Leverhulme
Centre for Climate Change
Mitigation

CARDIFF UNIVERSITY
PRIFYSGOL CAERDYDD

What people think about Carbon Dioxide Removal

The University Of Sheffield.

LEVERHULME TRUST

Funded by Leverhulme Trust Research Centre Award RC-2015-029

This report should be cited as:

Cox E., Spence, E. and Pidgeon, N. (2021) What people think about Carbon Dioxide Removal. Leverhulme Centre for Climate Change Mitigation (LC^{3}M), University of Sheffield, U.K.

Contacts:

coxe3@cardiff.ac.uk
pidgeonn@cardiff.ac.uk

Dr Emily Cox
Prof. Nick Pidgeon
School of Psychology
Cardiff University
Cardiff
Wales
CF10 3AT

+44 2920 870838

YouTube

www.lc3m.org

@lc3m_cdr

Table of Contents

Summary

The Earth's climate is changing as a result of humans burning fossil fuels for energy, which releases greenhouse gases such as carbon dioxide. Climate change caused by these greenhouse gases is already having a major impact around the world. To tackle climate change, we must stop producing and consuming as many fossil fuels. Additionally, we might also remove some carbon dioxide from the atmosphere, using Carbon Dioxide Removal (CDR) techniques.

Developing safe, effective, scalable techniques for Carbon Dioxide Removal is not just about getting them to work in a lab or a field; it's also about using them in the 'real world', in ways which will interact with people and everyday lives. To get them right, it is important that we listen to people's opinions and their concerns.

This study aimed to find out what people think about Carbon Dioxide Removal, using a large survey and six workshops in the United Kingdom and the United States. We focused especially on three techniques: Bioenergy with Carbon Capture and Storage (BECCS), Direct Air Capture and Enhanced Weathering.

Wildfires, like in Australia and California, have been made more likely by climate change.[i]

Key Findings

A 'non-transition': One of the biggest problems with the Carbon Dioxide Removal technologies studied here is that they do not necessarily reflect people's vision for a sustainable future society. Participants were concerned about energy-intensive and 'industrial' aspects of all three techniques. People also feel that tackling climate change isn't worth degrading the environment in other ways.

A temporal dilemma: People see climate change as immediate and urgent. Participants were concerned that new Carbon Dioxide Removal techniques might not be ready quickly enough: they felt that it would be unwise to roll them out before they have been tested properly, but this means they may be too slow to tackle the urgent problem of climate change. At the same time though, people felt that these proposals may not be sustainable in the long-term. Therefore, publics may see Carbon Dioxide Removal as both too short-term and not short-term enough.

Support for research: The general concept of removing carbon dioxide from the atmosphere was generally well supported. Research under well-controlled conditions is likely to be generally acceptable. However, some things are harder to test and control, and techniques which interact with the ocean might be seen as particularly risky.

Cross-national differences: Responses were quite similar in the UK and the US but UK participants perceived more benefits. Part of the reason for this is that people in the UK are more worried about climate change. People in the UK also felt more strongly that Carbon Dioxide Removal could buy time to reduce emissions, perhaps because UK participants were generally more optimistic about future generations being environmentally friendly.

Fracking policy has created problems in the UK: Government policies have created public stigma around fracking. In particular, loss of trust has occurred. This has spilled over onto Carbon Dioxide Removal, even for technologies like Enhanced Weathering which are quite unlike fracking. Policy decisions in one sector have important knock-on impacts on other sectors and other technologies.

Bioenergy with Carbon Capture & Storage preferred: People generally saw BECCS as more natural and more feasible than Direct Air Capture or Enhanced Weathering. Illinois farmers saw an economic opportunity in BECCS. However, BECCS would need to avoid causing other environmental problems, and simply planting forests would generally be much more preferred. With BECCS there are well-documented concerns about storing carbon dioxide underground, which may be a major barrier for Direct Air Capture as well.

Direct Air Capture is less easy to understand: The process of capturing carbon dioxide from the air is not intuitive, and people may wonder why it is being deployed in unpolluted areas. Apart from this, the main concerns around DACCS were carbon dioxide storage underground (the same as for BECCS); and concerns about energy requirements.

Enhanced Weathering is perceived as risky: People initially saw Enhanced Weathering as too energy-intensive and too industrial. However, people also said that there are currently "too many maybes" around this technique and would mostly support more research. The biggest concerns were around ocean impacts, and the idea of opening new mines for the rock resource.

More information makes people more favourable: After a long discussion about Enhanced Weathering, people's perceptions of it improved significantly, even though we provided a balance of information. Feelings of trust and familiarity were important for this.

Policy Recommendations

- Pursue a portfolio of options for tackling climate change; cutting emissions must be the priority.
- Stick to a coherent narrative for a sustainable future.
- Remember that climate change is not the only goal; prioritise techniques which also generate non-climate co-benefits.
- Address temporal dilemmas.
- Build trust and promote inclusive dialogue.

For more detail, see the accompanying Policy Brief

Tackling Climate Change

The Earth's climate is changing as a result of human activity. The burning of fossil fuels such as coal, oil and gas releases carbon dioxide and other greenhouse gases which trap heat near the earth. Climate change is already having a big impact around the world: it threatens human health and wellbeing; it is damaging ecosystems and causing species to go extinct; it is causing sea levels to rise and it increases the risk of some types of extreme weather.[ii]

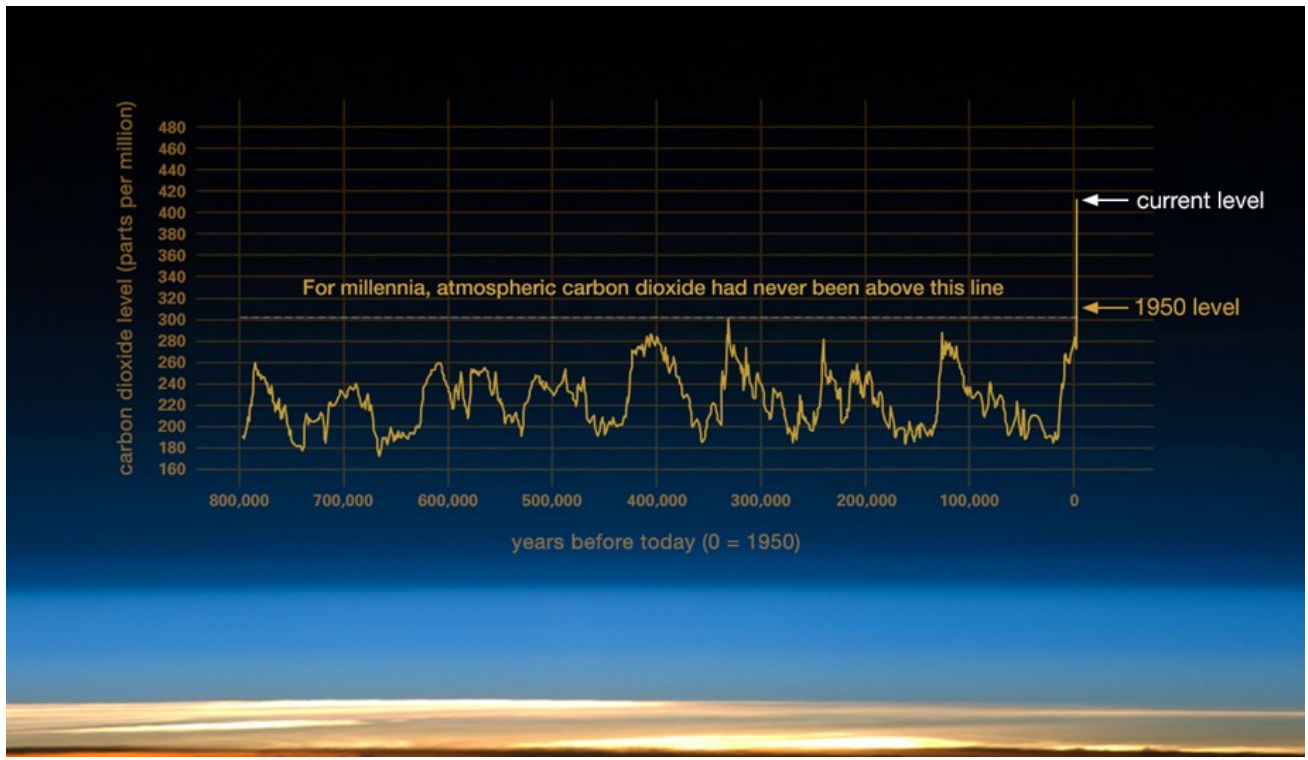


Image credit: NASA. Luthi, D., et al.. 2008; Etheridge, D.M., et al. 2010; Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO_2 record

There are many ways in which we can try to slow or stop climate change.

