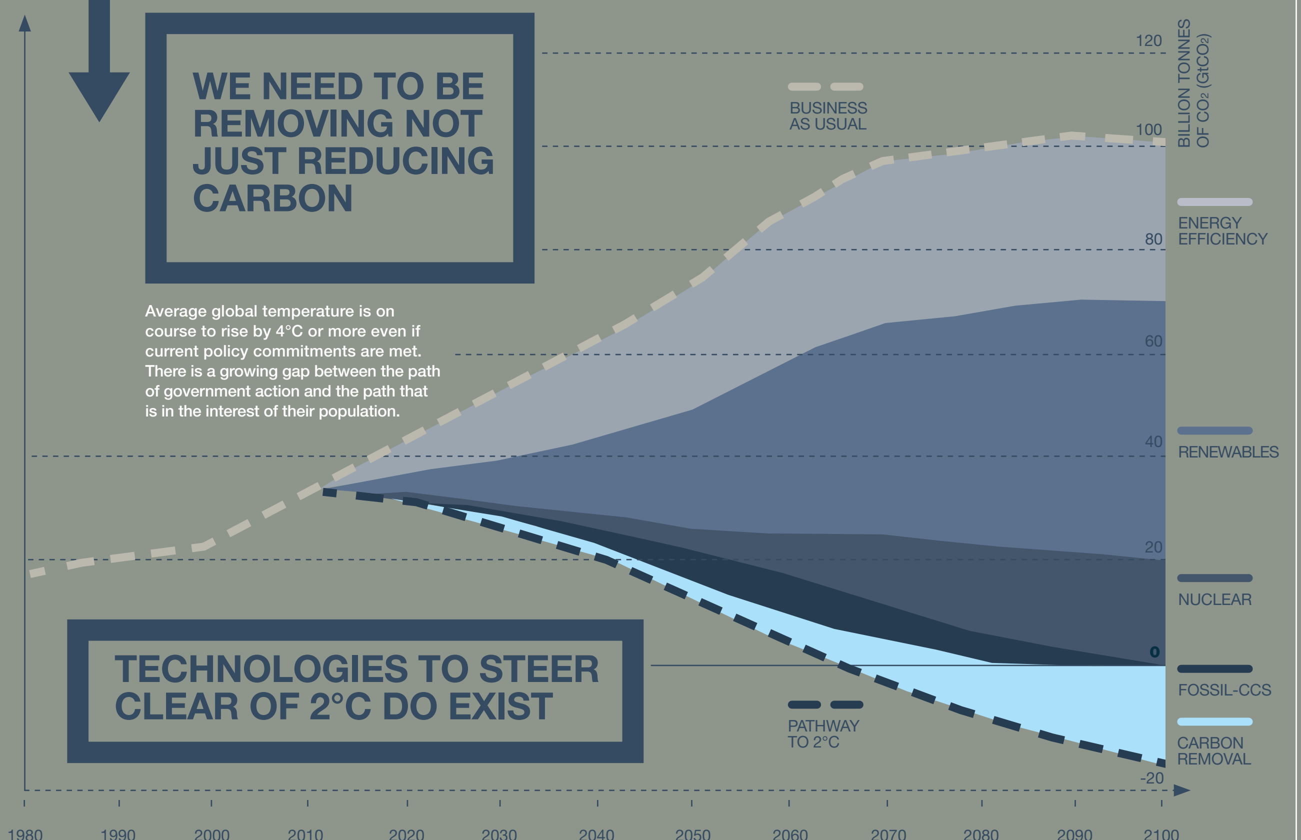
THINK OF IT AS A BATHTUB OVERFLOWING

WE NEED TO TURN OFF THE TAP AND PULL THE PLUG ON EMISSIONS

To avoid the bathtub overflowing, we need to turn off the tap but also pull out the plug on emissions. We need to remove carbon from the air.

WE NEED TO BE REMOVING NOT JUST REDUCING CARBON

Average global temperature is on course to rise by 4°C or more even if current policy commitments are met. There is a growing gap between the path of government action and the path that is in the interest of their population.



TECHNOLOGIES TO STEER CLEAR OF 2°C DO EXIST

Calculations by The Climate Institute based on the share of technologies examined in the IEA (2012) *Energy Technology Perspectives* 2012 and IIASA (2012) *Global Energy Assessment*.

WHAT CAN BE DONE?

Utilisng nature's blueprint and human ingenuity.

The life and death of plants creates a natural carbon cycle. While biomass can be harvested, more must be planted to start the cycle again.

BIOMASS IS PLANT MATTER

(like wood and crop stalks)

If left to decompose the CO_2 is released back into the air.

As plants grow they take in energy from the sun and absorb CO_2 from the air.

IF HARVESTED, CO_2 STAYS IN THE BIOMASS

By removing this CO_2 from the carbon cycle we can harness it, preventing it returning to the air.

