A critical pathway for a manageable future for humanity

Stewardship towards international consensus for urgent global action on climate change
But now time is out of joint. Human-caused climate change has run down the clock and soon there will be no time left to meet the goals set by the Paris Agreement. What we do in the next five to ten years will determine the future of humanity for the next millennium.

This is why we have formed the Climate Crisis Advisory Group: to deliver cutting-edge science at breakneck speed.

By putting expertise directly into the public domain, our aim is to reach the public and civil society as well as the financial sector and policymakers’ decision processes.

We are not just saying ‘this is the state of the global climate’. We point to necessary and achievable options for the global response from governments, companies and the public.
The world has an interconnected weather system that ebbs and flows across continents and oceans. As the impacts of global heating play out, the whole planet is subjected to new, chaotic and extreme weather events. Many of the extreme weather challenges of recent years – fires, droughts, floods, sea level rise, food production pressures – are the direct result of this global shift. But these are ‘only’ warning signs: our planetary situation will get much worse without urgent and focused intervention.

If a manageable and equitable future is to be achieved, simultaneous action is required along three axes. We must pursue the 3R’s for mitigation of climate change, each with equal vigour:

**REDUCE** emissions urgently, deeply and rapidly, while ensuring an orderly, just transition;

**REMOVE** CO₂ from the atmosphere in vast quantities;

**REPAIR** broken parts of the climate system, starting with the Arctic, to try and reverse local changes and stop the cascade effects of those changes through global climate systems.
The need for resilience

Even with concerted efforts to Reduce, Remove and Repair, human societies and ecosystems will need to adapt and build Resilience to the inevitable impacts of a changing climate. Pursuing Climate Resilient Development involves working with communities and employing best scientific evidence to live well in a warmer world.

Adaptation measures for resilience should be developed to be fair and inclusive of all citizens, local and indigenous communities, and groups who are the most vulnerable. Climate Resilient Development takes place in close connection with the 3Rs for mitigation. Scientific evidence and long-held indigenous knowledge point to ways for adapting to rapidly changing weather patterns. CCAG will gather and disseminate evidence-based insights to the public and decision-makers to support and accelerate systematic Climate Resilient Development across the world.

CCAG’S guiding principles

We are a group of leading international climate scientists who have come together to provide a new avenue for discussion and engagement. We are CCAG.

- CCAG has been created in response to the escalating climate crisis: the pace and accessibility of our communications must be in line with the scale of this crisis. The publication of scientific papers, reviews and reports takes anything from several months to many years. CCAG is nimble. Speed, solution-orientation, and strong accountability are central to what CCAG does.

- CCAG will hold nations and organisations publicly accountable for their promises.

- CCAG has depth and breadth. Its 15 members are all acknowledged as experts in different and crucial aspects of the climate challenge, with experience amassed over many decades and an international reach spanning every global region.

- CCAG makes clear recommendations, built logically from the expertise of its members.

- CCAG is without vested interests. Its unaffiliated standing allows it to engage and inform across the widest global landscape.

- CCAG is committed to shining a light on places and people that are often marginalised, such as less developed and developing regions, indigenous peoples and traditional and local communities.

- CCAG emphasises the urgent demand for institutional arrangements and systemic structures that will secure trust, accountability and safety in a rapid-response process.

- CCAG’s approach involves changing the global agenda via civic engagement; hosting public conversations with deep scientific backing, and empowering citizens to make informed demands for change.

- CCAG cares about global impacts; but is concerned about the lives of real people, the importance of credible science, and promoting ‘made in the region’ solutions.

- CCAG has no particular geography; it uses knowledge to push for change globally, regionally and at a community level.
On governance

Across the 3R’s, participation and consent from the outset by local and indigenous communities is fundamental, especially if actions take place in their home areas or have an impact upon them. And if financial benefits flow from investment in marine biodiversity and GHG removal, for example, those benefits (such as improved fish-stocks, enhanced bio-diversity supporting tourism, and so on) must be shared locally and equitably. Governance structures must secure direct benefits for communities without reliance on distribution by supra-national bodies or by the mechanics of national economic policy.\(^2\)

Small-scale studies must be transparent, carefully regulated and monitored; they must also be positively accommodated in new regulatory arrangements.

A new governance system must include:

- Local representation, at community level, from the outset.
- Recognition that responsibility for damage is linked to responsibility for the costs of repair.
- Development of appropriate fiscal and regulatory policies to accelerate mitigation.
- Participation of all key stakeholders, including the financial sector.