Firstly, we can change the way energy is supplied, by using fewer fossil fuels, for instance by using the sun and wind to power our homes and using low-carbon electricity to power our cars.

Secondly, we can change the way we use energy, for example by using cars and planes less, consuming less energy and fewer goods, or by shifting to a non-meat-based diet.

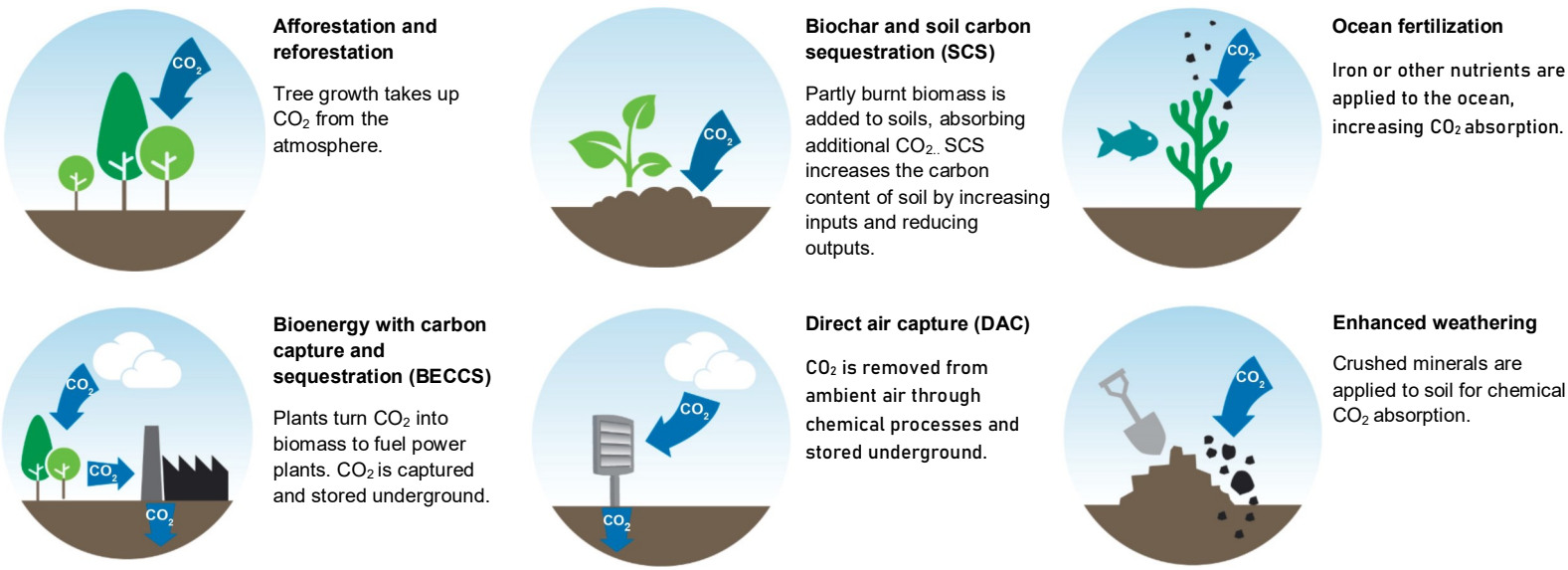
Thirdly, we can adapt to climate change impacts, for instance by building flood defences, irrigating crops, or migrating to areas which are less affected by climate change.[iii]

To tackle climate change we need to use less fossil fuel, for instance by using renewable energy.

Removing Carbon Dioxide from the Atmosphere

All these strategies for tackling climate change will be important. However, they might not be enough or some might just be too difficult on the kind of scale that we need them. Therefore some people have suggested that we could try to take some of the carbon dioxide out of the atmosphere using Carbon Dioxide Removal, or CDR. The removed carbon dioxide would be stored by plants, in soils, or deep underground and in the deep ocean so that it cannot contribute to an increase in the Earth's temperature.

Several carbon dioxide removal options have been proposed:



Source: Minx et al (2017). Image credit: MCC.[iv]

It is becoming clear that most industrialised economies will require some large-scale Carbon Dioxide Removal in order to meet their climate change targets. For instance, the UK aims to have 'net zero' carbon emissions by 2050. Projections suggest that doing this may require 130 million tonnes of carbon dioxide to be removed each year by 2050.[v]

What people think about Carbon Dioxide Removal

Not actual participants. We keep all our participants' details confidential and use aliases throughout our reporting.

Developing effective technologies is not just about getting them to work in a lab. It's also about using them in the real world, in ways which will interact with ordinary people and everyday lives. Research over many decades has shown that the real-world potential of new technologies depends, in part, on people's attitudes toward them.

The public can also help us to understand more about these technologies, because experts spend so much time working on very detailed aspects of these technologies that they sometimes don't see the bigger picture. By taking a broader view and thinking about technologies in terms of their everyday lives, non-experts can help us to spot things which experts may have missed.[vi]

Many of the Carbon Dioxide Removal options are at an early stage of development. We are still learning about their risks and benefits. To get them right, it is important that we listen to people's opinions and their concerns.

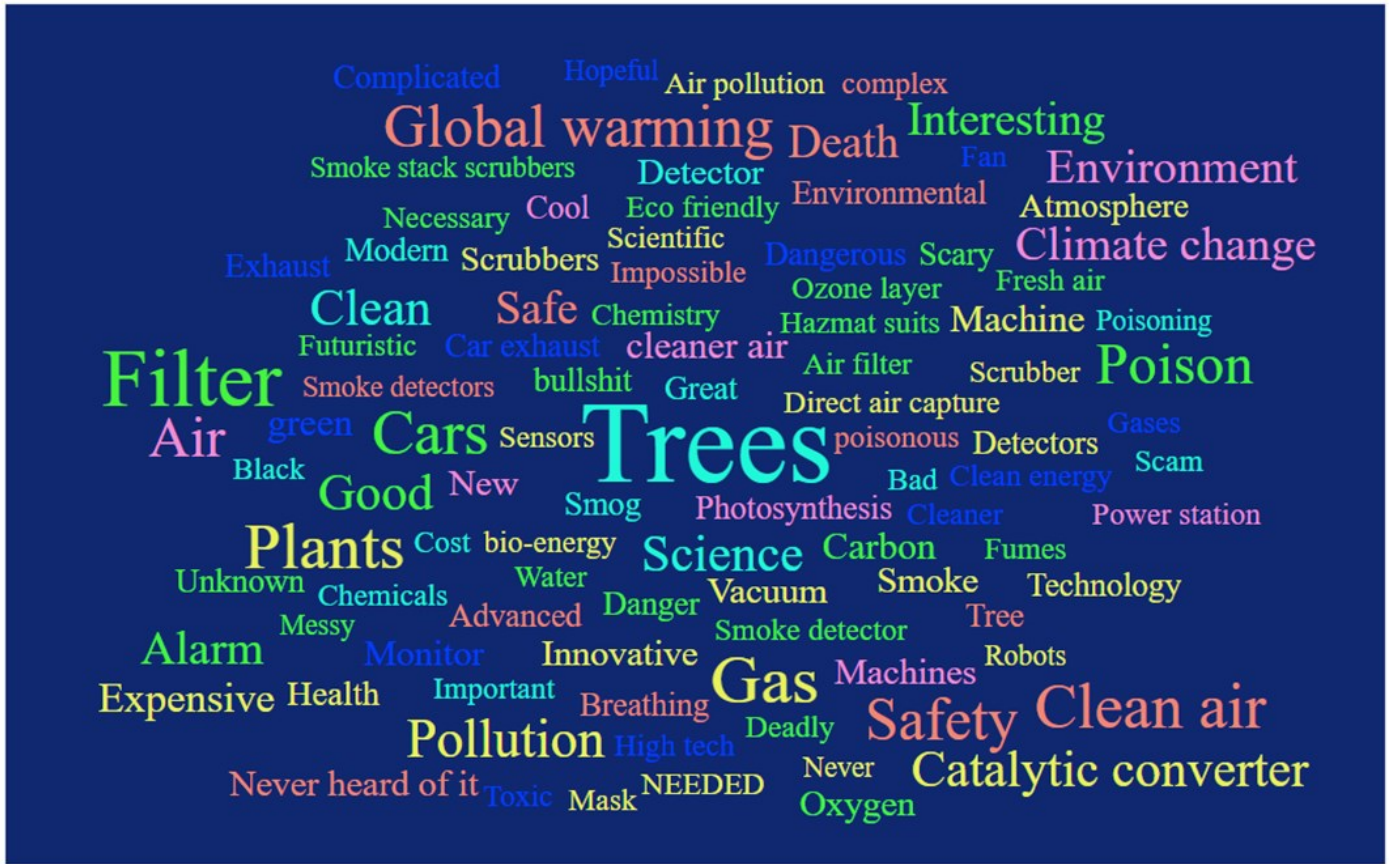
This study aimed to find out about people's attitudes to Carbon Dioxide Removal. We conducted a large survey with 1000 people in the UK and 1026 in the US, and six discussion workshops in the United States (Illinois) and the United Kingdom (East Anglia and South Wales).[vii] We focused on three technologies: Bioenergy with Carbon Capture and Storage (BECCS), Direct Air Capture and Enhanced Weathering.