THIS CO_2 CAN BE STORED IN A NUMBER OF WAYS

	AFFORESTATION & WOOD STORAGE	BIO-CHAR	BIO-CCS
	Using wood in construction prevents it from decaying, storing the carbon pollution.	Bio-char (charcoal) fixes the carbon into the biomass which can be used to improve farmland soils.	Bioenergy can generate electricity and heat. Carbon can be captured and stored underground.
CAPACITY TO REMOVE EMISSIONS	1.3 – 14 $GtCO_2e$ per year in 2030	3.7 $GtCO_2e$ in 2030	10 $GtCO_2e$ per year in 2030
COST	\$25 – \$115 /tCO_2e in 2030	\$140 /tCO_2e today	\$60-115 /tCO_2e today
PERMANENCE	Pressures on land may cause deforestation. Wood as a building material can last over 100 years.	A fraction of the CO_2 will be released immediately, the rest: 100-1,000 years.	99% stored for greater than 1,000 years.
CO-BENEFITS + RISKS	+ Cooling, flood protection, biodiversity, amenity. Wood in costruction replaces energy intensive building materials like cement and steel. - Afforestation can compete with food production and does not create revenue so incentives are limited.	+ Higher-carbon soils may improve plant growth and reduce need for fossil-based fertilisers. - Stability variable and methane may be released.	+ Displaces fossil fuel use in industry and power generation. - Needs sustainable biomass supply that respects conservation and cultural values.

Something to watch

New technologies are being trialled that mimic these natural processes. Artificial trees capture CO_2 from the air in a sticky resin and store it underground. Current cost estimates ~ \$600 /tCO_2.

Afforestation & Wood Storage

Nearly 20 per cent of emissions each year are caused by changing the way land is used - clearing forests for timber and making space for food production. The net result of deforestation (clearing forests) and afforestation (planting new forests) creates a loss of 7 million hectares of forest *each year*. That's an area larger than Tasmania.

Studies show mixed results on how much carbon forests breathe in over their lives. Some find forests take in more and more carbon as they age.[8] Others find a forest's ability to absorb carbon diminishes, reaching *carbon neutrality* at around 100 years old.[9] The carbon remains locked up as long as the forest remains standing. However, food production and urban development put competing pressures on land use, and these stresses will grow as the population expands.

Native forests should be safeguarded to protect these natural carbon stores as well as for their biodiversity and other important cultural values. Creating new plantation forests will absorb carbon, at least up to a certain threshold. To ensure carbon continues to be removed, some wood can be harvested from plantation forests and used in construction, which locks up the carbon for decades. This allows new tree growth, thus continuing the process of carbon removal.

Estimates of capacity for emission removal vary greatly, from 1.3 to 14 billion tonnes of CO_2 ($GtCO_2e$) removed per year in 2030.[10] Aiming for higher levels of afforestation means it becomes more difficult and costly to find land, and harder social trade-offs around land use need to be made. To reach the full potential, costs could rise to US$ 115 /tCO_2e.[11]

Bio-char

A second carbon-removal option – bio-char, a charcoal-like material – is created by heating biomass in a low-oxygen environment. It results in *fixing* the carbon into the bio-char, preventing it from decomposing and returning to the air.

Bio-char can be mixed into farmlands to improve the soil condition, enhancing water retention and recycling vital nutrients. In turn, this improves plant growth; taking in more CO_2 and in some cases can replace fossil-based fertilisers. The process has been under trial since it was discovered from ancient Amazonian farming practices, where soil has retained carbon since around AD 450.

Bio-char's resilience to decomposition is variable. A large portion of the carbon is stable over the time frame of 100-1,000 years. Stability depends on the properties of the feedstock, pyrolysis conditions and soil type into which it is applied.[12] However, the influence of bio-char on the release of non-CO_2 greenhouse gases (such as methane and nitrous oxide) is still not well understood. There are opportunities to utilise bio-char to mitigate these emissions, but some instances of increased emissions have been observed.

Estimates of global carbon-removal potential are around 0.15 $GtCO_2e$ per year, rising to 3.7 $GtCO_2e$ by 2030, given ambitious biomass resource estimates.[13] Bio-char can be sold to farmers, creating sources of revenue, and currently costs around US$ 140 /tCO_2e to produce.[14] Research is underway around the world. Costs could fall substantially if it becomes widely produced.[15]

CO2CRC Otway project, Australia. Image courtesy of CO2CRC.

Bio-CCS

Bio-CCS (also known as renewable-CCS) involves the combination of two well-known technologies: bio-energy and carbon capture and storage (CCS). Biomass has been burned for thousands of years for cooking, and more recently in power stations to generate bio-energy, heat, electricity and transport fuels. Rather than allowing the gases to carry the CO_2 back into the air, CCS can be fitted, removing the CO_2 and storing it in geological rock formations (over 0.8km deep).

Twelve commercial-scale CCS sites are operational, and a further nine plan to open by 2015, including the first large-scale bio-CCS facility in Illinois (trialled since 2011).[16] Together these plants will store carbon, equivalent to taking 8 million cars off the road.