\(^2\) Indigenous Peoples and Local Communities are directly managing around 17% of the carbon stored in forests. They rarely receive direct funding, and there is a clear, massive funding gap for securing of customary land rights. There is good evidence that land-right security enhances forest management by IPLCs. This is explained in the CCAG report ‘Aftermath’ following COP26, page 13. https://www.ccag.earth/s/CCAG_Reflecting-on-COP26.pdf
To help restore climate stability, the emission of CO$_2$ and other greenhouse gases (such as methane) into the Earth's atmosphere must be drastically reduced from the current level of more than 40Gt per year, consistent with an ordered, rapid withdrawal globally from fossil fuels.

Reducing the concentration of CO$_2$ in the atmosphere requires an immediate reduction of the sheer volume of CO$_2$ being produced by human activities all over the world. If the 1.5°C target is to have a fighting chance of being achieved, we must reach zero emissions in the next 25 years. This rapid and radical reduction of emissions must also be fair.

Our commitment

- Wherever possible, CCAG will spotlight examples of extreme weather events and explain any links to climate change, global warming and climate systems. It will also highlight effective or ineffective actions taken by different groups to reduce emissions.\textsuperscript{3}

- CCAG will speak to policymakers, civic society groups and individuals, COP workers and media. In addition, CCAG members will accept invitations to attend private meetings where that is the most effective way of supporting policy makers or civil society.

- Our public discussions, podcasts and reports will remain freely accessible to all. As well as guiding decision-makers, our aim is to empower citizens to make the demands that will help deliver the reductions in greenhouse gas emissions that are urgently needed.

- CCAG messaging is evidence-based and realistic but will focus on what can be done. Many proposals to reduce emissions deliver significant personal, societal, and environmental benefits, as well as energy security.

- CCAG commits itself to securing the presence of less-heard, poorer, or more marginal participants at every discussion. CCAG members include those who act with or represent marginalised groups.

- CCAG will establish a programme to capture, track and report on the progress of CO$_2$ emissions-reduction pledges made by large emitters, at a national and sector level. Formal commitments will be taken into account, but so will promises made outside of formal undertakings such as the Paris Agreement. No country should be able to evade accountability by taking its commitments outside formal international processes.

- CCAG will monitor and comment on policy and fair and just reduction, removal and repair approaches. CCAG will always reflect on the social impacts, as well as techno-economic aspects, of emissions reductions efforts.

A concerted effort to reduce emissions to net-zero across the world by 2050 may still not be enough to secure a manageable future for humanity. This has led to a set of assumptions that are captured in the idea of a Carbon Budget (see Carbon budgeting, page 13). This analysis confirms that humanity is already on track to ‘borrow’ emissions from the future, and therefore must take steps to ‘repay’. Those steps involve CO$_2$ Removal and climate Repair.

The need for speed

The pace and scale of the change required is unprecedented.

We can learn from the great surges that have been made in human development in the past, such as the new technologies and industries that catalysed the Industrial Revolution. Rapid transformation can happen when aided with supportive policy, regulatory frameworks and protocols.

Trust between the ‘Global North’ and the ‘Global South’ must be restored

It will not be possible to reach net-zero by 2050 without international cooperation between all countries, and this will not be possible without the restoration of trust, especially between the historically wealthy Global North and the nations of the rest of the world.

Rich countries have benefitted from the last 200 years of emissions, but they have been slow and unreliable in reducing their emissions. Against this troubled historical background, recent unmet pledges of climate finance and the deeply concerning situation in Ukraine, trust in the Global North is rightly low. This has been compounded by the refusal of wealthy countries to contribute sufficiently to addressing and adapting to the consequences of climate change in the poorest areas, as well as continued underinvestment in technologies to reduce or remove GHGs. In effect there is a double debt: the debt of insufficient investment and roll-out in technological solutions; and the debt of failing to commit finance, and thus delegating the financial burden of adaptation to poorer nations already bearing the brunt of climate externalities.

Absence of trust, exclusion of vulnerable or forgotten communities, and under-valuing of local knowledge or citizens’ perspectives, are difficult legacies that must be addressed if future global action is to have an impact.
Additional efforts to test and deploy GHG removal solutions must start today and the target must be to limit temperature rise to 1.5°C - and to reduce from there.

Removal of GHGs at scale is vital for the world and its future stability. Already, at 1.2°C above the preindustrial temperature, we are faced with the prospect of rising sea-levels of well over 1 metre by 2100 and possibly over 5 metres by 2300 under high emissions scenarios. Moreover, methane emissions from the thawing permafrost regions of the Arctic Circle could lead to temperatures considerably greater than 1.5°C above the pre-industrial level. All of this arises from what is happening, right now, in the Arctic Circle.