This report introduces our findings and gives a set of policy recommendations at the end. Our policy findings are also available in an accompanying Policy Brief.
Our headline results are reported in a research paper at *Nature Climate Change.*[viii]
Our methodology is available in the Technical Appendix to this report, available from the LC^{3}M website.
A full protocol is available in [viii] supplementary materials.

Results

We asked 2,026 people in the UK and US:

"What is the first thought or image which comes to mind when you hear the term 'Carbon Dioxide Removal'?" [ix]



This word cloud shows the responses; the larger the word, the more commonly it was mentioned.

"What is the first thought or image which comes to mind when you hear the term 'Carbon Dioxide Removal'?"

The majority of people in our survey were not familiar with Carbon Dioxide Removal. Only 5.7% of people in the UK and 9.6% of people in the US said they knew "a great deal" or "a fair amount" about it. Therefore most people will have been relying on associations and their gut feeling to answer this question.

Later in the survey, we gave people a description of Carbon Dioxide Removal to use when answering the rest of the questions.[x]

We can see that 'trees' was the most common word (as well as 'plants').

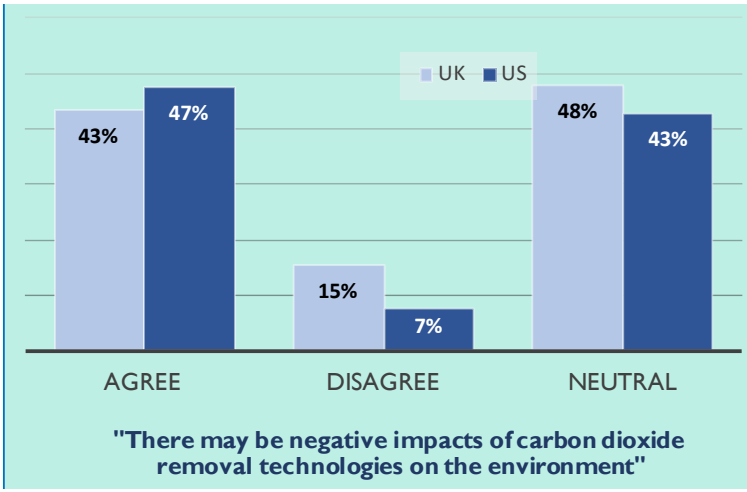
Trees and plants remove carbon dioxide when they photosynthesise, and planting new forests is indeed one significant option for Carbon Dioxide Removal.[xi] The idea of planting trees to remove carbon dioxide was mentioned unprompted in many of our workshops as well. People were generally very positive about the idea of planting trees to address climate change, although they pointed out that these need to be diverse woodlands which can support wildlife as well.

The word 'filter' was also used a lot, as well as 'scrubber' and 'catalytic converter'. 'Pollution' was also mentioned many times. In our workshops, we found a strong association between carbon dioxide and cars.

There were lots of positive words, including 'interesting', 'innovative' and 'needed'. However, there were also lots of negative associations, including 'scary', 'dangerous', 'death', 'scam' and 'bullshit'!

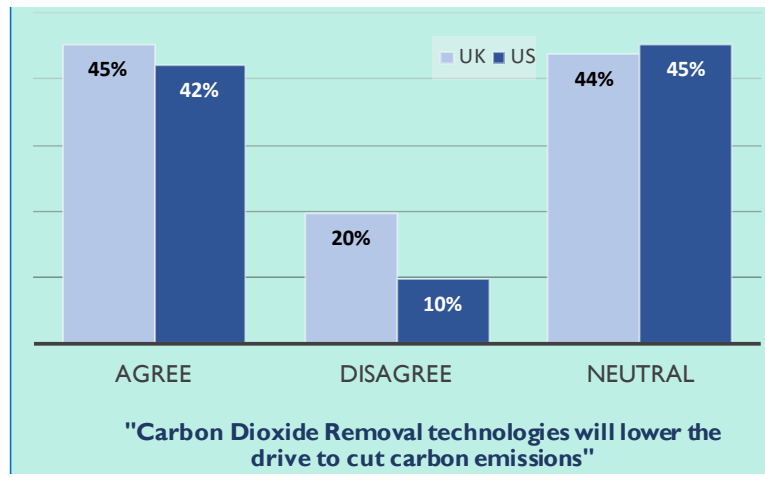
Do people support Carbon Dioxide Removal?

People are generally supportive of research into Carbon Dioxide Removal, as long as it is done under well-controlled conditions.[xii] People think that research trials should start small and work their way up, so that any unexpected negative effects can be spotted before they have too much of an impact on the wider world. Our participants were generally positive about scientific progress, but they were sometimes sceptical about whether science would always be able to predict or prevent unintended consequences.[xiii]



For most people, one of the biggest problems with Carbon Dioxide Removal technologies is that they do not reflect their desired vision for a sustainable future society. Mankind has often failed to deal with waste in a responsible manner, and these technologies were seen as a way of 'pushing it under the carpet', in a similar way to landfill, nuclear and industrial waste, or plastic waste in the ocean.

Some things might be more difficult to test in a controlled way. In particular, people are concerned about impacts on the oceans.[xiv] Some of these technologies need the carbon dioxide to be stored in some form in ocean waters, on the seabed, or under the ocean floor. People are concerned that this may harm vital ecosystems on which animals and humans rely and that we might not be able to identify or reverse negative effects in such an open environment.



"It just seems like each [CDR proposal] is kind of reactionary...I think we need to shift our whole attitude to the way we use the planet."

"I wouldn't be willing to pay for any of them unless they were part of a package that required reduced emissions in the first place.

If it's just something to try to keep us doing what we've been doing, it's a lose-lose."

"It seems a bit like shutting the gate after the horse has bolted.

We should be trying to control the horse."

"I spoke to my daughter…. she was like:

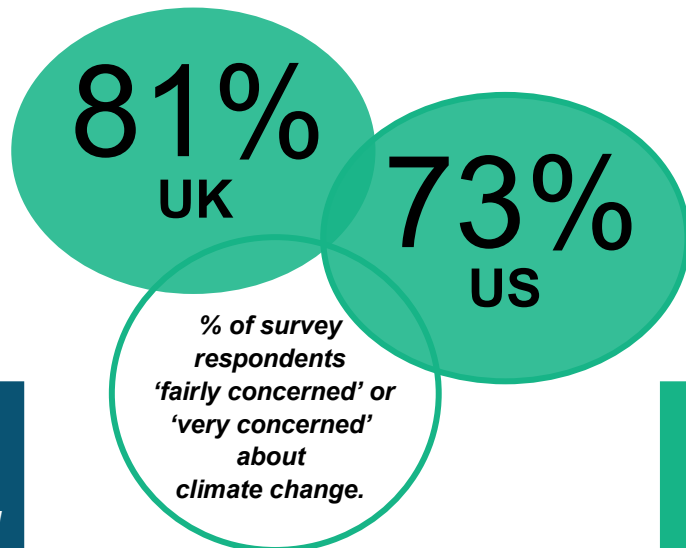
'For one problem to be solved, you're creating more problems by doing the stuff that you're doing. To solve one problem, you're creating nine.' "

"Are we burying the problem for later generations?

It's like we're not actually getting rid of the carbon, we're just hiding it."

