The Climate Crisis and a Renewable Energy and Materials Economy (REME): A Global Green New Deal (GGND) that Includes Arctic Sea-Ice *Triage* and Carbon Cycle *Restoration*

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Abstract: A Global Green New Deal (GGND) that Includes Arctic Sea-Ice Climate Triage and Carbon Cycle Climate Restoration, and that, following (Eisenberger, 2020), would move us toward a Renewable Energy and Materials Economy (REME) is necessary to turn our current civilization and species threatening climate crises into an opportunity to stabilize our planet's climate and advance to a new more equitable and prosperous stage of human development. Immediate, potentially catastrophic, global climate impacts of imminent Arctic Sea-Ice loss, the first global climate "tipping point", are reviewed, and practical and efficient potential climate *triage* methods for avoiding this are summarized. Longer-term Direct Carbon Removal (CDR) and Carbon Storage, Sequestration, and Use (CCSU) methods that would move us toward long-term carbon cycle climate *restoration* are presented. A general reframing of climate policy, and specific GGND policy proposals that include Arctic Sea-Ice climate triage and carbon cycle climate *restoration* that would rapidly move us toward a REME and avoid increasingly catastrophic climate impacts are proposed.

I) Introduction

The Covid-19 pandemic has demonstrated to all of us how fragile our civilization is in the face of a natural calamity, particularly, as in with the US, when we fail to plan for it, and take advanced measures to reduce its impact. As I write this we are at or near the peak of suffering and mortality from Covid-19 but also are deploying vaccines that we all expect will eventually subdue the pandemic and allow a return to ex-ante "normality". President-elect Biden has even built his campaign around the slogan "build back better".

But unfortunately, "building back" is not going work as we face the risk of greater and more lasting damage to our environment if we do not prevent the imminent melting of the Arctic. We need to learn the lesson of the pandemic and take urgent climate *triage* measures now to prevent this from happening. The choice being doing something and doing nothing could not be starker. We need to act on this now even as we also act to ramp up at an emergency pace (just as with vaccine development) climate mitigation, adaptation, and carbon cycle *restoration* efforts.

A Green New Deal, or even better a Global Green New Deal (GGND), is a critically important, and socially and economically transformative, goal that the US alone, by creating dollars at roughly the 2008-2011 rate (which though historic, is considerably less than the 2020 rate[1]),

[1] Over ten years from 6/2009 to 6/2019 the Fed stock of T-Bills increased by $1.7 T (Baiman, 2020: 3). Over eight months from 2/12/2020 to 10/28/2020 the Fed stock of T-Bills increased by $2.1 T, see: https://fred.stlouisfed.org/series/TREAST (downloaded 11/23/2020). As the Fed is legally required to turn over all of its profit (minus negligible operations costs) to the Treasury, this represents money created by the Fed for Treasury.

could fund for almost thirty-years (Baiman, 2020: Sections 2 and 6).[2] In fact, a case could be made that as the current custodian of the world's global fiat currency, the US government has a responsibility to employ its unique monetary power to help all of humanity by issuing dollars to restore a stable global climate (Baiman, 2020).

However, as the first major calamitous climate change tipping point, "Arctic Sea-Ice Melt", is about to occur, and as decades of global and national GGND-like efforts to reduce and end GHG emissions in time to stay within a "Carbon Budget" that could cap global warming at 1.5, or even 2.0, degrees Celsius above preindustrial levels have (partially for good reasons – see below) failed (Figure 1). We need to *also* immediately double-down on promising and practical climate, *triage* and *restoration*, remedies (Dorman, 2020) (Baiman, 2020: Section 3). If we do not prevent the Arctic Sea-ice from melting through urgent climate triage measures, and do not commence to rapidly implement a carbon cycle carbon restoration that begins with Carbon Direct Removal (CDR), our efforts to prevent accelerating climate catastrophe through *mitigation* and *adaptation* alone will fail.[3] Climate triage to prevent the loss of Arctic-sea ice to prevent Imminent catastrophic climate feed-back effects, and a climate *restoration* approach to reducing GHGs (primarily carbon dioxide) in the atmosphere, and a recycling of at least part of this carbon into a REME that will speed up the pace of CDR, is necessary. We also need to once and for all stop thinking of climate change and GHG emissions as a *flow-reduction* problem, and to correctly frame the problem in *stock-capacity* waste-management, carbon-cycle closure terms. Mitigating and adapting to lower emissions will not stop climate change. We need to stop emitting, and clean-up and recycle carbon from our dump site.[4]

A cessation of dumping, carbon waste-management and recycling approach should provide a large additional impetus to the development of GGND activities that: reduce or do not emit carbon, have a net-zero effect on the stock of atmospheric carbon, or that capture and sequester or utilize carbon from the atmosphere. As many of these approaches sequester carbon in building or other materials they also serve to propel us forward toward a Renewable Energy and Materials Economy (REME), that may ultimately be a key factor in scaling these

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[2] Similarly, in their recent *Washington Post* Op Ed, Sir David King, former chief scientific advisor to the British Government and emeritus professor and founding chair of the Center for Climate Repair at the University of Cambridge, and Rick Parnell, the president and chief executive of the Foundation for Climate Restoration and former chief operating officer of the United Nations Foundation, point out that "Stopping climate change could cost less than fighting covid-19" (King and Parnell, 2020). King and Parnell also call for immediate climate *restoration*, including Direct Air Capture, in addition to *mitigation* and *adaptation*.

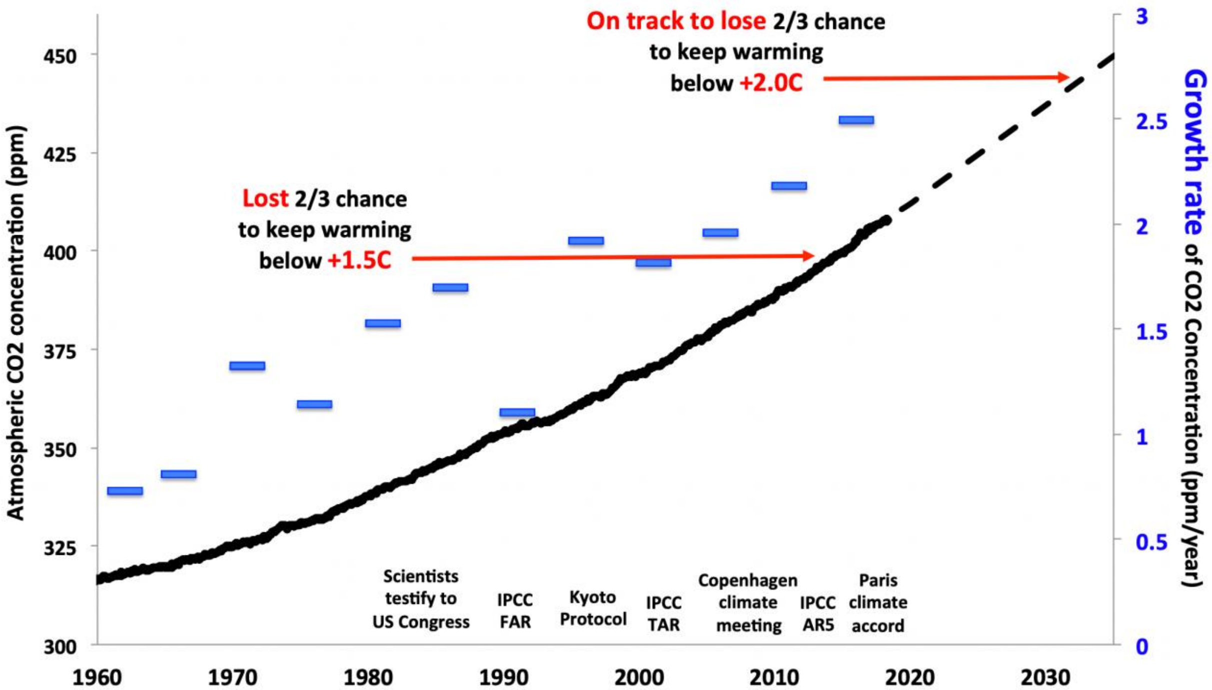
[3] This was officially acknowledged in 2018 as the IPCC stated that CDR was necessary to keep below (an obviously too high given the melting Arctic) 2 degrees Celsius guard rail (Hausfather, 2018)

