SIX WAYS TO COOL THE PLANET

1. Capturing CO2 from ambient air

Humanity has proven remarkably adept at building machines that release carbon dioxide into the atmosphere, so might we be able to reverse this and build machines that remove it?

If we could develop a cheap, clean and sustainable method of scrubbing carbon dioxide directly from the air, and storing it somewhere safe, we could limit or even reverse climate change. This would allow us to treat the cause of global warming, rather than just disguising the symptoms.

‘Air capture’ is already possible with current technology, but would prove very expensive, given the low concentrations of CO2 in the air around us. However, scientists are currently working on a number of different designs for carbon-scrubbing technologies, with the aim of bringing the energy requirements and cost down. A high global carbon price would help the economics of air capture, which would provide a genuine and verifiable method of carbon offsetting.

Pros: minimal side effects; virtually unlimited potential.

Cons: very expensive, and very slow to work; a long way off large-scale deployment; still needs substantial R&D.

Effectiveness: High

Affordability: Low

Timeliness: Low

Safety: Very High

2. Ocean fertilisation

In areas of the surface ocean where there are sufficient nutrients, blooms of algae grow, drawing in carbon dioxide. When the algae die, a small amount sinks to the bottom of the sea, trapping that carbon in the deep ocean. Ocean fertilisation techniques involve adding nutrients to the sea where they don't occur in sufficient natural abundance, to encourage the growth of the algae, and so increase the absorption of CO2. These nutrients could be nitrates, phosphates or iron.

Of course, ocean fertilisation is not without its drawbacks: the potential for unexpected side effects on marine life is very significant; it is inefficient (because most of the plant material is rapidly recycled); it would be very slow to be effective; and it's likely to be quite expensive.

Currently, the dumping of such substances is also banned under the UN's London Protocol, except in cases of legitimate scientific research.

Pros: a carbon removal technique which would address the cause of climate change.

Cons: uncertain consequences on sea life; very slow and likely to be quite expensive

Effectiveness: Low

Affordability: Medium

Timeliness: Low/Very Low

Safety: Very Low

3. Enhanced weathering

Carbon dioxide is removed naturally from atmospheric air when it reacts with certain basic rocks to form soluble bicarbonates. This process occurs very slowly in nature (less than 1 gigatonne of carbon per year is removed from the atmosphere). It could be enhanced by mining large amounts of suitable rock, grinding it to increase the surface area, and spreading it over fields. In theory, applying $7km^3$ per year of the right kinds of rock would offset human emissions.

To give some context, that is roughly twice the volume of coal that's mined annually, and would cover several million square kilometres of land.

Despite the enormity of the scale of mining required, the science behind the process is quite well understood, and the carbon is eventually stored securely in the ocean or as carbonates. However, more research into the effects on soil would be needed before this could go ahead at scale. The mining and transport required would use large amounts of energy, and if this were provided by fossil fuels it would partially offset the effect.

Pros: very large potential for carbon storage in oceans and soils; few side-effects on the atmosphere.

Cons: very expensive, requiring substantial further R&D; slow to have impact; could have serious effects on local soil quality.

Effectiveness: High

Affordability: Low

Timeliness: Low

Safety: Medium to High

4. Marine cloud brightening

A fleet of ships roams the seas, spraying jets of seawater droplets into the air. The fine mist of seawater droplets evaporates, forming additional nuclei for the condensation of cloud water droplets. The effect is to brighten the stratocumulus clouds that occur naturally in abundance over parts of the world's oceans. These brighter clouds, in turn, reflect a little more sunlight back into space and so cool the planet. It is estimated that a fleet of 1,500 such 'cloud ships' would be needed to counter the effects of concentrations of atmospheric CO2double that of pre-industrial levels.

The process could be shut off quickly: if the cloud ships stop spraying, nearly all the seawater particles would rain or settle out of the atmosphere within ten days. However, the increased reflectivity would be limited, and would not be uniform around the world, which could result in changes to local weather patterns over nearby land masses. There could also be an impact on marine currents.

Pros: relatively quick to work, and could be switched off again quickly.

Cons: potential adverse effects on weather patterns and ocean currents; does nothing to counter other effects of increased greenhouse gas emissions such as ocean acidification; likely to be quite expensive.

Effectiveness: Low to Medium

Affordability: Medium

Timeliness: Medium

Safety: Low

5. Stratospheric aerosols

When Mount Pinatubo erupted in The Philippines in 1991, it blasted millions of tonnes of tiny reflective particles – sulphate aerosols – into the stratosphere. These encircled the globe on the stratospheric winds, reflecting away a small percentage of inbound sunlight and cooling the Earth by 0.5°C over the next couple of years. By deliberately injecting aerosols into the stratosphere, we could mimic such effects, and so reduce global temperatures in much the same way.

Deploying stratospheric aerosols would be likely to be cheap, could cool the Earth as much as we desired, and work quickly. A fleet of high-flying jets or a very long hose could deliver the aerosols to the upper atmosphere, where they would stay for a couple of years.

If this sounds too good to be true, that's because it probably is. The (predictable) potential drawbacks include uneven regional effects on weather, particularly

rainfall, possible ozone depletion, reduced direct sunlight and increased haze (and therefore fewer blue skies), as well as a raft of political and ethical issues.

Pros: likely to be very effective, quick acting and affordable.

Cons: effects would be unevenly spread; may affect stratospheric ozone and biological productivity, as well as modifying weather patterns and reducing sunshine.

Effectiveness: High

Affordability: High

Timeliness: High

Safety: Low

6. Orbital mirrors

Imagine trillions of tiny reflectors floating between the Earth and the sun. It certainly captures the imagination – but though it may sound like science fiction, the idea has received some consideration from serious scientists.

In theory, space mirrors might be the most elegant and desirable way to reduce incoming solar radiation. The reduction would be uniform around the world, and it would not involve the release of any chemical into the atmosphere.

However, while technically possible, the scale of the endeavour alone could well be prohibitive. To achieve the desired effect, we would need stacks of one million reflectors to be launched every five minutes for about 30 years. The deployment costs would be astronomical, but once in place the system would have a very long lifetime, giving us long-term control over the energy we receive from the sun.

As it would take decades to get the reflectors into space, this could never be a short-term response to a climate emergency. And as with other solar geoengineering techniques, it could also change regional weather in unforeseeable ways.

Pros: could be very effective.

Cons: would take decades to be fully operational, though the effects would start working within a few years; extremely expensive, with impacts unevenly spread.

Effectiveness: High

Affordability: Very Low to Low

Timeliness: Very Low

Safety: Medium

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