Carbon Removal and Climate Change

Carbon Dioxide Removal sometimes involves risks to humans, animals or the environment. Most of our participants saw climate change as a very important problem but felt that tackling climate change would not be worth degrading the environment in other ways, or causing other risks to our communities and societies. We need to make sure that the solution is not worse than the problem itself. We should support technologies which create non-climate co-benefits.[xv]

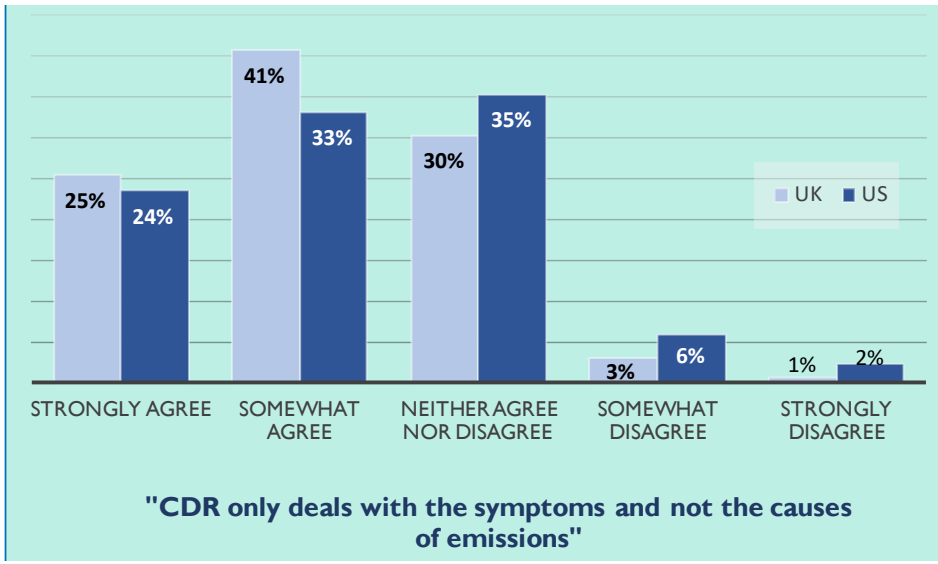


"...and it's like, destroying natural resources to save our natural resources? It's counterproductive."

"...because if we could improve the situation with climate change, but then if we're wrecking the environment in another way, we're not really improving things at all."

Most people felt that removing carbon dioxide does not tackle the root cause of climate change. People are also concerned that supporting these technologies will reduce our willingness as a society to cut our emissions in the first place, which could lead to greater climate change risk in the long term.[xvi]

All these factors mean that Carbon Dioxide Removal is seen by many people as a 'non transition'.



"How quickly is the problem going to overrun the solution? We should be trying to reduce the carbon dioxide emissions as well as trying to balance the scales. I don't want big industry to say, 'We can do what we like because that's there.' "

"They say they dump it in the middle of the ocean and it goes down, I don't know where, but it comes back."

"But there's too much going on. You could have all three of these things in place and at the same time, you've still got the emissions that are coming in…"

Will Carbon Dioxide Removal be ready in time?

Most people said that, to them, climate change is an immediate and urgent problem. People often have personal experience of extreme weather, including floods, droughts, and severe storms. Extreme weather is made more likely by climate change.

The three Carbon Dioxide Removal technologies we discussed might help to deal with climate change. However, people raised questions about how soon they would be ready. People are aware that technology development takes time.[xvii]

It would be unwise to roll out these technologies before they have been tested properly but this means they may be too slow to tackle the urgent problem of climate change. At the same time though, people felt that these technologies might not be sustainable in the long-term. Therefore, people may see Carbon Dioxide Removal as both too short-term and not short-term enough.

"Really we need to make a start now or sooner the better. The idea is okay but if it's like, 20, 30 years, is that going to be too late?"

"I don't think it'll have much impact because the damage is being done too rapidly."

Image credit: Kai Stachowiak, publicdomainpictures.net.

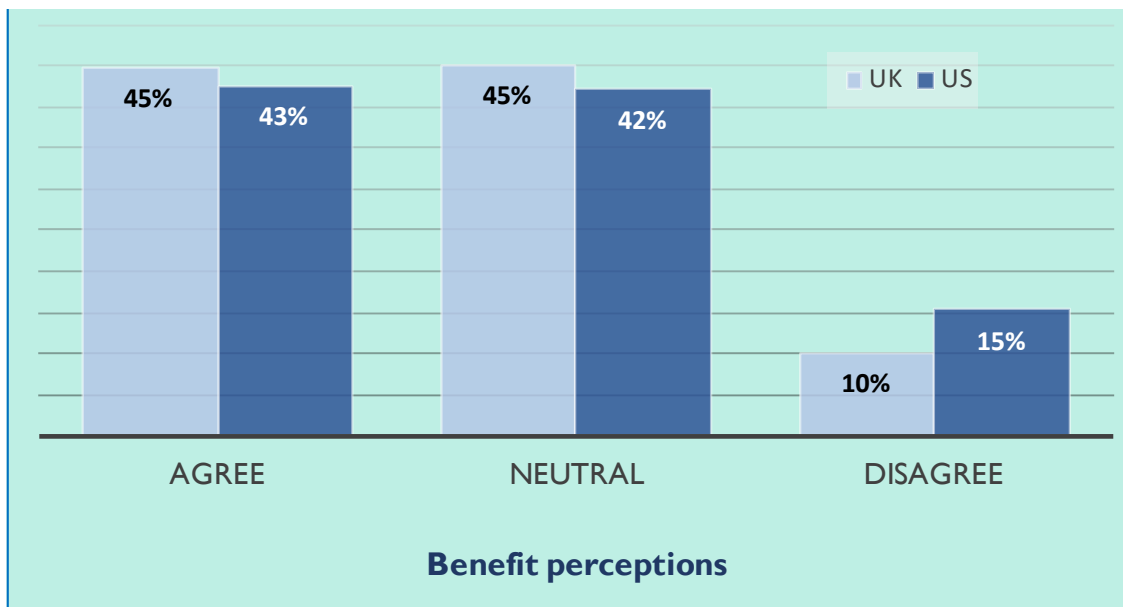
"There's so much happening throughout the Earth, the flooding and the wildfires…The temperature is changing and now because of what we see every day."

"How far away is it from being able to be used? Is it like 20 years away? Don't we need that a bit sooner than that really?!"

Were there differences between the UK and the US?

In general, responses were quite similar in the United Kingdom and the United States. In our survey, there was no significant difference in how risky people thought Carbon Dioxide Removal would be. However, people in the UK were slightly more likely to think that it could create benefits.

We looked at why this might be, and found that it was partly due to the fact that people in the UK are more concerned about climate change. People who are more concerned about climate change are more likely to think that Carbon Dioxide Removal could be beneficial.[xviii]



Survey responses to three 'benefits' questions:
"CDR-Ts could help to provide more time to reduce emissions"
"It will be cheaper to use CDR-Ts than to reduce the consumption of fossil fuels"
"CDR-Ts will help slow climate change down faster than by simply cutting greenhouse gas emissions"

In the workshop discussions, people in the US were more concerned about risks to human health. This is probably because some areas in the United States have contaminated land due to industrial activity in the past.

"When our generation was younger, you didn't throw stuff away…"
(US participant)

"I think youngsters are quite socially and environmentally aware; the ones I speak to anyway."
(UK participant)

People in the UK felt more strongly that Carbon Dioxide Removal could buy time to reduce emissions. From the conversations in our workshops we realised that this might be because, when talking about the environment, UK participants were generally more optimistic about future generations.

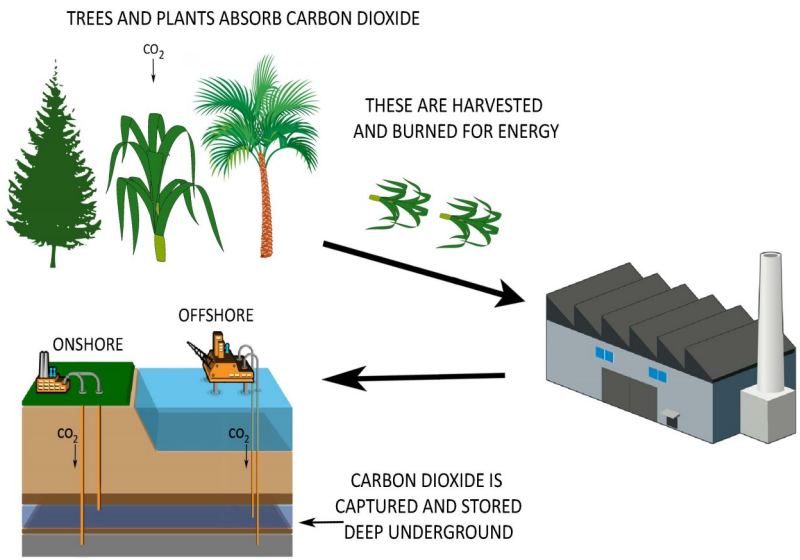
In the UK, people felt that recycling rates were increasing and that young people are more aware of climate change and more likely to do pro-environmental things. In the US, many people felt the opposite. For these people, there would be little point in buying time for action on climate change in the future because people are sceptical that that sort of action will occur.

This suggests that support for Carbon Dioxide Removal is linked to people feeling like their country, their government, and their community, will take ambitious action to improve the environment in the near future.

"They've been taught from a young age. It's just bringing it up like a natural occurrence."
(UK participant)

"Teenagers her age right now, they don't care about the environment, they just care about other stuff."
(US participant)

Bioenergy with Carbon Capture & Storage (BECCS)



Stage of development: Ready, but too expensive to be used at present.

