As Much as Possible, as Soon As Possible:

Getting Negative About Emissions[1]

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Abstract

This paper is a report on the viability, both technical and ethical, of negative emissions technologies (NETs) in climate change mitigation. Given present levels of atmospheric carbon dioxide, NETs are almost certainly required in order to avoid the most serious consequences of anthropogenic carbonization. Critics argue that we should not rely on the promise of future NETs because that could be taken as an excuse to avoid decarbonization in the near term. The concern is genuine, but if the prima facie arguments for drawing down carbon as soon as possible are correct, ways must be found to counter the incentives to defer the immediate deployment of NETs and other forms of mitigation. A policy instrument is sketched which could help accomplish that task.

1 Introduction: A Growing Debate

This paper is an opinionated report to the philosophical community on a growing policy debate in climate science about the viability, both technical and ethical, of so-called *negative emissions*. I'm going to take a run at offering a perspective of my own, but my major aim is to get

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philosophers who are interested in climate, sustainability, and energy to think about this very pressing problem. As Lenzi et al. recently put it,

> … there has been no systematic evaluation of the ethics of carbon removal methods by the climate assessment community or professional philosophers. … Carbon removal methods must be ethically evaluated in the context of climate policy pathways. (Lenzi et al., 2018, p. 304)

Like many tough problems having to do with climate, environment, and energy, the scientific, ethical, and policy aspects of this problem are profoundly entangled. What we *should* do about the carbon in our atmosphere cannot be discussed separately from trying to grasp what we *can* do—what technical options, if any, we may still have at this late date. For it *is* getting late—the 'Summary for Policymakers' in the IPCC's Special Report: Global Warming of 1.5°C states,

> In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO_2 emissions decline by about 45% from 2010 levels by 2030 … reaching net zero around 2050 …. (Intergovernmental Panel on Climate Change (IPCC), 2018)

Let us be as blunt as possible: net zero fossil carbon emissions by 2050 means either the *total* replacement of fossil fuels as an energy source for human activities, or the deployment of technology that can miraculously capture *all* of the carbon dioxide released by the combustion of fossil fuels, in every conceivable energy-using device from large-scale electrical generation plants to lawnmowers. As Wim Carton sardonically observes, 'Projections of how the world can avoid dangerous climate change are increasingly resembling science fiction' (Carton, 2019, p. 750). This need not have been the case. If the first warnings about anthropogenic global warming had been heeded, more than thirty years ago, then likely humanity could have managed a relatively soft transition from fossil fuels to whatever may lie beyond, and certainly with no need for the consideration of exotic carbon-removal technologies that, in fact, largely do not yet exist. But that ship has sailed. Thus, if philosophers hope to provide useful perspectives on negative emissions and related topics around climate and energy, it will increasingly be in the context of an international emergency—a context with which, I suspect, most philosophers are not especially comfortable.

First of all, what are 'negative emissions'? This is a catch-all term for any method of reducing CO_2 concentration in the atmosphere. It could include anything from planting trees to hi-tech methods of capturing CO_2 directly from the air (DAC, 'direct air capture'). Sometimes negative emissions are also referred to as *drawdown*, *carbon removal*, or CDR (*carbon dioxide removal*) and the literature often uses 'NETs' (or 'NET') for 'negative emissions technologies'. It is also important to make a distinction between NETs that are passive in the sense that once set up they will absorb CO_2 from the atmosphere with little intervention, and active DAC that must be powered by some source of energy. The latter have the potential for drawing down carbon at a greater rate than passive technologies, but they are much less well developed, and the large problem of finding adequate energy sources for them, at the scale required, remains to be solved. We will return to the question of energy requirements for NETs, since it is a crucial part of the story.

While there are many ways of removing CO_2 from air, there is (are) no method(s) at present that would allow us to remove atmospheric CO_2 at the rate or scale that many scientists fear is required to prevent climate catastrophe. And yet, many policy pathways are predicated on the assumption that negative emissions technologies will be developed at scale in the future (typically well before the end of this century) (IPCC, 2018). This affects our estimates of how much new fossil carbon emission we can accept *now*. In principle, we can imagine that we can emit more now (put off the reduction challenge until later) because we will have massive drawdown technologies in the future. Markusson et al. (2018) refer to this process of deferring hard decisions now on the basis of future miracles as 'mitigation deterrence'; I'll follow Minx et al. (2018) and call it 'mitigation deferral'. It would be as if an overweight person put off reducing food intake, and maybe even chose to eat more food, on the expectation that an instant weight-loss pill will be developed some years in the future. The apparent option of mitigation deferral is a classic moral hazard: if we delay mitigation now for the sake of short-term profit or convenience, others who come after us, and who had no hand in our present self-serving actions, will suffer.

