Climate crisis: seaweed, coffee and cement could save the planet

Greenhouse gas levels are on track to exceed the worst-case scenario. But, as world leaders meet in Paris for the UN climate summit this month, Tim Flannery argues that there are still realistic grounds for hope

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This month's meeting in Paris marks the 21st annual occasion on which nations have met to try to deal with the climate problem. After two decades of failing to agree, there is finally hope that a deal will be reached, with action to commence in 2020, and run until 2030. The world wonders whether Paris will be a success. But it is already a success, to the extent that the existing, unconditional pledges to limit greenhouse gas emissions made by nations in the lead up to the meeting are sufficient to shift humanity from the disastrous trajectory we are currently on. But the long failure of the negotiations to limit emissions gases will be felt way beyond Paris.

For the last decade, greenhouse gases emissions have tracked the worst case scenario of the Intergovernmental Panel on Climate Change. In 2009, the most recent year for which figures relating to all human-caused greenhouse gases exist, our emissions were around 50 gigatonnes of CO_2 equivalent. And since then they have only grown. (CO_2 equivalent is calculated by converting the warming potential of all of the 30-odd known greenhouse gases into the warming potential of a given volume of CO_2 - rather like converting various currency values into a single currency). One way of grasping the significance of 50 gigatonnes is to consider what would be required to get a small portion of our annual emissions - say, four gigatonnes - out of the air.

If we wished to remove this amount by planting trees, for example, humanity would need, over a 50 year period, to cover an area the size of Australia with forest, planting a New York State-sized area every year, and maintaining the growing trees in a healthy state. It's important to understand that, despite all of the CO_2 that would be drawn out of the atmosphere by the trees, the Earth's surface would continue to heat up. That's because we would be replacing bright grasslands and desert - which reflect sunlight into space - with a dark forest canopy, which would capture sunlight and turn it into heat. As this thought experiment illustrates, the best way to think about CO_2 by the gigatonne is that it is a volume of greenhouse gas that is significant in terms of planetary function.

The runaway emissions of past decades have pushed average global temperatures to around 0.9C (1.7F) higher than they were prior to the industrial revolution. This increase means that almost every aspect of the Earth's climate system is now influenced by humanity, and the consequences - droughts, heatwaves, megafires, melting glaciers and rising oceans - are now well understood. But if temperatures continue to rise, the consequences will not be linear, for climatic thresholds and tipping points will be reached and exceeded, leading to further destabilisation of the climate system.

Enough atmospheric greenhouse gas now exists to push global average temperatures to 1.5C (2.7F) above the preindustrial average, even if all emissions stopped today. At 1.5C of warming, Australia's Great Barrier Reef will be dead, many coastal areas will be covered by the rising sea, and the impacts on extreme weather will go from serious to devastating. At 2C (3.6F) of warming, the climate scientists warn, we will be at the threshold of climatic disruption so severe that it may threaten global civilisation. Despite this grim warning, fossil fuels will almost certainly be burned for decades to come. We are clearly coming to the climate problem haltingly, and very late. Despite this, I think that there is real hope that we can avoid a civilisation-threatening catastrophe. My optimism springs from two realisations: a new analysis by the International Energy Agency (IEA), and a realisation that a major new tool, which most people are hardly aware of, exists to combat climate change.

In early 2015 the IEA announced that in 2014 global emissions of greenhouse gases "stalled", while global economic growth continued apace. If emissions growth has finally decoupled from economic growth, humanity has passed a critical watershed many years earlier than anyone had dared hope. Two factors appear to account for this historic shift: the rise of wind and solar power, and greater energy efficiency.

Today, wind and solar power can offer electricity at a cost close to or equal to that of fossil fuels. As a result, investment in renewables has outpaced investments in fossil fuels for three years running. Renewables are self-evidently the future of electricity generation. The only question is how long it will take for them to replace fossil fuels. But the second factor, energy efficiency, has been equally important. For more than a decade now many of us have been changing light bulbs, insulating houses, cycling to work, and much more - all too often with little hope that it makes very little difference. But the IEA figures tell us that our billions of collective actions have added up to something massive. They have seen many developed nations pass peak oil and coal demand as our cities and farms become ever cleaner and more efficient. That this has occurred six years before the actions to be agreed in Paris is a cause for celebration.

Having said that, the decade of lost opportunity has made it all but impossible, using emissions reductions alone, for humanity to avoid breaching the 2C safety barrier. That lost decade established an emissions trajectory that has us aiming at 4C of warming by 2100. The actions committed to in Paris will probably put us on course for around 3C by 2100. That would be a welcome shift. But because energy systems take time to change, and greenhouse gases warm the Earth for decades or centuries after they're released, we're headed for 2C of warming pretty much no matter what we achieve in Paris, or in the two decades afterwards.