[4] Here I am paraphrasing an arguments Klaus Lackner: https://youtu.be/iVkpNQlcMfw , and Peter Eisenberger have been making (Eisenberger, 2020). In 2010, 76% of GHG emissions are carbon, 16% methane, 6% nitrous oxide, and 2% F-gases: https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data. As approximately 25% of carbon released into the atmosphere that is not dissolved into the ocean stays in the atmosphere for thousands of years, and methane and nitrous oxide are removed more quickly (25 and 300 years, respectively). The focus of GHG climate change analysis (in this paper and others) is on carbon: http://blogs.edf.org/climate411/2008/02/26/ghg_lifetimes/

activities at a sufficiently rapid pace to avoid crossing more tipping points (Eisenberger, 2020). We need to work on all fronts. There is no question that over the long-term we must work to: address our existing unconscionable environmental justice issues; stop despoiling and destroying natural habitats; work on medium term soil and water-cycle climate regeneration as outlined in Baiman (2020: Section 4); and reduce human population encroachment into hitherto distant viral and bacterial pools increasing the incidence of global pandemics. But in the short term we must prevent immediate catastrophe by trying to limit the damage as much as possible through immediate technologically driven climate *triage,* and *restoration* that will include elements of our existing private, public, and non-profit fossil fuel infrastructure, and financial power and expertise.

The long and medium term social transformations that we on the left envision as a solution to the climate crises require a fundamental reorientation of our political economy, including both *forces* (technologies) and *relations* (social organization) of production that will likely take decades, if not centuries, to accomplish on a global scale. But the climate crisis will not wait for us to achieve this kind of transformation of our economies and societies. The clear record of the last few decades indicates that this method of massive political economic transformation has been inadequate to the task of reducing, let alone ending and reversing, global fossil-fuel use and GHG emissions, at near the rate that would be required to begin to slow down and reverse the climate crisis, see Figure 1 below.

Figure 1: The Failure of Global Climate Mitigation and Adaptation Policy



The **thick black line** is the atmospheric concentration of carbon dioxide measured from Mauna Loa Observatory, after removing the cyclical seasonal effect. **Blue bars** indicate independently sampled points of a 5-year running average of the yearly global CO_2 growth rates estimated by NOAA. Red arrows point to critical points with respect to the Paris targets of 1.5°C and 2.0°C.

Source: https://www.policyforum.net/dont-feed-the-fossil-fuel-elephant/

This should not be viewed as a fundamental political or moral failure of our species. There are objective reasons why this approach has largely failed. Modern civilization is dependent on energy growth and fossil fuels remain the most economical and widely available principal source of energy, and raw material inputs, for much of modern industrial civilization (Baiman, 2020).[5] This is slowly changing. Solar is catching up and, in many cases, is less expensive than fossil fuel in terms of unit energy cost (even without taking into account the externality costs of carbon dumping that most fossil fuel producers do not currently bear), but not in-terms of dispatchability and portability. Carbon-negative cement and concrete, and carbon-based substitutes for steel and aluminum, as well as organic-carbon based substitutes for feed and fertilizer, currently exist or are being developed. But especially for developing countries, and

[5] Lackner has estimated that there are only three currently known energy sources with the potential to power modern human civilization into the 22nd Century: fossil fuels, solar, and nuclear fusion. Other sources of sustainable energy like hydropower, wind, geothermal, and ocean wave, can and should be used but not do not the capacity or scalability to be primary sources of energy into the next century. For now, as practical (if ever) nuclear fusion appears to be decades away, the most realistic options are to continue carbon-neutral fossil fuel use (through CCS and DAC), and a combination of solar and synthetic carbon-based fuel for optimal storage and portability, (Lackner,2020).

particularly those who have large oil or other fossil fuel deposits and national resource based economies that are dependent on fossil fuel or natural resource exports – often by public companies, there are no other current viable options.[6] As discussed below, a REME economy will develop these alternatives but not overnight (Eisenberger, 2020).

Whether or not, GGND *mitigation* and *adaptation* measures reduce carbon emissions growth and level carbon emissions, or eliminate carbon emissions that are low hanging fruit in the short-run, these efforts alone will not produce a stable climate, and in the near future at full implementation are not realistic for many countries.[7] The truth is that it is likely that, at least in the near future, human civilization will continue to use fossil fuels that In 2019 made up 84% of global energy use and are a critical important for many other applications, though of course in the long-run they will need to be replaced Rapier, 2020).[8] The challenge is how to manage this transition.

Though natural, biotic or chemical, carbon drawdown techniques may be more efficient in drawing down carbon and some also may provide other economic benefits like nutrition or other useful organic substances, other techniques (including some that stimulate biotic drawdown) that are generally based on bio-mimicry with or without needed additional CSS, may be able to produce commercial grade CO2 that can used to produce synthetic carbon based fuels. This would allow for continuing to responsibly use zero carbon emitting fossil fuels for application where they remain the most efficient option by capturing and sequestering carbon equivalent to what they emit, and when this become more economical to replace these with liquid synthetic fuels made from hydrogen (made from water electrolysis or biomass), and oxygen and carbon (captured from the air or ocean) that still employ, the very efficient energy storage capacity of carbon compounds. This storage capacity is unlikely to be surpassed in terms of weight or volume by battery or other energy storage technologies, and these fuels can easily substitute for fossil fuels using an energy infrastructure that is the same, or very similar to that being used today.[9]

Which gets us to a final political point. The current framing that fossil fuel use is politically unacceptable, immoral, and evil, and that the only choice we have is total and comprehensive transformation to a non-carbon fuels based economy, is not only, as noted above, infeasible

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[6] This was driven home to me by two incidents: a) the President of Ecuador offering to not exploit newly discovered oil reserves in the Amazon rain-forests if the international community would reimburse Ecuador for forgone oil earnings, and after getting no response, moving ahead with oil extraction, b) Norway (one of the most social democratic, environmentally responsible, and wealthiest (per-capita) countries in the world) going ahead with exploitation of newly-discovered north sea-oil reserves using "green" technologies. If Norway cannot resist cannot fossil fuel exploitation, I doubt that any other major country in the world will be able to.