In the following, I will review the reasons why many scientists now fear that negative emissions cannot be avoided, and the options and constraints (both technological and geopolitical) faced by negative emission. I conclude with a tentative suggestion for a policy instrument that could help to counter deferral, and a brief indication of the philosophical perspective that I feel cannot be avoided in order to give us any hope at all of getting through the climate crisis.

2 Why Talk About Negative Emissions in the First Place?

We must begin with a dispiriting litany of numbers.

Current global mean surface temperature is 0.9 to 1.1°C above pre-industrial (depending on how the baseline is defined) (Schurer et al., 2018). Surface air temperature is what immediately concerns most people, and yet over 90% of the excess heat goes into the oceans, where it contributes to hypoxia and sea level rise (from ice sheet melting and thermal expansion).

This increase in global heat content is almost entirely due to human causes, mostly through the release of greenhouse gasses: CO_2 (the long-term dominant factor), methane, nitrous oxide, and CFCs (chlorofluorocarbons). (Water vapour is also a powerful greenhouse agent but acts as a short-term amplifier of warming.) Global heating is not caused by an increase in solar output, cosmic rays, natural variation, or volcanism—these possibilities have been exhaustively checked. Most of that CO_2 comes from the combustion of fossil fuels, though deforestation is an important contributor as well.

Despite Paris 2015, and much brave talk, CO_2 emissions continue to increase: there was a new record of over 37 billion tonnes released in 2018 (Carrington, 2018). Current atmospheric levels of CO_2 are hovering around 416 parts per million (ppm) (Scripps Institution of Oceanography, 2021) and increase by over 2 ppm/year, though the rate of increase is increasing as well. The pre-industrial level of CO_2 was about 280 ppm, and in the peak of the ice age it was about 220 ppm. We are now at the highest CO_2 concentration since the Pliocene epoch, 3 to 5 million years ago.

Paleoclimate studies tell us that mean sea level correlates fairly well with CO_2 concentration. In the mid-Pliocene, sea level was 15 to 25 metres higher than at present. If the precedent provided by paleoclimate is relevant, at 416 ppm we were *already* dialed in for disastrous sea level rise (SLR) and temperatures that would make the continuance of agriculture, and indeed the sheer habitability of some parts of the world, problematic. In a recent study of Pliocene sea levels, Grant et al. state,

> Although ice-sheet, ocean and continental geometries were subtly different during the mid-Pliocene, our results suggest that major loss of Antarctica's marine-based

> ice sheets, and an associated GMSL [Global Mean Sea Level] rise of up to 23 m, is likely if CO_2 partial pressures remain above 400 ppm. (Grant et al., 2019)

It would take some centuries for sea level to get to Pliocene heights but there is a near-certainty of damaging sea level rise by the end of this century even if we reduce emissions to near-zero, mainly because of the excess heat that is already in the seas. The precarious state of certain glaciers in Antarctica is a matter of particular concern (Morlighem et al., 2020; Siegert et al., 2020).

Sea level rise is not the only worry, of course: if CO_2 levels remain over 400 ppm there will be a continual risk of extreme weather, heat waves, permafrost melt, and biosphere disruption at least as severe as that which we are now experiencing. Although a sustained CO_2 level around 400 ppm probably would not by itself push global mean surface temperature past 1.5°C (IPCC, 2018) it would be still sufficient, as noted, to cause significant ecological disruption, especially over a period of a few centuries. In addition, if atmospheric CO_2 stays over 400 ppm then it would be much less likely that the excess CO_2 in the oceans would be able to diffuse out sufficiently to bring oceanic pH back to normal levels. The (understandable) focus on holding global mean surface temperature below a certain number tends to distract from the fact that CO_2-equivalent levels are also well-correlated with global changes such as sea level rise; thus, aiming at CO_2 reduction to a certain level (such as 350 ppm as suggested by Hansen et al., 2008, or even lower) may be a more meaningful policy goal; I will return to this point.

Stopping further emissions of course does not by itself remove CO_2 that is already in the atmosphere, which will remain for centuries or millennia if no further steps are taken to remove it. So even if by some combined miracle of technology and political will we reduce further emissions to near-zero immediately, we still face outcomes, notably including catastrophic sea level rise, which could threaten the biosphere and organized human life as we know it. The only thing that could have a chance of obviating these risks is a significant reduction in *present* greenhouse gas levels. Hence the probable need for negative emissions *even if* anthropogenic greenhouse emissions could somehow be halted almost immediately. In fact, present carbon budgets—the amount of further emissions that we would fondly like to believe is safe—are constructed on the assumption that significant emissions will continue for some time (IPCC, 2018). This only increases the amount of negative emissions that ultimately will be needed to prevent the worst effects of global carbonization, and (the longer it is delayed) the rate at which those negative emissions must ultimately be applied. As Lenzi, et al. put it, it has become an 'open secret' that '[s]taying within 2°C could mean extracting billions of tonnes of CO_2 this century'.