Scale: Large amount of land required, some of which is currently open space or used for farming.

Storage: Long term; the carbon dioxide is transported by pipelines to a storage facility deep underground or under the ocean.

Possible benefits: Provides a renewable energy supply.

Possible barriers: Competition for land for food; need to safely transport the carbon to storage sites; might decrease biodiversity.

BECCS involves planting, growing and harvesting plants to use as a fuel source. The plants absorb carbon dioxide as they grow and, once they are mature, they are harvested and burned as an energy source.

This releases carbon dioxide which is captured and absorbed through a chemical process, then compressed into liquid form and piped deep underground to be stored indefinitely. [xviii]

Biomass silos at Drax power plant in North Yorkshire. Drax are hoping to be one of the first large-scale BECCS projects in the world.
Image credit: Alan Murray-Rust.

How did people feel about BECCS?

Using plants is positive

Our results showed slightly higher support for BECCS than for the other two technologies. Lots of people said that they prefer the greenness, naturalness and beauty of plants. BECCS is generally seen as more natural than some other engineered carbon removal approaches.

But, 'there's natural and there's natural'

People were worried that BECCS might create problems for ecosystems and wildlife. People were familiar with monocultures, for instance fir tree plantations, and the problems that these sometimes create for wildlife. Burning the plants might also create local pollution, which people are concerned about for health and environmental reasons. Removing carbon dioxide is not necessarily more important to people than reducing or removing other airborne pollution.

Forests are preferred

Many people raised the topic of afforestation (planting trees) spontaneously. People spoke of afforestation very positively and many felt that we should be protecting forests instead of burning biomass and storing the carbon dioxide. When we gave participants information about the vast scale at which forests would need to be planted to remove the same amount of carbon dioxide, people asked why we couldn't do more to protect the existing rainforests. Therefore when it comes to certain environments, people may prefer protected spaces over human intervention.

BECCS is familiar and easy to understand

The process by which plants capture carbon dioxide is familiar to most people.[xx] This means that BECCS might be more intuitive than some other technologies. People also thought BECCS would be more feasible using existing infrastructure because we already have most of the technology needed to grow and burn the plants. Many people are familiar with biomass projects in their own area, particularly in crop-growing areas such as East Anglia and Illinois.

Land requirements

Scientists have long voiced concerns about the large land area which may be required for BECCS. This may bring BECCS into conflict with other land uses, such as food. Many of our participants were concerned about this as well; however, they also felt that food shortages are a problem of unequal distribution, not just lack of supply. People were also keen on the idea of using waste biomass, for instance forestry residues, for BECCS.

Illinois farmers favourable toward BECCS

Farms may be important for Carbon Dioxide Removal, for instance by providing the energy crops used for BECCS. We spoke to a group of grain farmers in Illinois to find out their thoughts. They generally preferred BECCS to the other technologies. They were already familiar with the technology, including with some local carbon storage projects. Farmers saw BECCS as fitting well with their 'vision' for the future – they saw BECCS as part of the transition, rather than a non-transition.

"I like that it's green plants, which absorb CO_2.

But then I saw that we're burning them and I went, eugh, that doesn't sound so positive anymore."

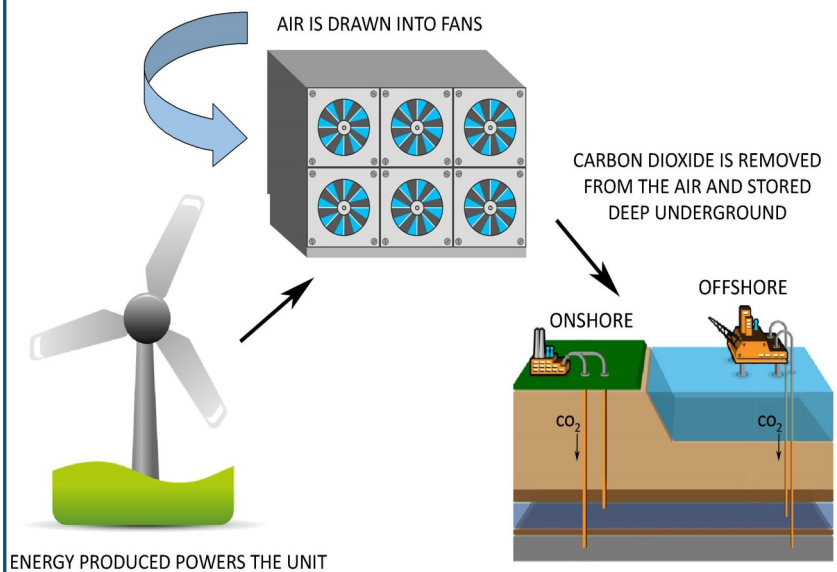
"It's moving towards mimicking nature though, I guess. Which is the ultimate solution."

"Where we're going to eat less animal protein to reduce carbon footprint, that's going to make land less valuable.

If it's less valuable, BECCS might supplant that, keeping profit where it needs to be and the value of the land."

(US farmer)

Direct Air Capture



Stage of development: Being researched in labs.

Scale: Direct air capture units would be about the size of a building.

Storage: Long term; the carbon is pumped into a storage facility deep underground or under the ocean.

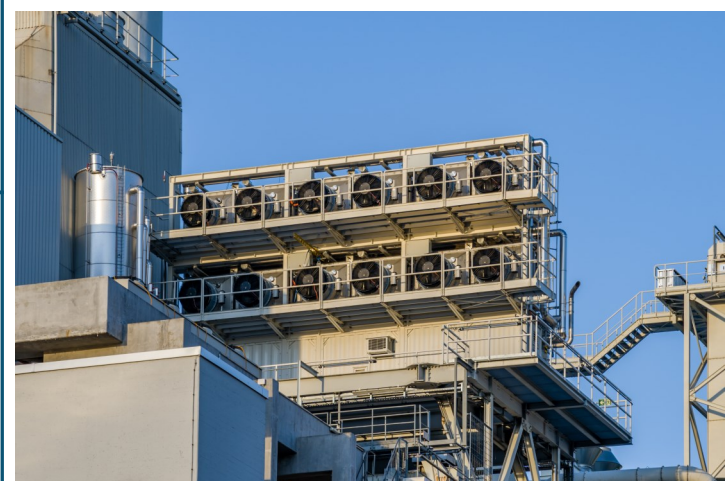
Possible benefits: Doesn't take up as much land; can be located close to the storage facility.

Possible barriers: Expensive; absorbing carbon from air requires lots of energy.

Direct Air Capture involves a chemical process to capture carbon dioxide from the air and store it. Air is drawn through absorption traps by fans and the carbon dioxide is separated out.

The carbon dioxide, compressed into liquid form, is then piped deep underground to be stored indefinitely.

A large amount of energy is needed and it is assumed that renewable energy would be used.



The ClimeWorks plant in Switzerland, one of the world's first full-scale Direct Air Capture projects. Image: Getty

How did people feel about Direct Air Capture?

‘Just using the air’

Some participants liked the idea of scrubbing carbon dioxide straight from the air because it seems more straightforward and doesn’t require incineration or large land area like BECCS. A few participants had heard of ClimeWorks (a Direct Air Capture project in Switzerland) and said it seemed like a good idea.

Energy requirements

People felt that Direct Air Capture would require an ongoing energy resource and therefore may be less sustainable in the long-term. People felt that we do not currently have enough renewable generation capacity to power the units in a low-carbon way, especially if the energy required to build the units is also taken into account. Therefore some participants saw Direct Air Capture as complex, industrialised and not a transition.

Tricky to understand

One of the main problems for Direct Air Capture could relate to people’s understanding and engagement with the process. The process of separating carbon dioxide from the air is not intuitive or easy to explain. However, the fact that it involves a chemical process was not generally received negatively.

“I didn’t understand that one at all.

I read it and read it and I thought, meh, it’s a little over my head.”

“I sense that the energy required to do that would mitigate a lot of what you’re gaining. I mean, if we could do it all with windmills, okay, but I don’t…you couldn’t do it all with windmills and other renewables.”

“I like that it’s not taking up the land….

I think yourselves are using the air. You’re not using anything else, are you? It’s just the air that’s being drawn in.”

Picturing CO_2

Many participants thought of CO_2 as grey, dirty and toxic, which probably comes from the way the media sometimes uses images of air pollution to portray climate change. Therefore projects sited in areas of otherwise good air quality, such as the countryside or offshore, might be met with scepticism about the goal of the project.

Cost

Direct Air Capture is one of the most expensive proposals for Carbon Dioxide Removal at the moment. People mentioned issues of cost for all the technologies and there were concerns (especially in the US) that energy bills might go up to pay for these things. However, some participants felt that policy-makers use this as a convenient excuse not to act. The bank bail-out in 2008 was used as an example to show that money could be made available, if needed.