The achievement of GHG removal at scale will give a clear chance of a manageable future, with reason to hope that new tipping points will be avoided – such as the loss of the Atlantic Meridional Overturning Circulation (AMOC), the total loss of Himalayan glaciers, degradation of the Amazon forests, and overwhelming sea-level rise for many coastal cities, island nations and much of South East Asia.

Options for Carbon removal will depend on regional context and available resources. Some options will fit into industrial processes, such as carbon-neutral or carbon-negative building materials. Others belong in rural or less-developed areas, such as soil management for CO2 capture, or reinstatement of wetlands, tropical forests and mangrove forests to reduce methane emissions and recapture GHGs already lost by their removal. In places such as Africa, where the carbon footprint is low, nature-based solutions will feature quite prominently.

There is a very clear prospect that the oceans can capture permanently tens of billions of tons more CO2 today, regenerating ocean fish and mammal stocks in the process. In this way ocean biodiversity and climate change are tackled simultaneously.

Duration of carbon storage is important. Many carbon off-set schemes, implemented by airlines, for example, make assumptions about the future health and maintenance of forests, which are acknowledged to be difficult to judge - especially in the absence of any consistent and transparent, globally agreed, accountability mechanisms. Climate change itself threatens forests and their efficiency as natural sinks. Such off-set schemes, at worst, may be no more than greenwash. Action is needed to close off opportunities for industries to ‘go through the motions', whether for reasons of conscience or profit, rather than seriously to curb emissions.

Carbon removal that is inherently reversible must be considered temporary – and regulated and transparently managed to stay out of the global atmosphere. In parallel, permanent storage options must be expanded. They may not add to other aspects of environmental gain, but they provide storage certainty and opportunities for certification of removal. This may assist the development of global Carbon Pricing schemes and regulations.

If Removal fails, then Repair (see below) will take longer, the benefits of Reduce may be lost, and we will be forced to rely more heavily on building Resilience: a potentially catastrophic scenario.

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5 ‘In ‘Twenty-first century sea-level rise is likely to exceed IPCC projections for strong-warming futures’ (2020), Siegert et al explain how the IPCC report for sea-level rise of between 0.61 and 1.10 at over 4°C warming is likely to be exceeded. IPCC acknowledges that greater rises are possible through mechanisms not fully incorporated into their models. Observed ice-melt has exceeded IPCC expectations in recent observations. There is a chance that sea-level rise to 2100 will fall within the IPCC range, but almost no chance that it will be below the IPCC projections. There is a considerable possibility of sea-level rise exceeding the IPCC range. https://www.sciencedirect.com/science/article/pii/S2590332220305923


7 See page 12 for details about Marine Biomass Regeneration
As damage done to the Arctic by rapid climate change is causing weather patterns to shift all over the world (see The case for Arctic repair, page 15), it is the most urgent area for repair.

A clear-sighted view recognises that damage to the global commons\(^8\) has been caused by wealthy nations over many years. Those nations owe it to everyone to fix things. But they must approach their duty with humility, care and a commitment to creating safe governance, building trust as they go.

Indigenous and local community members must be drivers and partners in any repair programme. Their willingness to engage will be a litmus test for the whole process. Building these new partnerships is the foundation of new governance structures.

There are huge gaps in existing international regulatory frameworks. Some existing frameworks fail to support climate-preserving actions.\(^9\) New approaches are needed. Building new frameworks is urgent and essential.

Small-scale studies will be the first step in repairing the Arctic. Biomimicry may well emerge as the safest first approach. Early studies of climate repair should be incrementally scalable – so they can be paused or reversed at any point. Transparency and good governance will consolidate trust in the process.

\(^8\) We use the term ‘Global Commons’ to denote a part of the world’s ecosystem that is – and should be – regarded as belonging in common to all of the planet earth, including all of humanity. Nobel Laureate Elinor Ostrom was passionate about the potential for identifying and managing ‘the commons’ at all levels of human society. See for example her book ‘Governing the Commons’ (2015) https://www.cambridge.org/core/books/governing-the-commons/A8BB63BC4A433A50A3FB52EBB897D5.

\(^9\) International regulations, such as the London Protocol have the potential to impede legitimate studies for regenerating ocean biomass, for example. See the National Academies of Science, Engineering and Medicine (2021) page 39 for a discussion https://www.nationalacademies.org/our-work/a-research-strategy-for-ocean-carbon-dioxide-removal-and-sequestration.'
Focus on: Marine biomass regeneration

Marine biomass regeneration is an example of biomimicry in Climate Repair and CO₂ Removal. The aim is to recreate the deep-ocean conditions in which whales used to thrive before the mass eradication of whales by humans. Whales are now understood to be drivers of very healthy marine ecosystems, as well as indicators of biodiversity in their own right. Small scale regeneration of ecosystems to bring whales and other marine species back to areas that are currently marine deserts will increase biodiversity, enhance fishing grounds, and create new CO₂ sinks.