Bio-CCS contributes doubly to emission reduction because it displaces fossil-based energy sources like coal, improving air quality and the health of local residents. As with all options discussed here, it is important to ensure the biomass comes from a sustainable source, protecting conservation and cultural values.

Unlike other carbon-removal techniques, bio-CCS does not rely on the biological properties of the biomass to store the carbon. Instead, geological formations store 99 per cent of the CO_2 for over 1,000 years allowing it to bind to the rock forming a mineral.[17]

Sustainable bio-CCS could remove 10 $GtCO_2$ each year in 2050, roughly a third of all energy related emissions.[18] Costs are estimated at US$ 125 /tCO_2 for power stations in 2030, and revenue can be generated from the sale of power or heat. Once bio-CCS infrastructure is in place and construction risks fall, costs are projected to drop by 10-15 per cent by 2050.

Emerging technologies

New technologies are being trialled that mimic natural processes. The artificial tree is being developed at Columbia University. According to its creators, it is 1,000 times more efficient than its naturally-occurring counterpart. It works by capturing CO_2 from the air in a sticky resin, which is washed off with water, and transported and stored using carbon storage techniques. An advantage of artificial trees is they could be deployed almost anywhere. However, they currently use a substantial amount of energy and water and would need to be positioned close to a reliable supply.[19]

Direct air capture processes have been used for years to remove CO_2 from the air in submarines, and are currently used in industrial processes to separate air into its constituent gases. There are a range of approaches currently being trialled that are similar to this, for example the soda-lime process which uses the chemical reaction of lime with CO_2 to capture atmospheric CO_2. There are currently no stand alone commercial direct air capture plants, so cost estimates are high and uncertain, averaging around $600 /$tCO_2$.[20] The priority in terms of development is to bring the costs down and find commercial applications for captured CO_2.[21]

Moving forward

Carbon removal is not an alternative to deep cuts in emissions; it is a vital part of the package to deliver a safer and more prosperous future than the one we are heading for.

We need to start taking the climate challenge seriously by developing innovative carbon removal solutions that can take us below zero emissions.

NOTES

1 See for example IPCC (2013) *The physical science basis* and UNEP (2013) *Emissions Gap Report 2013.*

2 See for example OECD, lecture by Secretary General *The climate challenge: Achieving zero emissions.* 9 October 2013 http://www.oecd.org/

3 Potsdam Institute for Climate Impact Research and Climate Analytics, *4°: Turn Down the Heat,* The World Bank, Washington, DC, November 2012.

4 The Climate Institute (2012) *Carbon 101 Explainer.*

5 See for example Potsdam (2011) *The RCP greenhouse gas concentrations and their extensions* from 1765 to 2300 and UNEP (2012) *Emissions Gap Report 2012.*

6 International Institute for Applied Systems Analysis (IIASA) (2013) *Global Energy Assessment.*

7 Luderer et al (2013) *Economic mitigation challenges: how further delay closes the door for mitigation targets.*

8 Stevenson et al (2014) *Rate of tree carbon accumulation increases continuously with tree size,* Journal of Nature.

9 Lippke et al. (2011) *Life cycle impacts of forest management and wood utilization on carbon mitigation: knowns and unknowns.*

10 IPCC (2007) *Climate Change 2007: Working Group III: Mitigation of Climate Change.* Ch9.

11 IPCC (2007) *Climate Change 2007: Working Group III: Mitigation of Climate Change. Ch9.*

12 Australian National Low Emissions Coal Research & Development (2012) *Novel CO2 capture taskforce report.*

13 UK Biochar Research Centre (2008) *Biochar, reducing and removing CO_2 while improving soils: A significant and sustainable response to climate change.*

14 Grantham Institute for Climate Change (2012) *Briefing paper no 8: Negative emissions.*

15 See for example CSIRO coordination http://www.csiro.au/

16 Global CCS Institute (2013) *Global Status of CCS 2013.*

17 *Carbon dioxide capture and storage,* IPCC Special Report, UNEP, Cambridge University Press, 2005, pp. 14.

18 Ecofys for IEAGHG (2011) *Potential for biomass and carbon dioxide capture and storage.*

19 Grantham Institute for Climate Change (2012) *Briefing paper no 8: Negative emissions.*

20 Socolow et al (2011). *Direct Air Capture of CO_2 with Chemicals: A Technology Assessment for the APS Panel on Public Affairs.* The American Physical Society, Washington DC.

21 See for example MIT research http://web.mit.edu/newsoffice/2014/new-catalyst-could-lead-to-cleaner-energy-0305.html

Cover: The image on the front cover shows the cellular structure and 3 annual growth rings of a plant stem at 25 times magnification.

Below Zero is the first part of a project examining the role of carbon-removal technologies in reducing global emissions below zero. The project has been supported by the Global CCS Institute. The Climate Institute is an independent research organisation and has been advocating the need for carbon-removal technologies since 2007. The lead author of this report is Clare Pinder, Policy and Research Fellow at The Climate Institute.

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