3 An Intense Simplicity?

If we do have to draw down carbon, if emissions reduction is not enough, how much carbon would that have to be?

Here is one estimate, from an authoritative review published in 2017:

> To limit the LPHI [low probability high impact] warming below dangerous levels, the CES (carbon extraction and sequestration) lever must be pulled as well to extract as much as 1 trillion tons of CO_2 before 2100 to both limit the preindustrial to 2100 cumulative net CO_2 emissions to 2.2 trillion tons and bend the warming curve to a cooling trend. (Xu & Ramanathan, 2017)

Is it remotely feasible that we could develop and deploy the technology that could accomplish such a feat in the next few decades?

To give some sense of the scale, a simple calculation shows that if 300 Gtonne of carbon (equivalent to about a teratonne of CO_2) could be extracted as coal, it would be roughly equivalent to 200 km^3, a smallish mountain range. Pulling down at least a teratonne of CO_2 is a huge engineering undertaking, one that we presently are not remotely equipped to accomplish, but if it could be done it would reduce atmospheric concentration of CO_2 to levels that would probably (although not certainly) prevent the most dire consequences of anthropogenic carbonization. Could it be that simple—just pull a teratonne of CO_2 out of the atmosphere? A famous Churchillism comes to mind: 'Out of intense complexities, intense simplicities emerge.' In fact, even if this could be done, there would still be so much excess heat and CO_2 in the oceans that some dire consequences (such as partial collapse of some major ice sheets and widespread disruption of oceanic food chains due to heat, anoxia, and acidification) could occur anyway. Furthermore, Xu and Ramanathan emphasize that this massive carbon drawdown is *in addition to* the total or near-total cessation of fossil carbon emissions well before the end of this century—it is not a substitute for that. Carbon dioxide removal technologies, no matter how effective, cannot be *sufficient* by themselves to solve the many-pronged environmental challenges occasioned by the anthropogenic carbon crisis, but it is increasingly apparent that they may be *necessary*. It must be clearly understood, however, that the aim of arguing for the use of NETs is not to buy more time for the fossil fuel industry, but to increase our slender chances of avoiding global climate catastrophe.

4 Spectrum of Opinion

According to one senior climate scientist, whether or not we need to use negative emissions technologies (NETs)

> depends on the target or course. Obviously, if it's 1°C we would need negative emission as we're already past it. For 1.5°C, we probably need it too. For 2.0°C, we can still get there in all likelihood with rapid reduction of carbon emissions. BUT there is uncertainty in all of this, in the climate model projections, in the carbon cycle dynamics, etc., so it comes down to what level of certainty you want, i.e., how risk averse you are. (Michael Mann, private communication)

Mann's observation about certainty is very pertinent. Typical projections from the IPCC will offer only 66% certainty (one sigma) that a certain carbon budget would allow us to meet a certain temperature target. I'm not sure I'd hop on a flight if I thought there was only a 66% chance it will land safely.

Here is the recent view, somewhere in the middle ground, of James Hansen and co-authors:

> Targets for limiting global warming … now require negative emissions … If phasedown of fossil fuel emissions begins soon, improved agricultural and forestry practices, including reforestation and steps to improve soil fertility and increase its carbon content, may provide much of the necessary CO_2 extraction. … Proposed methods of extraction such as bioenergy with carbon capture and storage (BECCS) or air capture of CO_2 have minimal estimated costs of USD89–535 trillion this century and also have large risks and uncertain feasibility. (Hansen et al., 2017)

Finally, Peter Wadhams expresses with admirable clarity what some would consider an extreme view, and others might take to be an inescapable 'intense simplicity':

> [T]he overwhelmingly important need is to undertake a colossal scientific and technical research programme on geoengineering and on carbon dioxide removal. … The only thing that can really save us is the direct removal of CO_2 from the atmosphere through some device which sucks ordinary air in at one end and emits it again at the other minus its CO_2 content, and does so at less than impossible price. … If we don't solve [this problem], we are finished. (Wadhams, 2017, pp. 205-6)

Why would Wadhams' view be considered extreme? Partially because some would feel that he underestimates the potential for less technologically-intensive means of emission reduction or drawdown. Let us review the options.