Marine biomass regeneration offers the possibility of incremental scaling. If the effects are not positive, it will be easy to stop the processes. If successful, there is a chance of restoring marine populations in all its biodiversity alongside CO₂ removal equivalent to tens of Gt – a chance that should not be missed.10

10 It is difficult to calculate exactly the full potential impact of marine biomass regeneration, based on the current available data. However, the American Academies of Science (2021), in their plan for a research strategy, show that several Gt of CO₂ per year from phytoplankton can be sequestered to deep ocean – with estimates in relevant model studies ranging from 1 to 5 Gt per year via addition of limiting nutrients. These estimates are likely to be an underestimate of the potential for carbon sequestration, since they exclude carbon from regenerated fish and whale populations as well as other elements of a healthy ocean ecosystem. https://www.nationalacademies.org/our-work/a-research-strategy-for-ocean-carbon-dioxide-removal-and-sequestration See Pershing et al (2010) and Savoca et al (2021) for insights into the role of whale in sequestering carbon. https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0012444 and https://www.nature.com/articles/s41586-021-03991-5
In the Paris Agreement, countries agreed to an objective of “holding the increase in the global average temperature to well below 2°C and pursuing efforts to limit the temperature increase to 1.5°C”; this goal was affirmed in the Glasgow Pact signed at COP26 in November 2021. These temperature rises can be associated with a “carbon budget” that is based on the near-linear relationship between the global temperature increase and cumulative CO₂ emissions.

The IPCC provides regular updates on what level of emissions remain to be in line with these temperature rises. The latest assessment from the IPCC indicates that around 320 billion tonnes (Gt) of CO₂ can be emitted from the beginning of 2022, to have a 67% chance of staying below 1.5°C, and 420 Gt can be emitted for a 50% chance. This CO₂ ‘budget’ is a key factor in determining the necessary pace of emissions reduction, and when the world will need to achieve net zero emissions, if we are to limit the temperature rise to 1.5°C. For example, a near-50% reduction in CO₂ emissions from current levels by 2030, and net-zero CO₂ emissions by 2050, is needed in order to limit the temperature rise to 1.5°C with a 50% probability.

There are a large number of uncertainties that impact upon estimates of the remaining carbon budget. The figures above assume strong action on non-CO₂ emissions, no big shift in the AMOC, and that we do not cross any unexpected tipping points; in other words, no surprises. Further, this would only provide a certain probability of remaining below 1.5°C: there is a possibility that the remaining carbon budget for limiting warming to 1.5°C is already zero.

Even with very strong, committed action to reduce emissions from now, the Arctic will continue melting. In the Arctic there is a series of potential tipping points, each causing chaotic weather and climate patterns. We already see the distortion of the Polar vortex and Jet Stream bringing ‘never before’ weather events across the globe. IPCC AR6 says ice on land is irreversibly melting. Further changes which threaten the world, and could become irreversible, include weakening of the AMOC system. Any one of these represents a ‘tipping point’ if it becomes irreversible, with consequences that will ripple out very rapidly across the whole planet.

Feedbacks in climate crisis events also matter. As permafrost thaws, explosive releases of methane happen in the Arctic. These explosions increase GHG concentrations, speeding up heating and thawing processes. Similarly, melting sea-ice transforms ocean
surfaces from reflective to absorbing states. Ocean heating speeds up, and ice melts more rapidly. Such feedback loops accelerate progress towards tipping points: the chance of slowing or stopping changes slips away.

Given the importance of backing away from tipping points, and recognising the underlying logic of a remaining carbon budget, removal of GHGs from the atmosphere at scale is urgent. Net zero emissions by 2050 is crucial, but after that the world must get onto a ‘beyond net-zero’ pathway to ensure that GHG concentrations are systematically reduced year on year until a safe level (of about 350 ppm CO₂) is restored.

Removing GHGs will include technological removal. All removal is needed **in addition to** deep and rapid emissions reductions, and achieving global net zero emissions by 2050. No one country can be allowed a ‘get out’ by imagining that GHG-removal is instead of emissions reduction. We must dispel any perception that ‘if we plant 1 trillion trees’, the problems are all solved.

The central implication is that a fair and orderly energy transition away from unabated fossil fuel use to an emissions-free energy future needs to be set up immediately.