Image credit: pxfuel

"I think that would be more useful in major cities because if you're just sucking in the air per energy that you're using for the fan, you might not gather as much CO_2 versus the really, really populated areas."

It is not uncommon for media articles about climate change to be accompanied by images showing air pollution being caused by vehicles or factories.

Cars and factories are both big sources of carbon dioxide; however, the grey smoke which they release and which causes air pollution and smog is a different chemical. Carbon dioxide is odourless and colourless.

Box 1: Just like fracking?

Fracking is a process for extracting shale oil and gas, which has been very controversial in many places. Fracking has experienced public opposition relating to concerns about earthquakes, water and land contamination, and carbon dioxide emissions. In the UK and in some US States, public opposition has led to a temporary ban.

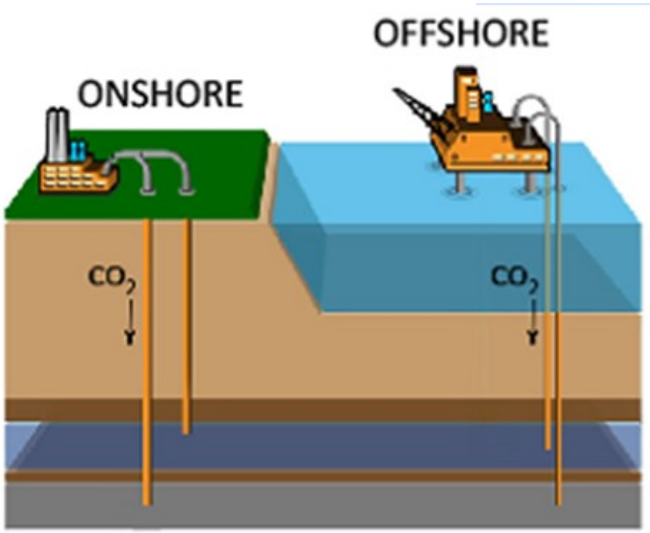
In terms of the technology, Carbon Dioxide Removal is not very similar to fracking. Enhanced Weathering, for instance, does not involve any of the same processes.

Our UK workshops showed that the stigma around fracking has had a negative impact on people's perceptions of Carbon Dioxide Removal. In particular, loss of trust has occurred. Many people feel that the government has given them mixed messages about what is required to tackle climate change in the UK. People felt that community concerns about the risks of fracking had been overridden or ignored and that decisions had been imposed on unwilling communities by distant elites.[xxi]

Our workshops were conducted far away from the sites of the fracking controversy. Our results, therefore, show that decisions around one technology, in one area, can have strong ripple effects to other technologies, sectors and locations. If Carbon Dioxide Removal is to be successful, policy-makers must acknowledge that policy decisions can have knock-on effects in other domains.

When scaling up Carbon Dioxide Removal technologies, we must learn important lessons from the fracking debate. It is crucial that people's voices are heard, that their concerns are not dismissed or thought of as 'irrational' and that developers do not attempt to deny or downplay the risks of the technology in the early stages.

Storage of carbon dioxide underground



Currently, captured carbon is mostly used to extract oil from depleted wells.

One of the biggest concerns for BECCS and Direct Air Capture was the idea of storing carbon dioxide underground. People were concerned about how long it could be stored for, whether it would be safe, whether it would leak and whether it would cause earthquakes. People in the US Midwest, who rely on underground aquifers for their drinking water, were concerned about contamination. Generally, people saw it as unsustainable, in the same way as landfill and nuclear waste.

There has been lots of very good previous research on what the public thinks about storing carbon dioxide underground. Most of our findings reflect these previous studies.[xxii]

Importantly, we found that concerns about sustainability were the same, even when considering technologies which don't involve any fossil fuels, such as Direct Air Capture units powered by renewable electricity.

We did not find a difference in perceptions between onshore and offshore storage. Some previous studies have suggested that people might be more favourable to offshore storage.[xxiii] However, our study suggests that people may be just as concerned about impacts to the ocean.

Many participants proposed the idea of using the carbon dioxide instead of storing it. People are generally positive about the idea of using a waste product in this way.[xxiv]

Carbon Capture and Utilisation (CCU) is a growing field of research. However, most ways of using carbon dioxide end up returning it to the atmosphere quite quickly: for example, using it in greenhouses to grow plants for food, using it in fizzy drinks, or using it to extract more oil from dried up wells.

"It's something negative that we're leaving for future generations.

You're storing things underground, you don't know what's going to happen."

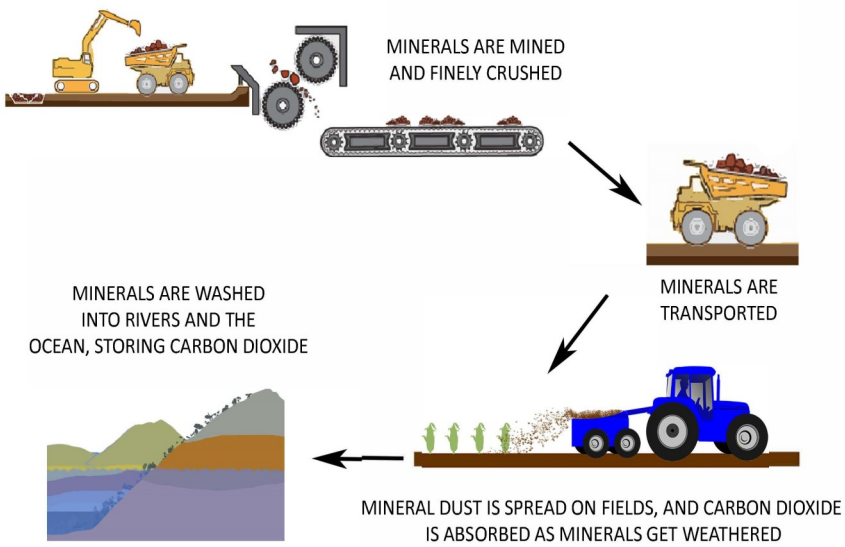
"Well surely, over the years, you must fill the land up with carbon dioxide?

It's not going to be empty forever."

"My question there, too, was what's going to happen in 100 years, 200 years from now?

We already know it's toxic and to put it under, it's just kinda like building ourselves a bomb under us."

Enhanced Weathering



Stage of development: Being tested.

Scale: Large amounts of farmland required.

Storage: Very long-term; carbon is stored as minerals, on the sea floor, and dissolved in ocean water.

Possible benefits: Might improve growing conditions for crops; might reduce the impact of climate change on ocean environments.

Possible barriers: Mining of rocks; lots of energy needed for crushing and transporting rock.

Weathering is the breakdown of rocks and minerals through wind, weather and living organisms.

Weathering is an important part of the carbon cycle that takes place over thousands of years. Enhanced Weathering speeds this process up by mining, crushing and spreading minerals onto fields. As they get weathered, these minerals absorb carbon dioxide, removing it from the atmosphere.

Spreading rock dust at the Energy Farm at the University of Illinois, one of the world's first Enhanced Weathering field trials. Image credit: Energy Farm, University of Illinois

How did people feel about enhanced weathering?

Industrial

People initially disliked Enhanced Weathering more than the other proposals discussed. People thought it would be industrial and would require heavy machinery to crush, transport and spread the rock dust. People didn't see it as fitting with their desired vision for how climate action should look.

Oceans

Some of the carbon dioxide absorbed in the Enhanced Weathering process may be stored in the ocean, as stable (non-reactive) bicarbonate. People were generally very uncomfortable with this idea. The ocean is an open, interconnected ecosystem, which makes accurate testing challenging. There were concerns that we wouldn't be able to predict or control unintended consequences for the ocean ecosystems, or for the people who rely on the oceans as a resource.

Mining

The idea of opening new mines for the rock resource may be another 'red line' for publics. This is mainly because of energy requirements but also environmental impacts from mining. Using rock by-product from existing mines was seen as a much better way of doing Enhanced Weathering. However, the distance between the mine and the farm would need to be short, as people are concerned about the pollution from transport.

Co-benefits

Enhanced Weathering could create co-benefits, especially by adding important nutrients and alkalinity to soils, rivers and oceans. When we provided this information, our participants were split: some were sceptical that the co-benefits would outweigh the risks. There is still a lot of uncertainty about Enhanced Weathering and people thought there were "too many maybes". Not everyone responds positively to assurances from scientists.

"We're speeding up the rate at which the ocean water is going to be more condensed instead of following the natural process. It would be better for the natural process to take its course."

"I just didn't like the fact about everything going into the sea. I love those documentaries and things and it's quite the unknown, we don't even know what's in there."

"Why would you, when you're trying to sequester CO_2, grind up rock, then spread it on a field, then put it in the ocean? It's just not a very feasible thing."