5 How?

If we want to draw down 1000 Gtonne of CO_2 by 2100, that implies at least 12.5 Gtonne/year *net reduction* from now on, irrespective of further emissions. (If we are still emitting, then of course it would be necessary to draw down at an even higher rate.) A good start would be to plant lots of trees. A recent quantitative study (Bastin et al., 2019) indicates that reforestation or afforestation of those lands that could in principle support it could eventually draw down perhaps 205 Gtonnes of carbon, though it would take some decades for this to take full effect. As Bastin et al. rightly observe, 'ecosystem restoration [is] one of the most effective solutions at our disposal to mitigate climate change'—and mitigating climate change is not the only good reason to practice it. In a similar vein, Moomaw et al. (2019) argue that there is neglected potential for carbon drawdown through *proforestation,* which they define as "growing existing forests intact to their ecological potential". However, while an eventual 200 or more Gtonnes from forestry is a great help, it would be neither enough nor soon enough. It seems highly likely that technological help will be needed as well.

The drawdown method that features most prominently in current policy discussions is BECCS, Bio-Energy with Carbon Capture and Storage. The basic idea is to grow vast quantities of plant matter (*Miscanthus*, elephant grass, is well regarded for this purpose). Combust it to release energy or convert it to biofuel. Capture and bury the CO_2 thereby generated. In principle, BECCS would be technically viable if the amount of energy required for capture and storage is less than the usable energy released. It is widely presumed that this would be the case for most forms of BECCS being considered (Fuss et al., 2014; Hickman, 2016; Minx et al., 2018). However, recent work by Harper et al. (A. Harper, 2018; A. B. Harper et al., 2018) strongly indicates that BECCS is a losing proposition as a form of negative emissions:

> [M]y colleagues and I find that expansion of bioenergy in order to meet the 1.5C limit could cause net losses in carbon from the land surface. Instead, we find that protecting and expanding forests could be more effective options for meeting the Paris Agreement. (Harper, 2018)

Another show-stopping failing of BECCS is the land requirement. Estimates vary of the amount of land that would have to be devoted to BECCS in order to meet the Paris temperature targets, but it would be a significant proportion of the arable land available on the planet. For instance, Fajardy et al. (2019) state,

> Across IPCC scenarios with a 66% or better chance of limiting temperature increase to 1.5°C, median CO_2 removal by BECCS is 12Gt of CO_2 per year … This massive deployment of BECCS would require between 0.4 and 1.2 billion hectares of land (25% to 80% of current global cropland). (Fajardy et al., 2019)

BECCS, employed at this scale, thus poses enormous problems not only of practicality, but of equity and justice. Appropriating that much land simply to produce electricity or biofuel to keep the wheels of industry turning will displace agriculture that feeds millions, and will co-opt the habitats of indigenous peoples and lands essential to preserve biodiversity. Turning a large part of the planetary ecosystem into a plantation to produce biofuels is hardly a "green" solution to the climate crisis.

The upshot: at the scale required, BECCS is a dubious proposition even if it could be made to work technically—yet it is a major tool used in calculating carbon budgets and emissions pathways. Is that simply because BECCS allows us to maintain some semblance of business as usual, an economy based, to the last gasp, on combustion (McKibben, 2021)?

In fact, other options exist, at least in principle. There are numerous ways of absorbing/adsorbing CO_2 from the air (Lackner et al., 2012), but the question is to find ways of making them work at the scale and speed required. Increasing attention is being paid to Direct Air Capture (DAC), combined with mineralization of the bulk of the captured CO_2. Some promising experimental technologies already exist for mineralizing carbon dioxide (Cartier, 2020; Snæbjörnsdóttir et al., 2020), although they would have to be coupled with an energy-intensive DAC technology to be effective at scale; for recent steps in that direction, see (Keith et al., 2018). Anything like this will inherently have high energy requirements; I'll return to the energy question below.

If DAC could be made to work at scale, it would have the advantage over BECCS of requiring a much smaller footprint, and the more energy-intensive it can be, the more this would be the case. It might only be necessary to have a relatively small number of sites, at locations where the geology is favourable for mineralization. Much more engineering and scientific study is needed to establish the potential and limitations of DAC, but, in combination with appropriate land management and forestry measures, it is increasingly looking like one of the most promising options.