A budget, by definition, must be divided; who is allocated what from the collective pot? It makes sense to think of emissions reduction as a nation-based activity, because that is where action can be managed. The allocation of the remaining carbon budget must encompass fairness, equity and capability.

GHG removal is better understood as a global ‘public good’, like disease eradication efforts, such as vaccines. In light of the uneven distribution of the covid vaccines globally, however, this analogy does not offer much confidence that fairness will automatically be a guiding global principle. Therefore, fairness, equity and capability must be central to any global conversation and decisions about how the carbon budget is allocated and used.

In the energy transition and GHG removal challenges, investment needs to step up. Investment in clean energy technologies over the period to 2030 has to be three times larger than annual levels seen in recent years to set the world on course for net zero emissions by 2050. There is some sign that some central banks are waking up to this – but wealthy nations must play their part. By the time of COP28 in 2023, climate financing for developing countries and communities in need must be a key part of the international agenda.
The impacts of rapid heating within the Arctic Circle – now at four times the global average – are confirmed as ‘likely an important cause of a chain of processes’ behind ‘never before’ dynamics.\textsuperscript{13} The Jet Stream is usually a steady, polar winter phenomenon of the northern hemisphere; now it is distorting and spreading as shown in Figure 1.

At the frontier of the distorted Jet Stream the temperature is cold, whilst inside the distorted loop temperatures can rise beyond anything experienced before. This phenomenon has caused extraordinary extremes around the world: for example, snow in Texas with temperatures below -16°C; a heatwave in Western Canada with temperatures of 49.6°C in Lytton, British Columbia.

As global weather patterns continue to become more chaotic, climate change driven from the Arctic will also bring large sea-level rise over many decades, extreme temperatures in the tropics, challenges to farming and food production, and threats to human life from massive loss of property and human habitat. There will be extreme heat, floods, spread of new diseases, potential for political instability and breakdown of the global economy.

What happens in the Arctic does not stay in the Arctic.

The case for Arctic repair

The rapidity of change in the Arctic, the risk that a tipping point has been passed, and the breadth of the consequences across the globe, makes the Arctic the first urgent focus for climate repair.

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Important Circumpolar Natural Processes in the North Polar Region

\textsuperscript{13} In CCAGs report “Extreme Weather Events in The Arctic and Beyond: A global state of emergency” (2021) the underlying dynamics are explained. https://www.ccag.earth/s/CCAG-Extreme-Weather.pdf See also, for example, ‘Linking Arctic variability and change with extreme winter weather in the United States’ (2021) Cohen et al Science https://www.science.org/doi/10.1126/science.abc9167
In meteorological terms the changes in the Arctic are arriving faster than anything experienced on the planet in the last 7,000 – 10,000 years. The cascade of consequences is moving faster than predicted. There is a clear link between Arctic heating and fires in California and Australia, fatal floods in Germany and China, ‘highest ever’ and ‘lowest ever’ temperatures around the world - and numerous other extreme weather events.

Adopting CCAG’s preference for biomimicry, there is a strong argument for small-scale experimentation with marine-cloud brightening. This approach proposes a fine mist of sea water being sprayed upwards throughout the Arctic summer. The spray will take fine salt crystals into the overhead clouds creating brighter, whiter clouds which reflect the energy of the sun away from the surface of the ocean, allowing new ice to remain through the summer and to thicken the following winter.

The biomimicry approach has many advantages. It brings no new materials into the environment; it imitates processes that occur naturally (if intermittently); it is intuitively scalable; the infrastructure required is small, non-intrusive and can be augmented piece by piece; it can be driven by wave power meaning that the process is carbon neutral.

However, even such a benign model should be carefully tested before being deployed at scale. It requires sensible groundrules, and clear stages and objectives. An entirely new governance model will be required, recognising both the deeply ‘local’ nature of the proposal, and the massively ‘global commons’ nature of the desired outcomes.

The local aspect demands that governance structures include the most local participation. Below national level, the focus should be on indigenous and local community presence in the design process. The participation at the most local level will secure the benefit of deep local knowledge of how the local climate works, and how to operate in harmony with nature to ensure that benefits are achieved – and that nothing is made worse by the climate-repair intervention.

At the global level, all categories of national representation will be important: wealthy countries and poorer countries must be heard. This is how the idea of a ‘global commons’ interest in the Arctic will be made real. Ultimately, the wealthy countries will have to pay the cost of the experimentation, the governance processes and, perhaps, the eventual roll-out at scale. Compared with the costs of damage that is being done (and the damage that will be avoided if the Repair programme is successful) the costs will be very modest.
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