[7] This was officially acknowledged in 2018 as the IPCC stated that CDR was necessary to keep below (an obviously too high given the melting Arctic) 2 degrees Celsius guard rail (Hausfather, 2018): https://www.carbonbrief.org/analysis-why-the-ipcc-1-5c-report-expanded-the-carbon-budget

[8] https://www.forbes.com/sites/rrapier/2020/06/20/bp-review-new-highs-in-global-energy-consumption-and-carbon-emissions-in-2019/?sh=d68448966a16

[9] https://batteryuniversity.com/learn/archive/batteries_against_fossil_fuel

and unnecessary, but may have also become an obstacle for progress toward a practical climate change solution.

As the impossibility of societies and economies around the world reaching this lofty standard of climate “purity” is now obvious, this framing leads to a narrative of increasing inevitable impending climate disaster that is so pervasive that it's become an inevitable “fact” in much of the climate community. This has led to pervasive despair, inability to think about this seemingly insolvable problem, and political demobilization.

This framing needs to be replaced with a practical and realistic waste management and carbon cycle framework – see below. We need to be pointing out that *climate change is fundamentally a* closing the carbon cycle (REME) *reuse problem* or, as it is likely to be impossible to reuse as much carbon as we need to sequester in the coming decades, a near-term *sequestering problem.* A stable climate can, and must, due to the time urgency, be restored within existing capitalist social and economic systems and with current and evolving technologies, but we need a GGND that includes Arctic Sea Ice climate *triage* and Carbon Cycle climate *restoration* to do this. This would be a GGND that works for a REME technological and economic transformation toward greater global growth and equity that would support and make possible (by preventing civilization and species climate catastrophe and eliminating or reducing energy and materials scarcity) a democratic socialist political and economic transformation over the long term – see discussion below (Eisenberger, 2020).

II) Saving Arctic Sea-Ice Climate *Triage*

Nothing I say about this topic will be news to climate scientists who have been carefully and methodically following humanity's race toward the cliff for decades. Furthermore, my purpose here is not so much to further alarm people (anyone reading this is probably sufficiently alarmed already) but to point out possible *triage* remedies that would temporarily allow us *to set back the clock* and avoid, what appears to be the most catastrophic and certain to occur without direct counter-intervention within one or two decades, arctic sea-ice disappearance climate tipping point, have been proposed and should be further investigated and piloted now.

Melting Arctic sea-ice is the first major climate tipping point because if this happens the global climate will be abruptly and dramatically impacted (Lenton et al. 2008) (Wang and Hausfather 2020). Melting Arctic ice, unlike the Greenland and Antarctic ice-sheets, is not voluminous enough to cause massive sea level rise, so this is not the major effect that makes this a climate tipping point. Rather this would be an abrupt and catastrophic global climate tipping point for, at least, the following reasons:[10]

[10] Copious evidence from the most recent NOAA 12/8/2020 Arctic Report Card amplifies the urgent need to stop and reverse Arctic warming: https://arctic.noaa.gov/Report-Card/Report-Card-2020 .

a) Numerous studies using different methodologies and data estimate that because of loss of polar reflectivity (or "albedo") when the ice is replaced by ocean water, Arctic sea-ice melting would lead to an increase relative in net global heating from the sun of about 0.5 W/m^2 (Watts per square meter) from its level in 2016 due to increased ocean solar radiation absorption.[11] This heating impact, based on current trends, would be roughly equal to that of 17.3 years of global green-house gas (GHG) emissions relative to the 2016 base level of CO2 in the atmosphere.[12] At the current average global GHG emission rate of about 40 GT CO^2 Eq GHG emissions per year, a GHG increase of this magnitude would blow through most 1.5 C "carbon budget" estimates in one abrupt event.[13]

In addition to this direct "albedo" effect, loss of Arctic sea-ice has other potentially catastrophic effects on global climate:

b) The increased solar polar heating from the loss of reflectivity will no longer be absorbed by melting ice that captures heat without raising water or surface air temperatures, but rather directly by the ocean water. This is likely to accelerate the pace of water warming beyond the direct albedo warming effect that has been estimated using existing relationships between solar heating and global temperature increases. A "warm water time bomb" has

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[11] The 0.5 W/m^2 range is based on real data analysis by four different studies using different methods and data sources: 0.71 W/m^2 (Pistone et al., 2019), 0.65 $Watts/m^2$ (Flanner et al, 2011), 0.825 W/m^2 (Cao et al, 2015) and 0.68 W/m^2 (Hudson, 2011), cited in (Pistone et al, 2019: 7476). The 0.5 $Watts/m^2$ is derived by taking the average of these four estimates 0.71625 W/m^2 for global warming from 1979 and subtracting estimated warming from 1979 to 2016 of 0.21 W/m^2 (Pistone et al, 2019: 7476). Wang and Hausfather (2020: 49), cite a (Hudson, 2011) modeling analysis that found that an ice-free summer artic would increase warming by 0.3 W/m^2 and accelerate global warming by about 8%. However, Pistone et al. (2019: 7475) note that observed arctic sea ice retreat per degree of global temperature increase is occurring more rapidly than the predictions of any of a suite of recent climate models and 2.1 times faster than the average of these models.

[12] The authors use the approximate formula f = (5.35 W/m^2) ln(x/R) were f is radiative forcing relative to R, and x atmospheric concentration (Pistone et al, 2019, p. 7479). For a given R and f this implies that: $x = Re^{(\frac{f}{5.35})}$. The authors used f=0.71 W/m^2 which they estimate is estimated increased radiative forcing from 1979 to an ice-free Arctic, but used 2016 400 CO2 ppm as the relative base value for R to get 456.8 as the CO2 ppm after Arctic sea-ice melting for an increase of 56.8 CO2 ppm. They then multiply this by 7.77 and divide by 0.44 to get 1002.5 increased GT CO2 equivalent. By dividing this by average current emissions of 40 GT they derive an estimate of 25.1 years of GHG emissions at current levels. However, they estimate 0.5 not 0.71 as radiative forcing from 2016 (Pistone et al, 2019, p. 7476). Correctly starting with f=0.5 W/m^2 and using the same procedure as above produces an estimate of 17.3 years of 40 GT emissions from 2016.