6 The Prima Facie Case for NETs

In sum, there is a prima facie scientific case for large-scale deployment of NETs:

1. Paleoclimate evidence shows that we are already at CO_2 levels that very likely guarantee SLR of 20 metres or more (though it would take a few centuries for this to fully cash out). If what happened in the Pliocene is relevant to our time in the way that now seems obvious, that by itself is sufficient to show that it is not good enough merely to cease emissions of fossil carbon—to have a fighting chance of saving the icecaps, we must reduce the present CO_2 concentration to something close to pre-industrial levels.
2. Modelling (including that cited by IPCC 2018) tends to show that there is little or no hope of holding temperature increases to any tolerable level unless a substantial percentage of the CO_2 already in the atmosphere is somehow removed in the relatively short term (a few decades at most).
3. There is already enough excess CO_2 in the oceans to cause a level of acidification that threatens the viability of the oceanic food chain; thus, we cannot rely on any further oceanic absorption of CO_2 to solve our atmospheric CO_2 overshoot.
4. As we reduce our greenhouse emissions we will also reduce industrial aerosols, which contribute to global dimming (Xu et al., 2018). This question needs further study, but it may be that this additional warming effect (ironically caused by efforts to clean up the atmosphere) could only be countered by CO_2 drawdown.

5. With the best of wills and under the most optimistic assumptions about the development and deployment of renewables or other alternative energies, fossil carbon emissions cannot be reduced to zero overnight. The replacement of fossil fuels is a process that is bound to take some years (I will not here attempt to estimate how many), even though CO_2 is already dangerously high. Using NETs to hold down CO_2 throughout the transition period could reduce the chance of disastrous overshoot. It is not in itself a bad thing that NETs could buy time, so long as it is understood that time is not being bought to eke out the profitability of fossil fuels but rather to move beyond fossil fuels.
6. This paper is not the place to fully evaluate the relative merits of NETs and solar radiation management (SRM). But NETs deployed soon enough and extensively enough could forestall or reduce the need for SRM, which has numerous technical and ethical disadvantages of its own (Preston, 2012).

I call this the prima facie case for NETs because it is, of course, always possible that further scientific analysis will reveal a more nuanced picture. Perhaps, if emission reductions occur much faster than anyone expects, we will not need the more technologically intensive forms of NETs, or at least we will need less of them. But there is one further point in support of the prima facie case, captured by the slogan "uncertainty is not our friend" (Lewandowsky et al 2014; Lenton et al. 2018; Siegert et al. 2020). The risk of an outcome is its probability multiplied by its negative utility. The risk curves for climate hazards have "fat tails", which means that the total risk is highest at the high negative utility end of the curve (Wagner & Weitzman, 2015; Mann, 2017). If there is even a small chance that a path not involving high technology NETs could, say, allow for the collapse of West Antarctica, the negative utility of that outcome is so unacceptably high that we should be willing to take extra precautions to reduce its probability, including precautions that might be quite costly in the short term. So even though there is still scientific uncertainty about whether we need NETs in order to meet current climate targets with a politically acceptable level of confidence, we can be very certain that we do not want to enjoy the consequences that would ensue if it emerges that we did need them after all.

I can't emphasize strongly enough that the prima facie scientific case for NETs implies that a suite of drawdown technologies and processes be developed and deployed *as soon as possible*, in concert with emission reduction. Because of nonlinearities endemic to the climate system, carbon drawn down now will be of much greater benefit, or will prevent much more harm, than the same amount of carbon drawn down later in this century. Thus, again, there can be no question of using a presumption of future NETs in order to avoid mitigation now, any more than we could delay emission reductions now with a promise of deeper reductions later on.

There is yet another reason for developing NETs as soon as possible rather than postponing the expense of doing so: Anderson and others rightly worry that NETs might never work as well as hoped, due to fundamental engineering or scientific limitations. Let us suppose that the best NETs we can devise can only remove, say, 30% of the carbon that ideally they should remove. It will be far better for us to have the benefit of that 30% reduction now than decades from now because more harm will be prevented, especially given the likelihood that the net risks increase with CO_2 concentration in a nonlinear manner. Also, we need to find out as soon as possible whether, in fact, any sort of NETs that we can presently envision will in fact work as well as we may now reasonably hope they do; we don't want to assume that they will work and then find out some decades later that they don't. Or it may simply take much longer to develop sufficiently effective NETs than anyone presently imagines. Morrow et al. (2020) are likely correct when they state, “scaling up CDR capacity to the multi-gigaton scale, if feasible, would take several decades.” We really should get started soon.

7 The Question of Energy

It is increasingly clear that any sort of high-technology NETs able to draw down atmospheric carbon in the amounts required and at the rates required must be energy-intensive. One could imagine band-aid solutions powered by natural gas (suggested by Wadhams, 2017) or dedicated fission reactors, but ultimately there must be new energy sources equivalent either to advanced fission, nuclear fusion, or to renewables deployed on a massive scale in conjunction with a world-wide smart grid. Or all of the above. And anything of this sort would guarantee the total obsolescence of fossil fuels. So band-aids and stopgaps notwithstanding, it cannot make any sense to suppose that someday NETs (at scale) and fossil fuels will coexist on a sustainable basis. The very thing that would allow NETs to do the job it must do (modulate the CO_2 concentration in the atmosphere on a sustainable basis) is also the very thing that would guarantee the end of fossil fuels anyway. Indeed, the pressing need for more effective NETs (especially DAC) could itself be one of the factors that spurs research and development of alternative energy sources. Fossil fuels must be replaced as humanity’s major source of energy—this is the largest *technical* problem of our time. NETs cannot be postulated in order to *put off* solving that problem, because NETs cannot work at the required scale without that problem having been solved.