The realisation of this has prompted some to look at a "second way" of dealing with climate change, in addition to reducing emissions. Geoengineering involves dramatically interfering with the Earth's systems - for example by injecting sulphur into the stratosphere to cool the

Earth's surface. Other geoengineering proposals include fertilising the oceans with iron to prompt algal blooms, placing mirrors in space, and pumping cold ocean water to the surface so that it absorbs CO_2 and heat.

While such activities might seem distant, perhaps even unlikely, it's important to understand that much research is being undertaken in this field. In China alone, four research teams are investigating geoengineering possibilities. Already, research has demonstrated that injecting sulphur into the stratosphere is relatively cheap, and is instantly effective at cooling the Earth's surface. However, there is no global treaty regulating geoengineering activities and, as the risks of a changing climate grow, so will the temptation to geoengineer a way out of the problem. Yet the consequences are likely to be horrendous. Stratospheric sulphur, for example, is likely to alter weather patterns globally, to inhibit crop growth, and to lead to further destruction of the ozone hole as well as acid rain. The East Asian monsoon will almost certainly be influenced, along with the 1.4 billion people who depend on it for food. I believe that geoengineering solutions are only temporary - they do nothing to cure the underlying problem of greenhouse gas concentrations. Moreover, they all too often involve fighting a poison with a poison. No matter what the benefits to an individual country, unilateral efforts at geoengineering are likely to lead to conflict - and even war. And they cannot solve the underlying problem.

There is, however, a third, largely unrecognised, way of dealing with climate change. Sometimes confused with geoengineering, it involves the deployment of technologies, methods and approaches that recreate, enhance or restore the processes that maintained the balance of greenhouse gases prior to human interference, with the aim of drawing carbon, at scale, out of the Earth's atmosphere and/or oceans. It's what plants, and a fair few rocks, do. This definition is strictly functional. If an approach is found to damage the Earth's systems, it should be considered geoengineering. If it strengthens it, it's a "third way" solution. The third way of addressing climate change has the potential, I believe by 2050, to make a very large difference to our climate future.

There are two routes within the third way - biological and chemical. Biological methods involve the removal of CO_2 from the atmosphere or oceans via photosynthesis, and then storing the captured carbon in a variety of forms - from living forests to charcoal and plastics, or locking it deep in the Earth's crust. Chemical removal options use the weathering of rocks, or artificial means, to capture atmospheric carbon, then sequester the carbon in a variety of places.

The energy required to drive the biological processes is free, being provided by the sun, via plants. This is a great advantage, but its flipside includes fundamental limits. We are already placing great demands on the biosphere for food, materials and space to live, and there are ways that the biological measures could do more harm than good. For example, if carbon-sequestering monocultures such as corn or sugar cane were used too aggressively, or if we relied too much on locking up carbon in biological stocks that may be destined to degrade, the long term consequences could be severe.

But many options, including reafforestation and biochar production, offer better ways forward.

Biochar is a mineralised form of carbon made from plant matter. It takes many forms, depending on what it's made from, and the temperature and speed at which it's made. Many types of biochar can be added to soils in ways that give additional benefits, such as moisture and nutrient retention. Despite its promise, the biochar industry remains in a very early stage, and would need to expand a thousand-fold before it was capturing a gigatonne of carbon per year.

The most exciting, if least well understood, of all the biological options involve the marine environment. Seaweed grows very fast, meaning that seaweed farms could be used to absorb CO_2 very efficiently, and on a very large scale. The seaweed could be harvested and processed to generate methane for electricity production or to replace natural gas, and the remaining nutrients recycled. One analysis shows that if seaweed farms covered 9% of the ocean they could produce enough biomethane to replace all of today's needs in fossil fuel energy, while removing 53 gigatonnes of CO_2 (about the same as all current human emissions) per year from the atmosphere. It could also increase sustainable fish production to provide 200kg per year, per person, for 10 billion people. Additional benefits include reduction in ocean acidification and increased ocean primary productivity and biodiversity. Many of the technologies required to achieve this are already in widespread use, if at a comparatively minuscule scale.

The chemical pathways differ from the biological ones in that they all demand manmade energy, either via electricity or the direct burning of fossil and other fuels. This is expensive, and until low carbon, renewable sources become widespread, it has the potential disadvantage of adding to the problem that it is trying to solve. On the other hand, many of the chemical technologies offer the advantage of both storing the carbon securely and creating something useful.