[13] Increased warming from 2016 of 0.5 W/m^2 is, based on current trends, estimated to be equal to the impact of emitting 691.9 GT CO^2 Eq (billions of metric tons of CO^2 equivalent) more GHG into the atmosphere – see Appendix. For the sake of comparison, an average of six carbon budget estimates of a 66% chance of not exceeding global warming of 1.5C allows for only 562.5 GT CO^2 Eq, or 14 years (since Jan. 2018) at 40 GT a year, of cumulative carbon emissions (Hausfather, 2018). 562.5 GT CO^2 Eq is an average of the six "Combined Observations and ESM" carbon budget point estimates provided in the first figure: "Remaining carbon budget for a 66% Chance of less than 1.5C warming" in Hausfather (2018): https://www.carbonbrief.org/analysis-how-much-carbon-budget-is-left-to-limit-global-warming-to-1-5c .

already been discovered accumulating under the Arctic that is accelerating ice loss in the region (Coghlan, 2018).[14]

c) "Arctic amplification", or disproportionate Arctic warming relative to mid-latitudes, impacts major atmospheric and oceanic circulation currents that drive much of the global climate. The warming Arctic's weakening of the Polar Jet Stream is producing extreme climate events in the northern hemisphere (Alfred Wegener Institute, 2019).[15] Similarly, the rapidly warming Arctic appears to be weakening the Gulf Stream (Rahmstorf, 2020).[16] A complete loss of Arctic sea-ice may cause the cold center of the Jet stream to move toward northern Greenland, 17 degrees latitude south of the north pole, exacerbating extreme planetary climate crises (Beckwith, 2018).[17]

d) Warming Arctic atmospheric and ocean water, increased Arctic humidity, and wobbly and slowing Jet Stream and Polar Vortex circulations causing more blocking events over Greenland (Garthwaite, 2018) [18], are accelerating the risk of longer-term and even more calamitous climate tipping points like Greenland Ice Sheet melting (Harvey, 2016)[19], and increased permafrost melt leading to amplified carbon dioxide and methane GHG release (Francis, 2018).[20]

Arctic Summer Sea-Ice Disappearance

As can be seen in Figure 1 below: the exponential, log, and 2nd order polynomial, fits for September Arctic Sea-Ice go to zero in 2025; the linear fit in 2027; and the Gompertz fit (with the highest displayed R2) appears to asymptote with the horizontal axis outside of the plot sometime between 2030 and 2040. In other words, direct measurement is telling us that if current trends continue there will be a zero "blue ocean" September Arctic sea-Ice event by 2025-2040.

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[14] https://www.newscientist.com/article/2178160-a-warm-water-time-bomb-could-spell-disaster-for-arctic-sea-ice/

[15] https://www.sciencedaily.com/releases/2019/05/190528140115.htm

[16] http://www.realclimate.org/index.php/archives/2020/09/new-studies-confirm-weakening-of-the-gulf-stream-circulation-amoc/

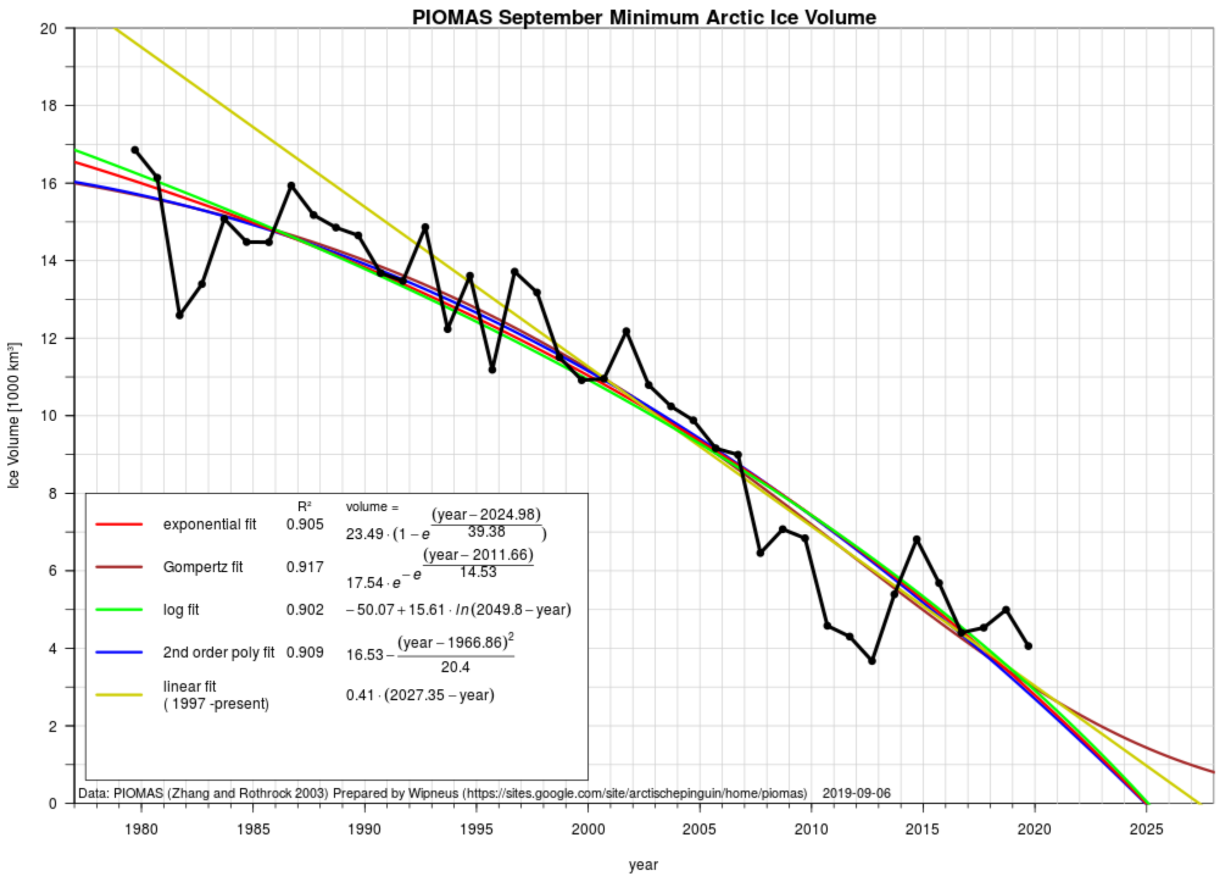
[17] https://www.youtube.com/watch?v=bFme3C9e-cs

[18] https://www.sciencedaily.com/releases/2018/07/180710110137.htm

[19] https://www.washingtonpost.com/news/energy-environment/wp/2016/05/02/dominoes-fall-vanishing-arctic-ice-shifts-jet-stream-melts-greenland-glaciers/

[20] https://www.scientificamerican.com/article/the-arctic-is-breaking-climate-records-altering-weather-worldwide/?print=true