8 The Ethical Dimension

As noted, a major concern expressed by several authors is not only whether NETs are required technically, but whether reliance on them, or more precisely reliance on the *promise* of NETs, could corrupt other essential components of climate mitigation. Ironically, the promise of NETs in the future might even be used as an excuse to delay developing NETs themselves today—because that will also be very expensive and will have no short-term financial return remotely proportionate to its likely short-term cost. As Shue (2017) notes, mitigation deferral involves a morally unacceptable transfer of costs and risks to those in the future who cannot escape the consequences of our choices today.

In this vein, a testy exchange occurred between negative emissions researcher Klaus Lackner and climate scientist Kevin Anderson and Glen Peters. The latter stated,

> Negative-emission technologies are not an insurance policy, but rather an unjust and high-stakes gamble … This is not to say that they should be abandoned … but the mitigation agenda should proceed on the premise that they will not work at scale. The implications of failing to do otherwise are a moral hazard par excellence. (Anderson & Peters, 2016b)

In response, Lackner and numerous coauthors defended drawdown research:

> K. Anderson and G. Peters … would sideline negative emissions technologies and remove potentially important options from the portfolio for mitigating and ameliorating climate change ... an inclusive approach would focus on stopping climate change as fast as possible while minimizing risk to vulnerable populations and to societal stability. (K. S. Lackner & 45 additional signatories, 2016)

Anderson and Peters replied in turn, ‘We stand by our claim that postulating large-scale negative emissions in the future leads to much less mitigation today’ (Anderson & Peters, 2016a). (See also Anderson, 2015).

Anderson and Peters did not say that we should not research NETs, but rather that we should no more depend upon their potential promise than I should run my household finances on the assumption that I will win a major lottery next year. In particular, they said that we should not use the promise of NETs in the future to put off other forms of mitigation today. Indeed, in 2012, Lackner (and other co-authors) said virtually the same thing:

> [T]he possibility of affordable air capture technology does not provide any justification for a delay-and-overshoot global strategy. (Lackner et al., 2012)

Proponents of NETs such as Lackner most certainly do not claim that we can fob off the need to reduce emissions with a high-tech promissory note. On the other hand, critics of NETs such as Anderson are calling not so much for the abandonment of research on NETs, as for *honesty* on the part of policy-makers.

If we have ethical obligations to future persons at all, and if the prima facie scientific case for NETs is correct, then we have quite as much of a moral *obligation* to carry out extensive carbon drawdown as we have to reduce emissions—and for essentially the same reasons. This obligation is both to future generations (who willy-nilly cannot escape the consequences of the choices we make now) and quite likely our own somewhat older selves, since it is not out of the question that the earth system is close to climate tipping points within the next decade or two.

Some have expressed a concern about the hubris that is implicit in grandiose schemes to manage the planet’s climate (Minx et al., 2018). This question demands larger consideration than can be given here, but it is perhaps a bit late to be worried about over-reach given the colossal impact that the human species already has on the earth system. Steffen et al. (2018) argue that what they call a Stabilized Earth pathway

> can only be achieved and maintained by a coordinated, deliberate effort by human societies to manage our relationship with the rest of the Earth System, recognizing that humanity is an integral, interacting component of the system.

Is this hubris, or simply the recognition of a heavy but inescapable responsibility?

The problem also has an economic dimension. Suppose we figure out how do what Wadhams wants us to do, and develop some DAC technology that could pull 20 or more Gtonnes of carbon dioxide out of the atmosphere every year (Wadhams, 2018). Some of this carbon dioxide can be used for such purposes as synthetic fuel, chemical feedstock, or stimulating plant growth in greenhouses. However, the only thing that we are going to do with most of that carbon is bury it. The whole point of the exercise is to take large amounts of carbon *out* of the carbon cycle; thus, most of the byproducts of DAC will never be sold for cash. (Not going extinct is a product that cannot be plastic-wrapped and marketed in a big-box store.) Like the responses that many countries have made to the coronavirus emergency, large investments in NETs and other mitigation measures are survival measures that cannot be predicated on their short-term viability in the global marketplace—although the requisite development of new technologies (especially energy technology) will eventually turn out to have been very good investments indeed.