One example of a chemical pathway involves capture of CO_2 by accelerating the weathering process of silicate rocks. This process occurs in nature, but is accelerated by breaking large rocks into smaller pieces and exposing them in situations where they will weather quickly. Between 3.6 and 5.1 gigatonnes of rock a year is required to sequester a gigatonne of atmospheric carbon, at an estimated cost of between £15 and £80 per tonne of CO_2 removed.

A Dutch company has developed a roofing product with a layer of silicate rock that reacts with rainwater to remove and permanently store atmospheric CO_2. Another company has a carbon negative lime-replacement product for soil remediation. Other proposals include the construction of monuments or public recreation areas, or artificial reefs for tourism and fishing purposes, using silicate rocks, or even using silicate rock fragments as a replacement for conventional sand in beach replenishment. Grains of silicate rock might also be used for constructing ventilation systems that will control CO_2 levels in buildings during the day; or they might be used to grow plants that hyper-accumulate nickel, or for producing magnesium carbonate spring waters similar to those that naturally occur in springs across Europe near silicate rock deposits. It's even been proposed that silicate rock carbon-capture devices be installed in ship's engines, where they would capture the CO_2 in emissions and turn it into a carbonate that, if released into the ocean, would lead to the removal of additional amounts of CO_2 from seawater.

Cement manufacturing offers another option. It contributes around 5% of our current greenhouse gas emissions. But it turns out that there are ways of making a cement that actually absorbs and sequesters CO_2 over long periods. Carbon-negative concrete is already being manufactured, and its producers claim that it is stronger, more durable, more flexible, and that it costs less than conventional concrete. But because it does not have a long track record, engineers are reluctant to use it. If this nascent industry is to sequester a gigatonne of carbon (the equivalent of 3.66 gigatonnes of atmospheric CO_2), carbon negative concretes would need to make up 80% of the world's production.

Carbon-negative plastics offer a potential solution for storing CO_2 captured from the air. One method combines air with methane-based greenhouse gas emissions to produce a plastic that its manufacturers claim can compete with oil-based plastics on both performance and price. From chairs to automotive parts to thin films, the material has already been trialled and proven to be equal or superior to plastics sourced from fossil fuels. But the world's annual plastic use would need to quintuple, with all of it coming from carbon-negative technologies, in order to sequester a gigatonne of carbon a year.

Yet another approach is being tested in Germany, where a team of researchers is transforming CO_2 into complex hydrocarbons using electricity. The basic approach involves providing CO_2 with energy, in a similar fashion to what happens in plant cells. Professor Maximilian Fleischer of Siemens says: "On windy and sunny days, Germany already has more electricity generated from renewable sources than it needs. What it lacks is sufficient energy storage capacity ... However, if the electricity were fed into photosynthesis modules it could be used to produce valuable chemicals. This would help to reduce demand for petroleum and thus cut greenhouse gas emissions. What's more, human beings will have incidentally managed to imitate the most productive chemical process on Earth. The dream of operating biochemical factories efficiently with sunlight could become a reality."

Currently, all of the chemical technologies outlined above require the use of energy - in most cases electricity - and it's hardly worthwhile using "dirty electricity" to capture atmospheric carbon. But as Fleischer notes, the wavy baseload caused by the varying generation of clean wind and solar electricity will at some point change all that. The point is that electricity is always available, and at times is excess to demand. Once wavy baseload comes to dominate Germany's electricity network, excess electricity can be used to capture and sequester CO_2.

Carbon nanofibres and nanotubes can be used to make very light, very strong, materials. Their potential use in everything from transport to housing and on to medical technologies is huge. But they are currently prohibitively expensive. In August a company announced that it had found a way of manufacturing carbon fibres directly from atmospheric CO_2 - at a fraction of the cost of existing production methods. This breakthrough is hugely exciting, as it opens the door to carbon fibres replacing emissions–intensive steel and aluminium at the same time that it draws CO_2 out of the atmosphere. It is difficult to imagine the technology drawing a gigatonne of CO_2 out of the atmosphere any time soon, but who knows where it will lead in future? In September, Korean researchers announced an even more amazing innovation. They invented a method for modifying used coffee grounds so that they store atmospheric methane - a greenhouse gas 60 times as powerful as CO_2 over the short term. With such breakthroughs occurring on a monthly basis, the possibilities of the third way are looking ever more crucial to our future.

Some third-way technologies require a repository for vast volumes of CO_2, and this is prompting a new look at carbon capture and storage (CCS). When applied to coal-fired power plants and storage in land-based rocks, CCS looks like a failed technology. It's just too expensive, and the buoyant gas is at risk of rising through the rocks. But CO_2 behaves very differently in marine sediments in waters 3,000 metres or more deep. Although stored only a few hundred metres into the sediment, it remains in liquid form, and over time natural chemical processes turn it into a stable solid hydrate. While research is at an early stage, it does suggest that the option should be examined further, especially if seaweed farming takes off.