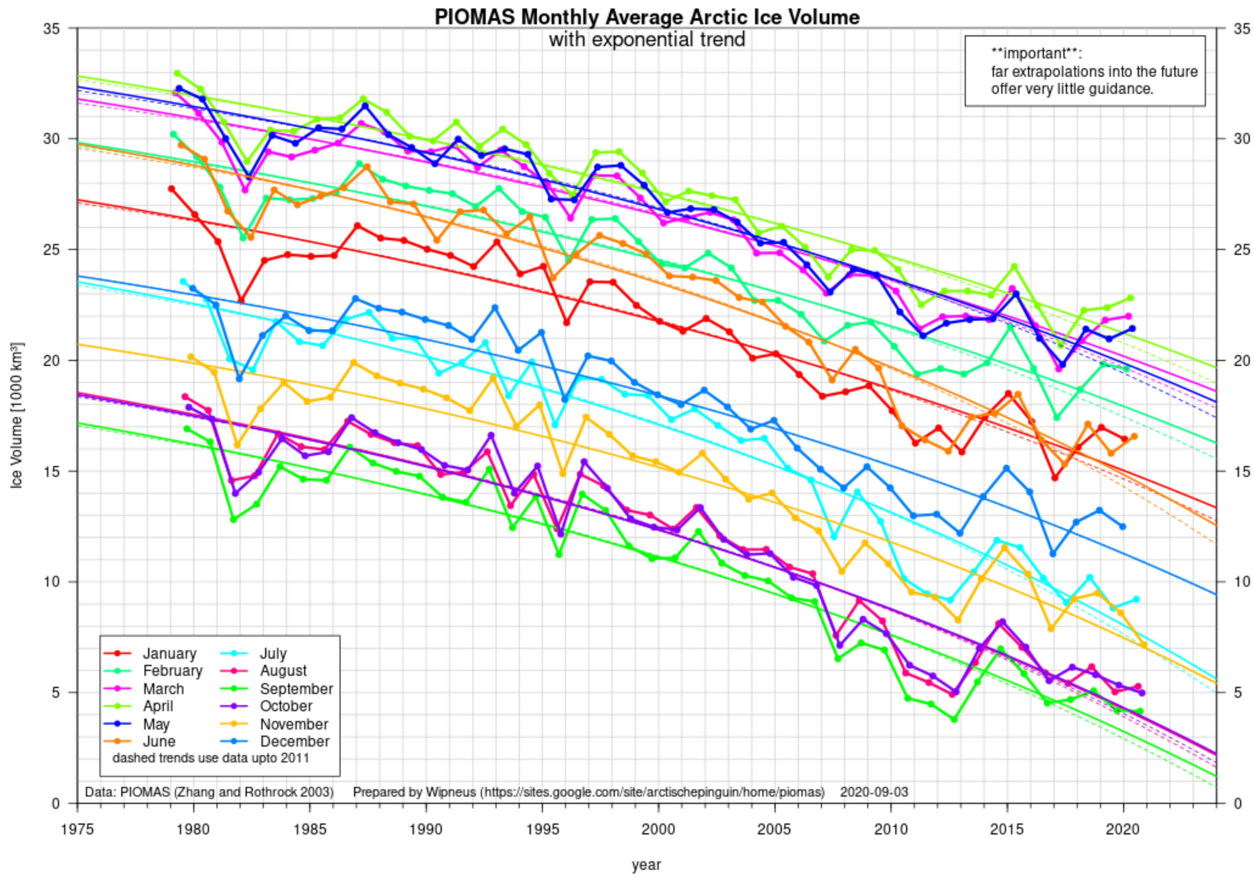
Figure 2: September Minimum Arctic Sea-Ice Volume 1979-2020



Source: https://sites.google.com/site/arctischepinguin/home/piomas

Complete Arctic summer (May – September) sea-ice melting will follow some years later as can be seen in Figure 2 below.

Figure 3: Monthly Average Arctic-Sea Ice Volume 1979-2020



Source: https://sites.google.com/site/arctischepinguin/home/piomas

Climate triage methods for saving the Arctic sea ice

These methods include the following, see Table 1 below:

Table 1: Methods for Saving Arctic Sea-Ice with Cost Estimates

Method	$ Cost/Yr	$ Start Up Funding	Persistence of Start Up Funding (Yrs)	Current Scope
Tropospheric Iron Salt Aerosol Injection (ISA)	1-5 B	2 M	0.1	Global. Has potential to temporarily restore Arctic Sea Ice loss and temporarily reverse many of the most harmful climate change effects. Also removes methane and fertilizes the ocean possibly drawing down carbon dioxide.
Stratospheric Aerosol Injection (SAI)	2 - 5 B	Complete	1.5	Global. Has potential to temporarily restore Arctic Sea Ice loss and temporarily reverse many of the most harmful climate
Floating Sand	5 B	2 M	0.5	Mainly Sea-Ice. Maybe Glaciers.
Ice Thickening with Sea Water Spray	10 B	5 M	1.0	Sea-Ice only.
Marine Cloud Brightening (MCB)	100 M - 5B	10 M	0.1	Feasability is being funded for coral reef saving.
Nano-Bubble Foam		3 M	0.1	Tropical and subtropical waters

Sources: (Fiekowsky et al, 2019: Table 3, p. 25) (Oeste et al, 2017)[21] (Smith and Wagner, 2018)[22] (Field et al, 2018)[23] (Desch et al, 2016)[24] (Mims, 2009)[25] (Kostigen, 2020, p. 108-117) (Clark, 2018)[26] (Seitz, 2010)[27]

Detailed descriptions of these methods and further references can be found in the listed sources.

It appears that none of them is prohibitive in cost terms as, for example, even the maximal cost of $10 B is a tiny fraction of the current trillions of dollars in allocations for (much needed) Covid relief in the US alone. Considering the likely catastrophic impact and global suffering that loss of Arctic sea ice would result in, this seems like a very small preventive cost.

Moreover, two of the methods, ISA and SAI, appear to offer the potential to temporarily slow or stop not just Arctic Sea Ice loss, but global warming in general, and one of them, ISA, may also, by drawing down carbon, with longer-term, relatively permanent, climate restoration.

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21 https://esd.copernicus.org/articles/8/1/2017/esd-8-1-2017.pdf
22 https://iopscience.iop.org/article/10.1088/1748-9326/aae98d/pdf
23 https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018EF000820
24 https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2016EF000410
25 https://www.scientificamerican.com/article/albedo-yachts-and-marine-clouds/
26 https://climategamechangers.org/wp-content/uploads/Fiztop.pdf
27 https://arxiv.org/ftp/arxiv/papers/1010/1010.5823.pdf

The ISA method attempts to mimic the way in which natural iron mineral dust supported global cooling during glacial periods and currently. Oeste et al (2017) review six different ways in which iron salt aerosols may support global cooling as well as ocean fertilization and carbon drawdown. They estimate that adding 180 gram of ISA precursor FEOOH per ton of combusted lignite coal to cleaned power station flue gas for just 100 large coal burning power stations would have a global cooling effect equivalent to eliminating current global CO2 emissions of 40 GT per year. The iron only needs to be elevated to heights of 1000 meters above ground and would stay in the troposphere for only weeks which would allow for quick cessation and reversibility of its impact in the event of unintentional adverse side effects. This contrasts favorably with the impact of SAI that would last 1 or 2 years and would have to be injected by specially designed aircraft for much higher up stratospheric injection. Also, unlike SAI, ISA may not only be climate triage method, but an ocean fertilization and CDR climate restoration method (Oeste et al, 2017, p. 33-35).