9 Deterring Deferral

The concern of Anderson, Shue, and other critics is genuine: given the expense and difficulty of developing NETs that could actually do the job required, and the continuing profitability of fossil fuels, the temptation to defer will remain severe for some time to come. One could also use a promise of emission reductions themselves in the future as an excuse to defer reductions now; the problem is more deferral itself than the technology or practices cited as an excuse to defer.

Human obstinacy knows few bounds, and there is no easy answer to the temptations of deferral. However, if the prima facie case for NETs is correct, we have to face this problem squarely. Here I sketch not a complete solution to the problem, but a few components of what I hope could be a solution to the problem (see also Honegger & Reiner, 2018, for a useful discussion in a similar vein).

Telling the truth, as clearly as possible, is a good start—the truth both about the scientific picture and about our obvious ethical obligations. Rational persuasion does work sometimes, and in an ideal world it is to be preferred because the attempt to persuade on the basis of reason and evidence implies respect for the intelligence and autonomy of one's interlocutor (Stevens, 2021). It is quite easy to give sensible arguments against mitigation deferral, which is not even in the rational self-interest of agents with any but the shortest time horizons. However, those most likely to indulge in mitigation deferral are those least likely to listen to rational arguments against it. Something else is needed, especially in the face of the urgency of the present climate crisis (Lenton et al., 2019).

Could we find a scientifically-founded policy instrument that can be used as a counter-incentive to the short-term advantages of mitigation deferral, recognizing that we can't count on moral suasion alone? Earlier in the paper I made the suggestion that aiming at reducing atmospheric CO_2 concentration to some particular level could be a more useful policy goal than aiming at a certain delta-temperature maximum. I hardly mean to suggest that scientists should cease to be concerned with other climate parameters such as temperatures, heat balance, heat content, or CO_2-equivalent. Rather, the aim here is to identify a clear public policy goal that is a necessary condition for meeting all other climatological targets, and that is simple and immediate enough to be used to motivate the necessary actions. Let us suggest, therefore, that the next round of climate talks should aim primarily not so much at limiting temperature increase to within a certain range by a certain date, but at setting the explicit goal of getting *present* CO_2 levels *down* to some level that will entail a cascade of risk reduction—perhaps the figure of 350 ppm suggested by Hansen et al. (2008), perhaps even lower.

Present policy (IPCC, 2018) is aimed at a projected estimate of temperature increase several years or decades in the future. These indirect and deferred temperature targets are scientifically meaningful and relevant, but they are possibly not the best motivators of the immediate actions that are required in order to achieve them because there is a long time delay before it can be seen whether a given practice is actually helping to achieve a given temperature goal. The connection between temperature and ultimate consequences such as ice sheet collapse is even less direct and subject to long time delay. It could be years before we know whether a change in practice is causing a measurable decrease in the rate of temperature increase, or whether it implies a different projection of when a certain temperature goal has a certain risk of being overshot by a certain date years or decades in the future. CO_2 levels are closer to the base of the causal chain than temperatures, and they respond quickly to changes in emissions. It seems likely (though this remains to be tested) that they would also respond quickly to drawdown if it were in sufficient quantity, which (as noted) would likely be on the order of ten or more gigatonnes per year.

There is in the present international political context little chance of *enforcing* this or any other climate target. Many countries, including the largest and most powerful, are reluctant to cede a shred of sovereignty, even in the face of global existential threat. What might work, though, and might in fact be more effective than any form of enforcement, would be an internationally-agreed system of economic incentives. They would be based on a country's measured contributions to CO_2 reduction, and jurisdictions can be rewarded for reducing emissions, or for drawdown, or for both. The global community would reward itself for measurable progress first in slowing the net increase in CO_2 concentration, and then in reducing net CO_2 concentration. No one gets rewarded for *promising* to reduce carbon emissions or *promising* to draw carbon down; only measurable results count. I will not here attempt to design such a system of incentives in detail. It could be as simple as paying private contractors very large sums of money for successful drawdown; it could be something more complicated. The key idea is to find a way of providing *immediate* reward for doing something (lowering CO_2 concentration) that our best science tells us would have the best chance that anything would have of steering the planet out of its current carbon crisis.

In effect I am proposing a form of *operant conditioning* on a geopolitical scale. The international community will reward itself for lowering the value of a certain parameter, with each jurisdiction being rewarded in proportion to its contribution. Effective behavior modification requires rapid feedback, and CO_2 readings, which are well correlated with deleterious consequences of warming such as sea level rise, are ideal for this purpose because they can be updated on a daily basis (Scripps Institute of Oceanography, 2021).