Another intriguing proposal for the geosequestration of CO_2 concerns the potential capture and storage of the gas in the Antarctic ice cap. It turns out that conditions over the Antarctic plateau are so severe that the storage of solid CO_2 (dry ice) might be possible. At sea level, CO_2 freezes at -78.5C (-109.3F). The Antarctic ice cap has an average elevation of around 2.5 kilometres, and temperatures of -89.2C (-128.2F) have been recorded at Vostok Station. At this temperature CO_2 freezes out of the air and begins to accumulate as snow, but changes back to a gas quickly when temperatures rise. The average temperature over the interior of the Antarctic ice cap is -57C (-70.6F), so in most weather conditions only around 30C of cooling would be required to cause CO_2 to fall out of the air as snow, and begin to accumulate.

Researchers propose building a series of 100-metre-cubed refrigeration chambers high on the ice cap. Air, cooled with liquid nitrogen to -78.5C, would cause the precipitation of about 40cm of CO_2 snow per day. All of the other components of the air would remain in gaseous form. The snow could be stored in pits in the Antarctic ice, and covered with ice and natural snow to prevent its loss on exposure to the slightly warmer air. The researchers estimate that only 16 1,200-megawatt wind plants (less wind power than currently exists in Germany) could provide all of the energy required to drive 446 such cooling chambers. And that would be enough to capture and store one gigatonne of CO_2 a year.

Antarctica is a windy place, and wind power is already in use at research stations there. Moreover, an existing global treaty provides a framework for scientific cooperation and international governance. One objection to the proposal is that Antarctica is the Earth's last continental-scale wilderness. Many would be reluctant to see large refrigeration cubes and wind farms scattered over its surface. But it seems to me that these objections share much with those of people who object to wind farms in the countryside on the basis that they don't like looking at them. As the climate problem grows, such objections will surely need to be reevaluated.

What other possible downsides might there be to storing CO_2 ice in Antarctica? One potential problem is that the concentration of CO_2 in the air over Antarctica might become greatly reduced, and this could affect the surrounding ocean, or indeed the southern hemisphere as a whole. And it's possible that the very cool air might affect global atmospheric circulation. Both outcomes are easily investigated with climate modelling, and this should be done. Indeed, even simple observations of what happens when air temperatures drop below -78.5C naturally would be highly useful in understanding the potential effects. In any case, CO_2 levels could be kept within the historic range (back to 1800) experienced over Antarctica, and since the atmosphere mixes readily, the local CO_2 depletion would not last long after the plant slowed down.

There is also the risk of CO_2 escape, if the ice cap were to warm. The conditions under which such a release might occur requires investigation, though they are extremely unlikely even on the 1,000-year timescale. Conversely, if we take a long view and examine a future Earth threatened with an ice age, the trapped CO_2 could be exposed and allowed to warm the atmosphere.

The cost of building the proposed infrastructure in Antarctica is very difficult to estimate, but in today's world is likely to be huge. Rough cost estimates of up to a trillion dollars might be conservative. But technologies and cost structures change, and with the project unlikely to be seriously considered before 2050, the situation may then be very different. If the technology, functionality and economics of the proposal became increasingly robust, it's not difficult to imagine that this might lead to the first globally crowd-funded project to save humanity's future.

While these possible applications of geological storage of CO_2 may seem unwarranted to some, we must calibrate that against the dangers of living with 450 parts per million (ppm) or more of CO_2 in the atmosphere for a century or longer. Whether that danger becomes a reality will be determined by the success of our efforts in reducing carbon pollution. In coming decades the idea of storing CO_2 at the South Pole or deep in the ocean's sediments may not look so risky after all.

It's hard to avoid the conclusion that the boom in third way technologies will result in a tech revolution far deeper and broader than that provided by wind and solar. If we discard highly speculative possibilities such as seaweed farming and capture of CO_2 over Antarctica, a conservative estimate of the third way's potential to capture atmospheric CO_2 is that, by 2050, it could be drawing down around 15 gigatonnes per year – a little less than is needed to reduce atmospheric concentrations by 1ppm. If that sounds like science fiction, just consider what nuclear, jet-age 1950 would have looked like to those living in 1915.

It is impossible to know which of the many third way technologies and approaches might prove successful. But we do know what problem those living 35 years from now will be struggling with: the immense burden of atmospheric CO_2 will not go away by itself. Instead, it will be forcing our climate into an ever more unstable and undesirable state. And that means that some of the third way approaches are likely to be in the frontline of the future battle to stabilise our climate.

• *Atmosphere of Hope* by Tim Flannery is published by Penguin.

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