The second method with potential global climate cooling triage impact, SAI, mimics the way in which large scale volcanic eruptions temporarily cool the planet by dispersing sulfate aerosols that reflect sunlight into the stratosphere (Watson, 1997).[28] For example, it is estimated that the Mount Pinatubo volcanic eruption in the Philippines released about 15 million tons of sulfur into the stratosphere and cooled the planet by about 0.6 degrees Celsius for 15 months (NASA, 2011).[29] Stratospheric Aerosol Injection (SAI) would mimic this by similarly, releasing sulfate aerosols (or some other agent) that would uniformly disperse in the stratosphere to cool the planet, and especially the polar regions, until more lasting solutions are put in place.

Prominent among these proposals has been that of David Keith, a professor of applied physics at Harvard, who has developed a detailed plan of action that, based on multiple state of the art climate models, would achieve an about 1.5 degree Celsius average cooling across the planet relative to scenarios with 2xCO2 (that would increase average temperature by about 2.5 degrees Celsius in these models) with no average change in precipitation, and reduced variation, and maximum, global temperatures and precipitation levels (MacMartin et al, 2017).[30] More specifically, models have indicated that this proposal would reduce a) variations in water availability, b) extreme precipitation, c) tropical cyclones, and d) extreme temperatures. Keith's proposal is to inject 1.5 million tons of sulfur per year into the stratosphere at an estimated cost of only $ 5 billion to build 100 customized aircraft that would make about 120,000 flights per year to do this (commercial flights per year are about 40

[28] The 1991 Mt. Pinatubo eruption also let to an oxygen concentration "pulse" in the Southern Ocean that is hypothesized to have been the result of volcanic iron dispersal causing a phytoplankton bloom in the Southern Ocean that drew down carbon and released oxygen – a carbon draw-down (and longer term global cooling) effect that OIF (see below) seeks to mimic (Watson, 1997).

[29] https://earthobservatory.nasa.gov/images/1510/global-effects-of-mount-pinatubo

[30] For a nice summary of how SRM could serve to "flatten the curve" until GHG mitigation and carbon draw-down are able to stabilize the climate, see MacMartin et al. (2017).

million) (Keith 2019) (Smith and Wagner, 2018).[31] In order to mitigate potentially harmful effects of sulfate aerosol into the stratosphere including ozone loss and water vapor concentration that could cause additional ozone loss and surface warming, Keith et al (2016) have suggested using calcite instead of sulfur aerosols.[32] They claim that calcite particles might help rather than damage the stratospheric ozone layer and also be roughly ten times more efficient than sulfur aerosols in reducing solar radiation.

Marine Cloud Brightening (MCB) is a more localized form solar radiation management that mimics the documented effect of sulfates from ocean going ship exhaust that become seed crystals for brightening marine clouds and reducing solar radiative forcing (Fiekowsky et al, 2019, p. 21). This method was first proposed by cloud physicist John Latham in 1990 (Latham, 1990)[33] and much research has been done on this since that time - see Marine Cloud Brightening Project[34] Stephen Salter has designed wave and wind powered ocean going drone "Albedo Yachts" that would spay sea water up into the clouds to achieve MCB.[35] Though this form of localized solar radiation management would appear to be less of a "geoengineering lift" than SAI in terms of international governance, it may actually be more problematic as targeted, as opposed to uniform global, cooling would have heterogenous climate impacts that may be difficult to predict. However, this may be an important form of at least, preliminary localized, climate triage for Arctic Sea-Ice and Coral Reefs that are also dying at an alarming rate (Kostigen, 2020, 114-117).

III) Carbon Cycle Climate Restoration through CDR and CCSU[36]

Carbon Direct Removal (CDR) climate *restoration* methods expand on GGND-like *mitigation* and *adaptation* measures that reduce carbon emissions by developing a more carbon (and GHG) efficient economy and society and using renewable energy. They also expand on natural methods for carbon drawdown, including most of the medium-term soil and water cycle climate *regeneration* and fifty-four (or eighty in the complete Project Drawdown list) GHG drawdown methods discussed in Baiman (2020). Though they often designed to mimic or enhance natural processes, CDR methods are direct, or active, human interventions to

[31] https://iopscience.iop.org/article/10.1088/1748-9326/aae98d/pdf
[32] https://www.pnas.org/content/pnas/113/52/14910.full.pdf
[33] https://www.nature.com/articles/347339b0
[34] https://mcbproject.org/research.html
[35] https://www.scientificamerican.com/article/albedo-yachts-and-marine-clouds/
[36] This paper focuses on carbon. For ongoing methods to drawdown other GHGs see for example (Project Drawdown, 2018).

accelerate or supplement natural methods for the removal and sequestering of carbon from the atmosphere and ocean.[37]

CDR projects are based on either biology or chemistry, remove carbon from the atmosphere or the ocean, and sometimes also produce economically useful output(s). Atmospheric and oceanic carbon are in rough balance with approximately 10 year lag (Revelle and Suess, 1957)[38], so that carbon has to be removed from both places to reduce its concentration in either. The objective of CDR is to sequester the carbon over the long-term (more than 100 years) in the land or deep ocean. From an economic view point they range from methods that: a) are potentially profitable without additional public compliance or subsidy regimes, b) require public compliance regulation to create an economically feasible offset market, c) require both compliance regulation and public subsidies and possibly direct public or non-profit provision to be economically feasible. Tables 2-5 below are a partial list of CDR methods, many of which are being implemented and scaled up as we speak.

[37] For example, the two compliance offset protocols for California's cap and trade law that primarily address carbon (Urban forest, and US forest) address carbon *mitigation* or natural drawdown. Similarly, the four other protocols (Livestock, Mine Methane Capture, Ozone Depleting Substances and Rice Cultivation) address methane and ozone depleting substances mitigation: https://ww2.arb.ca.gov/our-work/programs/compliance-offset-program/compliance-offset-protocols .

[38] Carbon Dioxide Exchange between Atmosphere and Oceans and the Question of an Increase in Atmospheric CO2 during the Past Decades, " *Tellus* 9 (1957) 18-27.

Table 2: Carbon Direct Capture from the Ocean using Biological Processes

Process	Method	Financeability	Scalability of Carbon Capture (>25 GT CO2/Yr)	Permanence (100 Yrs +)	Co-Benefits
Biological	Marine permaculture/ Seagrass, Kelp, or Macro Algae with upwelling	Potential profit though sales of kelp and commercial fishing licenses	Yes, either through sunk bio-mass or direct CCS	Yes	Food, Biofuel, other industrial products, incrased ocean biodiversity and conservation
Biological	Growing Phytoplankton with upwelling	Potential profit though sales of commercial fishing licenses	Yes, either through sunk bio-mass or direct CCS	Yes	Food, Biofuel, other industrial products, incrased ocean biodiversity and conservation
Biological	Costal Blue carbon in seagrass meadows, mangroves, salt marshes etc.	Would need public subsidies, public compliance, or charitable funding.	Very important carbon sinks but not scalable to CDR at GT level	Yes, if habitat survives	Water quality enhancement, nursuries for shell fish and fin fish, erosion protection
Biological	Ocean Downwelling	Would need public subsidies, public compliance, or charitable funding.	Unproven.	Possibly, but more reseach is needed.	NA

Sources: (Fiekowsky et al, 2020, p. 11), (Ack et al, 2020)[39], (Bryce, 2020)[40] (Krause-Jensen and Duarte, 2016)[41]