The relevance to our ethical problem is that *both* reduction of the rate of positive emissions and negative emissions can contribute, in very direct and immediate ways, to progress toward slowing and ultimately reversing the increase in atmospheric CO_2 concentration. Emission reductions will slow the rate of increase; negative emissions could in principle (if deployed on sufficient scale) reduce the existing total. It would be an occasion for great international rejoicing if we could even stabilize CO_2 for a one year period. As an intermediate goal, therefore, let our scientists and engineers tell us what combinations of reduction and drawdown would be sufficient to stabilize CO_2 by a certain date, as soon as possible. Then spend the billions it will take to get there. Once that target is reached, start cutting down the total year by year.

What I propose here requires to be worked out in much more detail (especially the system of incentives, which I have only sketched). It can't be guaranteed to completely prevent mitigation deferral, but it could produce a powerful countervailing incentive. The point is that since we almost certainly *must* employ NETs (indeed, as soon as possible), we *must* also find ways of defusing mitigation deferral, and a system of incentives based upon one readily measurable parameter may have the best chance of working to that end. DAC or other technologies that could remove over 10 Gt of carbon dioxide per year may deserve to be called science fiction, as Carton suggested, but with sufficient vision, investment, and incentive science fiction has a way of becoming science fact.

A more general objection to the use of NETs could be an unease with technosolutions to problems that are in important part social, economic, political, ethical, and philosophical—that is, behavioral, broadly speaking. Don't people simply need to be less greedy, more willing to tread lightly on the earth, more willing to cooperate, more thoughtful of future generations and other life on this planet? Don't our economic and political systems need to be more just, more equitable? I cannot disagree with such aspirations. But there is no way out of the present climate crisis that does not involve a heavy dependence upon high technology. (For important instance, the on-going process of finding batteries that can compete with a tank of gasoline is necessarily dependent upon cutting-edge research in quantum chemistry, materials science, and microelectronics; see, e.g., Willis, 2019.) Ideally, technology and the social and political structures that can employ it in the most effective and ethical ways would develop concurrently. As Thomas Homer-Dixon put it (2000), we need both *technological* and *social* ingenuity in equal measure. In particular, we need policy instruments that have a chance of producing results in this world's present fractious political climate, and, crucially, within a very short timeframe. Give people a simple task—as soon as possible, stabilize and lower the value of *one* highly relevant parameter—and reward them immediately for their measured contributions to that task. This, I submit, has a chance of working, and we don't even need to get every major jurisdiction in the world on-side in order for it to accomplish its primary task—which is to reduce the global CO_2 concentration to safer levels.

10 The Ecological Perspective

Protagoras famously declaimed, "Man [as in humanity, not just the male of the species] is the measure of all things." He was wrong. Outcomes such as the melting of icecaps, the decimation of insects and wildlife, the intensification of tropical cyclones, the emergence of novel pathogens, and the disappearance of forests and topsoil show that *it is not just about us* and that *we don't just make it all up*. Many modern humans, protected from the immediacies of survival by our energy-intensive technosphere, come to think that everything is negotiable or re-definable. In reality we live in a largely non-human physical universe from which we derive the possibility of our existence and sustenance, but which is vastly bigger, older, and more powerful than we are. It has its own rules of operation, of which we do have some limited grasp, but which take little or no account of our human interests. There are things that are negotiable between humans but they are set within a web of factors and constraints that are largely or entirely non-negotiable. There is nothing we can offer the Thwaites Glacier, no deal we can cut, that will persuade it to not collapse if the water underneath it gets warm enough. But perforce, we live in *its* world. Its problems are *our* problems. And right now, as far as our best science can tell us, it seems to have a major problem with the amount of CO_2 in the atmosphere.

The prima facie case for NETs in no way precludes the necessity of undertaking other remedial measures, including (but not limited to) the total replacement of fossil fuels as energy sources, measures to protect and extend habitat for the remaining wildlife on the planet, soil restoration and afforestation wherever possible, and the painstaking cleanup of plastic and other waste and toxic detritus left over from the oil economy. The fact that it will be both politically and technically difficult to do all of these things, including massive carbon drawdown, in no way changes the fact that they may well need to be done if certain consequences are to be avoided.

If it were possible for humanity to be concerned only with doing whatever it would take to steer ourselves away from the climate crisis, then of course it would be only reasonable for us to want to draw down as much carbon as possible, as soon as possible—among a suite of measures we could and should be taking to mitigate and deter the effects of anthropogenic carbonization. It would be ironic indeed if overcoming the behavioral barriers to doing the reasonable things end up being more difficult than the substantial technical barriers that must already be surmounted in order to do those things.

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