"It seemed quite an industrial process… I just don't see how any of it could be ecologically done."

Timescale

Most people are familiar with weathering processes and know that they naturally take place over thousands of years. The idea of 'speeding up' this process was seen by some as being unnatural and potentially having unintended consequences. However, others felt that this meant Enhanced Weathering could be a more long-term solution than some other proposals.

Health

There were not many major health concerns about dust from the rock spreading. A few people in the US were concerned about the safety of minerals being spread on crops that we eat.

Context matters

We started out by discussing Enhanced Weathering in terms of farms in the US and UK. However, it is also being tested with tropical agriculture, for instance in Malaysia where one of the project's field trials is located.

When we came on to discussing tropical applications, many people's attitudes shifted. People were concerned about social impacts, including whether workers would be treated fairly and safely. The tropical context also made people think of Enhanced Weathering at larger scale, which led to more concerns about ethical and environmental impacts.[xxv] Concerns about messing with nature came out much more strongly when we started discussing Enhanced Weathering in different environmental contexts, particularly rainforests and the oceans.[xxvi]

Image credit: pxfuel

Basalt is mined to make gravel and construction materials. Some of the rock for Enhanced Weathering could be produced as a by-product from these existing mines.

Box 2: Farmers' thoughts

Farms are an ideal place for Enhanced Weathering. They are large, managed and their crops might benefit from rock nutrients. We spoke to a group of grain farmers in Illinois to find out their thoughts.

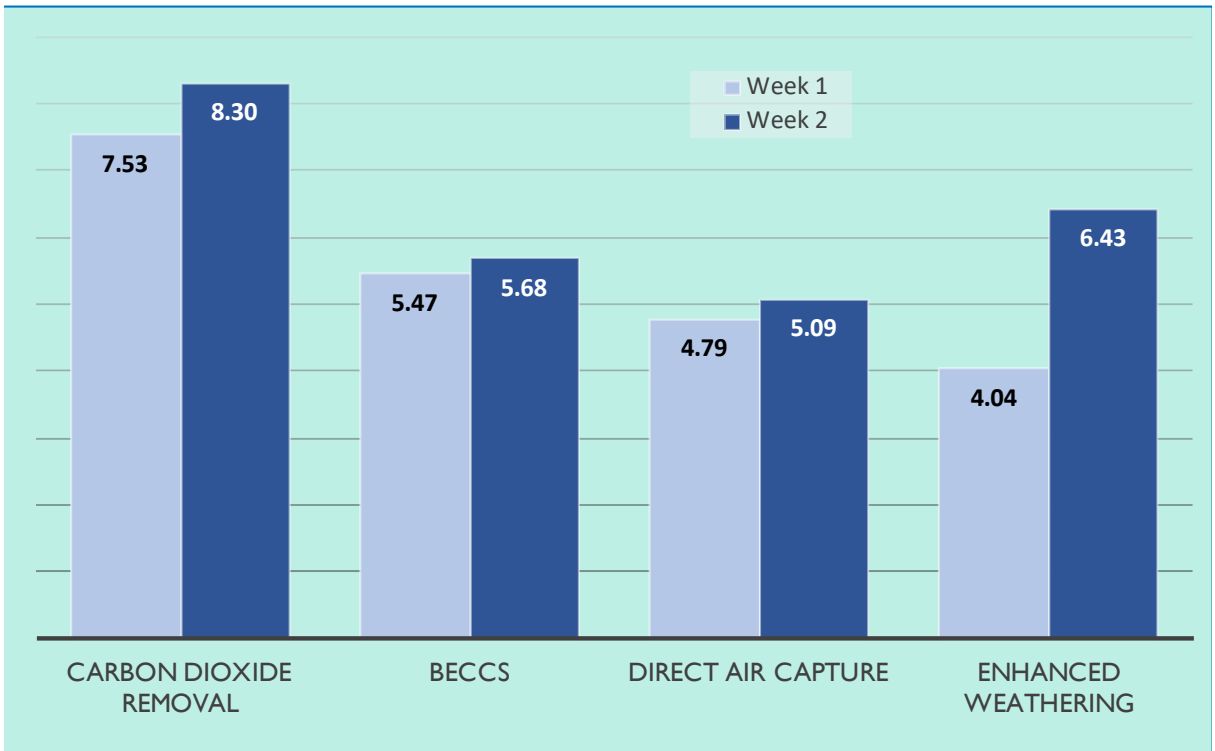
Farmers are obviously concerned about cost. The process would either need to be a similar cost to existing fertiliser techniques or they would need a subsidy. However, farmers are already using similar machinery, for instance to spread lime, and are generally familiar with the types of processes used for Enhanced Weathering.

Our farmers' group had strong faith in science and in technical expertise. This meant that they responded positively to some aspects which other groups perceived more negatively. Many farmers would be willing to try Enhanced Weathering if it did not reduce their income significantly. However, they would need more detailed and accurate information about the precise impacts on their crops, the precise impacts on their soils over time and the amount of CO_2 absorbed, as well as the costs.

Some farmers are interested in conservation agriculture, which is a range of techniques to improve farm soils in an environmentally-friendly way. In the future, Enhanced Weathering may stand a better prospect on farms if it is compatible with these techniques, particularly no-till agriculture and cover cropping.

More information makes people more favourable

During the second day of the workshops, we had an extended discussion about Enhanced Weathering and people's responses improved.[xxvii] This doesn't always happen; previous studies on fracking and geoengineering found that people often become less supportive of a technology as they learn more about it.[xxviii]



Workshop participants filled out a questionnaire at two stages in the workshop: at the end of week 1 (i.e. halfway through) and at the end of week 2, after the extended discussion about Enhanced Weathering. This chart shows the average (mean) scores, out of 10, for each technology.[xxix]

The main reasons for this improvement were:

- Discussing Enhanced Weathering in more detail, which made it seem more 'real' and generally having their concerns listened to
- The idea that techniques similar to Enhanced Weathering are already being used in some areas
- Information we provided about adding nutrients and alkalinity to soils and water
- Information we provided about the possibility of using by-products for the rocks, rather than digging new mines

The Energy Farm at the University of Illinois, which carries out research into crop science and agriculture, as well as Enhanced Weathering field trials

- Perceptions that it is being researched by trusted scientists, who are doing their best to improve the environment and to tackle climate change.[xxx]

"I was really against it until you said to me that these minerals would be neutral and would be a waste product, as opposed to a chemical produced thing."

"I'm already more comfortable. I know the work that the University of Illinois do… it's the fact that it's an educational institution that has a long-standing reputation."

"If it was proven. If they could, you know, demonstrate that it did make ocean water less acidic, then that's fine."

Policy Recommendations

For more detail, see the accompanying policy brief, available at www.lc3m.org

1. Pursue a portfolio of options

For many people, Carbon Dioxide Removal (CDR) is likely to be supported only as part of an ambitious package of policy measures to reduce emissions in the first place. This could help to ease concerns about CDR not tackling the root cause of climate change, or about it being a 'non transition'. Large-scale, engineered CDR technologies may be crucial for mitigating climate change, but reducing emissions in the first place must always take priority.

2. Stick to a coherent narrative for a sustainable future

People feel as though policy-making is currently missing a coherent narrative on the direction in which we wish to head. People are less likely to support CDR if policy gives mixed messages, for instance supporting high-carbon activities in some sectors and promoting low-carbon activities in others. A coherent narrative, across all sectors, will be vital. In the UK, the way the fracking controversy played out has made this even more challenging.

3. Remember that climate change is not the only goal

Most people feel that tackling climate change is crucial but not necessarily worth sacrificing other goals, such as human and environmental wellbeing, in the process. Climate experts have a tendency to 'fetishise' CO_2 and sometimes forget that most people see sustainability in a much broader way. Supporting CDRs which also generate non-climate benefits should be a priority.

4. Address temporal dilemmas

Our research showed that people see new CDR technologies as simultaneously too short-term and not short-term enough to tackle the urgent problem of climate change. Pursuing CDR alongside ambitious emissions reduction policies may help to reduce this dilemma. However, there is also a need for research to immediately identify and focus on the technologies which are likely to be scalable, in a safe and controllable manner, within the required short timescale for action on climate change. 'Overshoot' scenarios, where long-term CDR is used to compensate for higher emissions in the short term, have been shown to be highly risky and should be avoided.

5. Build trust and promote inclusive dialogue

If CDR is to be scalable, trust will need to be built and maintained. Two-way dialogue with publics, which listens to people's concerns and takes them seriously, is valuable even at a very early stage of the innovation process. All engagement processes must be inclusive, transparent, and ready to change or even abandon plans in the event that they turn out to be socially undesirable. Engagement should prioritise listening rather than talking; the overarching goal is not to educate people, but to learn from them and to amend plans accordingly.