[39] https://www.youtube.com/watch?v=wIMHLVRlx-k
[40] https://ensia.com/features/kelp-carbon-sequestration-climate-mitigation/
[41] https://www.nature.com/articles/ngeo2790?report=reader

Table 3: Carbon Direct Capture from the Ocean using Chemical Processes

Process	Method	Financeability	Scalability of Carbon Capture (>25 GT CO2/Yr)	Permanence (100 Yrs +)	Co-Benefits
Chemical	Ocean Iron Fertilization for growing Pytoplankton (OIF)	Potential profit though sales of kelp and commercial fishing licenses	Yes, either through sunk bio-mass or direct CCS	Yes	Food, Biofuel, other industrial products
Chemical	Enhanced weathering Alkalinazation using Olivine, Limestone, or Peridodite sometimes with ocean waves	Potential profit, for example by using Olivine as sand substitute for beach nourishment.	Yes, by increasing oceans appitite for CO2. Olivine is abundant and located around the world.	Yes	Reduced Ocean acidification over time
Chemical	Direct Ocean Alkalinazation	Would need public subsidies, public compliance, or charitable funding.	Yes, by increasing oceans appitite for CO2.	Yes	Localized reduction of Ocean acidification benefiting coral reefs and other ocean life during lag of increased carbon absorption
Chemical	Using Elecrochemistry methods to forcibly remove CO2 from seawater	Unkown	Unkown	Unkown	Currently benchtop scale demos

Sources: (Fiekowsky et al, 2020, p. 11), (Ack et al, 2020)[42] (Yoon et al, 2018)[43] (Oeste et al, 2017)[44](Emerson, 2019)[45] (Ilyina et al, 2013)[46]

[42] https://www.youtube.com/watch?v=wIMHLVRlx-k
[43] https://bg.copernicus.org/articles/15/5847/2018/bg-15-5847-2018.pdf
[44] https://esd.copernicus.org/articles/8/1/2017/esd-8-1-2017.pdf
[45] https://www.frontiersin.org/articles/10.3389/fmars.2019.00022/full
[46] https://epic.awi.de/id/eprint/34488/1/Ilyina13Wolf-Gladrow_Munhoven_Heinze.pdf

Table 4: Carbon Direct Capture from the Air Using Biological Processes

Process	Method	Financeability	Scalability of Carbon Capture (>25 GT CO2/Yr)	Permanence (100 Yrs +)	Co-Benefits
Biological	Soil/water cycle/Ag, Forestry, improved land use.	Switch to soil-carbon-sink improved water-cycle in Ag practice could be profitable but improved land use more generally would probably require public subsidies, compliance, or charitable funding.	No, scalability estimated at 1-11 GT CO2/Yr	Varies depending on situation and consistency over time.	Necessary in long-term to preserve top soil for sustainable agriculture, and green space for humans and other species.
Biological	Improved Livestock pasturing and raising also reducing methane production	Probably yes, as improved methods increase longterm health and viability of animal husbandry.	No, not that large a portion of CO2 emissions.	Varies depending on situation and consistency over time. Measured protocols have been developed, for example for California Cap and Trade law.	Necessary in long-term to preserve top soil for sustainable agriculture, and green space for humans and other species.
Biological	Bioenergy with carbon capture and storage BCCS	No, not competitive with fossil and other renewable energy sources, and competes for land use with food and forests.	No, Scalability estimated at 0-8 GT CO2/Yr	Yes	Provides carbon neutral energy

Sources: (Fiekowsky et al, 2020, p. 11), (Jehne, 2017), (Project Drawdown, 2017), (National Academy of Sciences, 2019), (Carter et al, 2020)[47]

[47] https://youtu.be/wFf1bWfgJ-A

Table 5: Carbon Direct Capture from the Air Using Chemical Processes

Process	Method	Financeability	Scalability of Carbon Capture (>25 GT CO2/Yr)	Permanence (100 Yrs +)	Co-Benefits
Chemical	Carbon negative synthitic limestone/building materials	Yes, is already being produced at competitive costs with current building materials	Yes, as current rock production alone is estimated at 53 GT per year.	Yes	Link to Reneable Energy and Materials Economy (REME) could power necessasry rapid scaling up of CDR
Chemical	Point source air capture and sequestration	REME for-profit co-production probably necessary for rapid scaling up. But also needs compliance and public policy support to reach scale.	Not quite, as global carbon emissions for electricity production in 2018 estimated at 22 GT per year	Yes, if sequestered in rock, aquifers, building materials or other stable products	Reduced carbon in atmosphere and REME source for building materials, fuels, fertilizers, pharmaceuticals, chemicals, and polymers.
Chemical	Direct Air Capture and sequestration	REME for-profit co-production probably necessary for rapid scaling up. But also needs compliance and public policy support to reach scale.	Yes, there is much too much carbon in the atomosphere and oceans. Estimated 1,710 GT needs to be removed to get to stable	Yes, if sequestered in rock, aquifers, building materials or other stable products	Reduced carbon in atmosphere and REME source for building materials, fuels, fertilizers, pharmaceuticals, chemicals, and polymers.
Chemical	Weathering/peridodite rock use	Unkown	Unkown	Unkown	May be more viable in oceans using shoreline wave action.

Sources: (Fiekowsky et al, 2020, p. 11), (Kauk et al, 2020)[48], (Soltoff, 2019)[49], (Lim et al, 2020)[50] (Lackner et al, 2012) (Rosenblum and Chodosh, 2019)[51] (Beerling et al, 2020)[52]

48 https://www.youtube.com/watch?v=eAjI3x_uSj0
49 https://www.greenbiz.com/article/inside-exxonmobils-hookup-carbon-removal-venture-global-thermostat
50 https://youtu.be/wX9-_UtdsDI
51 https://www.popsci.com/story/technology/best-engineering-innovations-2019/
52 https://www.nature.com/articles/s41586-020-2448-9

Methods, that currently (as of 2020) appear to be farthest along on the path to large scale implementation are two atmosphere-based chemical methods: point-source and ambient CDR capture from the air, another atmosphere-based (or land-based) method: carbon-negative building materials, and two ocean-based biological method: ocean fertilization and marine permaculture arrays with upwelling.

Numerous companies including Blue Planet and Carboncure are currently producing carbon negative, or reduced carbon, concrete, aggregate, and other building materials. This has been used in construction for the San Francisco airport (Blue Planet, 2020)[53] (CaronCure, 2020)[54] (Kauk et al, 2020). Fiekowsky et al (2020, p. 20) estimate costs of synthetic stone at $50/ton at capacity would be competitive with quarried stone at $30-$200 a ton, and that at $250 B per year capacity could be built up by 5 billion tons/yr and would have an IRR of 15%. Carbon negative building materials are currently one of the most understood and easily measured methods of carbon capture and use (a version of CCSU) accepted in voluntary CDR markets. Amazon for example, has teamed up with CarbonCure to help get to zero emission by 2040.[55] Concrete is the most widely used building material in the world as twice as much concrete is used as any other building material (Gagg, 2014)[56], and construction materials (at 35 GT in 2009) make up over a third of all materials used globally by humans (other major categories are: biomass, fossil energy, and ores and industrial materials) (Eisenberger, 2020, Figure 2).