Partner Institutes

Carl R. Woese Institute for Genomic Biology · Illinois · Cardiff University / Prifysgol Caerdydd · University of Southampton · UC Riverside · James Cook University Australia · SEARRP South East Asia Rainforest Research Programme · The Open University

Endnotes

i Wildfires like those pictured have been made more likely by climate change. Climate change has doubled the number of the riskiest fire days in California, and made the Australian wildfires in 2019 30% more likely. Goss, M. et al (2020) Climate change is increasing the risk of extreme autumn wildfire conditions across California, *Environmental Research Letters,* 15 (9)*;* Philips, N. (2020) Climate change made Australia's devastating fire season 30% more likely, *Nature,* doi 10.1038/d41586-020-00627-y

ii IPCC (2014) *AR5 Synthesis Report.* Intergovernmental Panel on Climate Change, Geneva. https://www.ipcc.ch/report/ar5/syr/.

iii These three ways of tackling climate change formed part of the introductory information we gave participants in our workshops. The full methodology can be found at Cox, E., Spence, E. and Pidgeon, N. (2020) Public perceptions of carbon dioxide removal in the United States and United Kingdom, *Nature Climate Change,* doi 10.1038/s41558-020-0823-z.

iv Minx, J., Lamb, W., Callaghan, M., Bornmann, L. and Fuss, S. (2017) Fast-growing research on negative emissions. *Environmental Research Letters,* 12, 3, 035007.

v Royal Society & Royal Academy of Engineering (2018) *Greenhouse Gas Removal*. London. Available at: https://www.raeng.org.uk/publications/reports/greenhouse-gas-removal.

vi Cox, E., Spence, E. and Pidgeon, N. (2020) Incumbency, trust, and the Monsanto effect: stakeholder discourses on Greenhouse Gas Removal, *Environmental Values,* 29, 2, 197-220.

vii In this report, where percentages are given (for instance in graphs), these are from the survey, which was nationally-representative in each country. Where quotes are given, these are from the workshop discussions. The survey did not ask people about BECCS or Direct Air Capture, therefore all information in those sections is from the workshops.

viii Cox, E., Spence, E. & Pidgeon, N. Public perceptions of carbon dioxide removal in the United States and the United Kingdom. *Nat. Clim. Chang.* **10,** 744–749 (2020). https://doi.org/10.1038/s41558-020-0823-z.

ix We have removed 'don't know', 'no comment', 'idk' etc. We have also removed 'carbon dioxide' and other responses which directly copied the question.

x See Technical Appendix for full methodology.

xi Although forests are popular and are considered more natural, one of the key constraints is that the carbon dioxide may only be stored for a short amount of time. When trees are cut down or burnt (for instance in a wildfire), the carbon dioxide they stored is returned to the atmosphere, where it continues to contribute to climate change.

xii Pidgeon, N. and Spence, E. (2017) Perceptions of enhanced weathering as a biological negative emissions option. *Biology Letters,* 13:4, 20170024.

xiii Macnaghten, P., Davies, S. R. & Kearnes, M. (2015) Understanding public responses to emerging technologies: a narrative approach. *Journal of Environment, Policy & Planning,* 1–19, doi:10.1080/1523908X.2015.1053110.

xiv This finding emerged from our workshops, when we discussed storage of CO_2 under the sea bed and when we discussed Enhanced Weathering processes which sequester CO_2 in ocean waters. We review public perceptions of ocean technologies in Cox, E., Boettcher, M., Spence, E. and Bellamy, R. (2021), 'Casting a wider net on ocean NETs', *Frontiers in Climate, 3.* https://doi.org/10.3389/fclim.2021.576294

xv Cox, E. & Edwards, N. (2019) Beyond carbon pricing: policy levers for negative emissions technologies, *Climate Policy*, 19:9, 1144-1156, doi: 10.1080/14693062.2019.1634509.

xvi 'Mitigation deterrence' is the idea that supporting Carbon Dioxide Removal technologies might reduce incentives to make timely, ambitious cuts in emissions, particularly on the part of policy-makers. Markusson, N., McLaren, D. & Tyfield, D. (2018) Towards a cultural political economy of mitigation deterrence by negative emissions technologies (NETs), *Glob. Sustain.* 1; McLaren, D. (2020) Quantifying the Potential Scale of Mitigation Deterrence from Greenhouse Gas Removal Techniques, *Climatic Change,* 162: 2411-2428

xvii Spence, E. and Cox, E. (2020) "Climate urgency dampens public acceptance of carbon dioxide removal". *Nature Springer, Behind the Paper blog series.* Available at: https://socialsciences.nature.com/posts/climate-urgency-dampens-public-acceptance-of-carbon-dioxide-removal.

xviii We conducted a factor analysis to show that the three questions relating to benefits could be grouped together in this way. This chart shows the mean average from the three questions. The role of climate change in benefit perceptions was demonstrated using a mediation analysis. See Cox et al (2020) 'Public perceptions of Carbon Dioxide Removal in the United States and United Kingdom' for full analysis and methodology.

xix The clip art images and the descriptions are the same as the ones we used in the workshops. We did not use photos or realistic images in the workshops or the survey.

xx Thomas, G., Pidgeon, N. & Roberts, E. (2018) Ambivalence, naturalness and normality in public perceptions of carbon capture and storage in biomass, fossil energy, and industrial applications in the United Kingdom, *Energy Research & Social Science* 46, 1–9.

xxi Cox, E., Pidgeon, N. and Spence, E. (2021) But they told us it was safe! Negative Emissions Technologies, fracking, and ripple effects in risk perceptions, *Risk Analysis,* Article in Press.

xxii Thomas et al (2018). Mabon, L. & Shackley, S. (2015) Meeting the targets or re-imagining society? An empirical study into the ethical landscape of carbon dioxide capture and storage in Scotland. *Environmental Values* 24, 465–482; Upham, P. & Roberts, T. (2011) Public perceptions of CCS in context: Results of NearCO2 focus groups in the UK, Belgium, the Netherlands, Germany, Spain and Poland, *Energy Procedia* 4, 6338–6344; L'Orange Seigo, S., Dohle, S. & Siegrist, M. (2014) Public perception of carbon capture and storage (CCS): A review. *Renewable & Sustainable Energy Reviews* 38, 848–863.

xxiii Upham & Roberts (2011) Public perceptions of CCS in context (op cit.).

xxiv An experimental study found that framing CCS in terms of 'dealing with a waste product' resulted in more positive attitudes than framing it as a climate change measure. Whitmarsh, L., Xenias, D. and Jones, C. (2019) Framing effects on public support for carbon capture and storage, *Palgrave Communications,* 5, 1.

xxv For most Carbon Dioxide Removal proposals, ethical concerns only really start emerging when they are proposed at large scale. Cox, E., Pidgeon, N., Spence, E. and Thomas, G. (2018) Blurred lines: the ethics and policy of greenhouse gas removal at scale, *Frontiers in Environmental Science,* 6.

xxvi The second day of our workshops focused solely on Enhanced Weathering. The in-depth discussions of this technique showed that context really matters for people's perceptions. The analysis from the second day is being written up for publication.

xxvii The improvement was statistically significant for Enhanced Weathering, but not for BECCS or Direct Air Capture. This suggests that it was the additional discussion of Enhanced Weathering on the second day, and the additional information we provided, which generated this improvement. The full statistical analysis, and full analysis of why people's attitudes improved, is being written up for publication.

xxviii Macnaghten, P. & Szerszynski, B. Living the global social experiment: An analysis of public discourse on solar radiation management and its implications for governance, *Global Environmental Change* 23, 465–474 (2013); Cummings, C. and Rosenthal, S. (2018) Climate change and technology: examining opinion formation of geoengineering, *Environment Systems and Decisions,* 38, 208-215; Howell, R.A. (2018) UK public beliefs about fracking and effects of knowledge on beliefs and support: A problem for shale gas policy, *Energy Policy*, 113, 721-730.

xxix The questionnaire asked participants the following questions: Would you like to see Carbon Dioxide Removal included as part of an overall strategy for reducing climate change risk? (1 = not include it at all; 10 = plays a major role); How do you feel about BECCS? (1 = very negative; 10 = very positive); How do you feel about Direct Air Capture? (1 = very negative; 10 = very positive); How do you feel about Enhanced Weathering? (1 = very negative; 10 = very positive).

xxx In Illinois, many participants saw the University of Illinois as a trusted actor, and liked the fact that they were carrying out field trials into this technique. The groups which increased their scores the most on average also voiced positive sentiments at the end about the workshops, the deliberation process, and the teams carrying out the research.

Funded by Leverhulme Trust Research Centre Award RC-2015-029

LEVERHULME
TRUST