Ocean iron fertilization (OIF) was implemented in 2012 in Gulf of Alaska and promptly shut down ostensibly due to lack of proper regulation and oversite (Lukacs, 2012).[57] However, more recent rigorous studies suggest that the if carefully implemented and monitored, the method may have enormous potential CDR drawdown (Yoon et al.,2018). Fiekowsky et al. (2020) estimate that one 60 mile (100 km) square OIF "pasture" could sequester 200 million tons of CO2 per year, so that 300 of these pastures could drawdown 50 GT CO2 per year. At relatively small implementation costs $ 300 million a year for 10 years for ½ GT drawdown per year, could even be profitable due to stimulation of fishing (IRR 20%), with additional public monitoring and oversite cost of $20 million per year.

Marine permaculture or more broadly sea grass or macro algae methods, are being implemented around the world and may have ocean carbon removal potential that may be up to 20 times faster than that of plants on land depending on sequestration in the bottom of the ocean (one study suggests about 11 percent) (Bryce, 2020). Importantly, they can be, and are in at least 35 countries including China, Japan, and S. Korea, grown for food and other products, and thus have the potential to also provide useful commercial products that may speed their

[53] https://www.blueplanet-ltd.com/
[54] https://www.carboncure.com/
[55] https://www.carboncure.com/news/amazon-and-breakthrough-energy-ventures-co-lead-investment-in-cleantech-company-carboncure/
[56] https://www.sciencedirect.com/science/article/abs/pii/S1350630714000387
[57] https://www.theguardian.com/environment/2012/oct/15/pacific-iron-fertilisation-geoengineering

deployment (Taylor, 2019)[58] Prototype Kelp permaculture arrays, using wave energy upwelling to draw nutrients from the deeper ocean, designed by Brian Von Herzen are being deployed in the Philippines with the goal of not only drawing down carbon but revitalizing ocean shell fish and fisheries. Roughly 70% of the earth is covered in ocean so that, unlike on land, there is enormous additional potential for biological, area-intensive, CDR. Fiekowsky et al (2020, p. 20) estimate that building Kelp permaculture arrays to cover 1 million km squared by per for 10 years would cost about $100 B/Yr, could be monitored by public officials for $10 m year, and have an IRR of 15%. However, their CDR potential may be fairly limited as a km squared array is estimated to remove about 500 tons of CO2 a year (Fiekowsky et al, 2020, p. 25).

Multiple point-source carbon air capture plants that capture carbon from a concentrated point source carbon emitter are currently operational and capturing carbon at scales of thousands of tons a year.[59] Global-Thermostat, a company founded and run by two academics Chichilnisky and Eisenberger who believe that rapid scaling up of DAC (Direct Air Capture) and CCSU is critical to solving the climate crisis, has in collaboration with Exon-Mobile built two plants that capture 3,000 – 4,000 tons of CO2 a year and is scaling up to a 50,000 ton CO2 a year plant (Soltoff, 2019). The plants are designed to added to existing natural gas fired electric power generators to draw down carbon from their flue emissions and from the air when the gas plant is operating using either using excess heat generated by the power plants, and exclusively from the air using concentrated solar energy when the gas plant is not operating with a net carbon negative outcome (Eisenberger, 2020, p. 11). The idea behind these plants is to use continued natural gas fossil fuel use to rapidly scale up CCSU to advance toward an REME (Eisenberger, 2020).

Unlike point source CDR methods, Direct Air Capture (DAC) captures carbon from ambient air. Another academic and former colleague of Eisenberger now at ASU, Klaus Lackner, who was the first to conceive of and prove that DAC is feasible, and his team, have developed "mechanical trees" that can remove carbon from the atmosphere much faster than ordinary land or sea based organisms. Just like real trees, Lackner's mechanical trees capture carbon passively by letting the wind blow it through them, reducing energy costs per ton of carbon captured to below $100 per ton and are not limited by access to a carbon rich point-source (ASUNow, 2020).[60] One tree can draw down almost 1 metric ton of CO2 a day, and a cluster of 1,200, like the one that Silicon Kingdom Holdings, the company that Lackner and ASU are working with, is planning to build in California, 36,500 metric tons a year. For comparison, a normal tree removes approximately 48 pounds CO2 a day, or almost 46 years to remove 1 metric ton. Large scale "farms" of 120,000 trees are estimated to be able to 4 million tons of C02 annually and will occupy a land area of about one square mile. 250 of these farms could

[58] https://cen.acs.org/environment/sustainability/Seaweed-farming-food-fuels/97/i34
[59] Examples include: https://carbonengineering.com/ , https://www.carbfix.com/, and https://globalthermostat.com/ .
[60] https://asunow.asu.edu/20190429-solutions-lackner-carbon-capture-technology-moves-commercialization

thus remove a gigaton of CO_2 (ASU Now, 2019).[61] This is critical as forests of trees, bamboo or Buffalo Grass can also potentially draw down vast amounts of carbon but over much larger areas.

On issue not addressed by many of these methods is carbon sequestration and use. *Sequestration* methods include mineralization, geological sequestration in basalt rock formations, sequestration in saline aquafers, or in enhanced oil recovery wells. It has shown for example that about 72% of CO_2 captured by CarbFix and injected into Basalt rock formations mineralized within about 2 years (Pogge von Standmann et al, 2019).[62] As Basalt rock, saline aquafers, and oil wells are widely available, there is not a near term problem with sequestration of even thousands of gigatons of carbon (Lackner, 2020).[63] Carbon *use* methods are discussed below and in Eisenberger (2020, 2020a).

[61] https://asunow.asu.edu/20191205-popular-science-picks-lackner-mechanicaltree-2019-top-technology
[62] https://www.nature.com/articles/s41467-019-10003-8
[63] https://www.youtube.com/watch?v=s5DEq-4ZpFU

IV) Climate Policy for a Renewable Energy and Materials Economy (REME)[64]

At the most general level we need to change our framing of climate policy. Though we need to urgently eliminate, and where this is not realistically possible, reduce, GHG emissions as much as possible, and multiple actors, most notably fossil fuel interests, have been criminally complicit in deliberately misleading the public and sabotaging efforts to effectively address the climate crisis, sometimes in direct contradiction to their own data and research to protect their narrow self-interests, in order to mobilize the world and rapidly build on our existing infrastructure and expertise, a forward thinking and optimistic climate policy framing will be necessary. The climate *crisis* needs to be turned into the climate *opportunity* for a fundamental transformation of the *forces of production* from "hunter-gatherers" of carbon-based fossil fuel energy and materials and one-way utilizers of the oxidization part of the carbon cycle, to "cultivators" of a "Human Designed Carbon Cycle Run by Renewable Energy" (HDCCRRE) (Eisengerger, 2020).

Up until now humans have relied on nature to close the carbon cycle for *reuse* through photosynthesis and *sequestration* through weathering mineralization and ocean sinks in a process of Carbon Capture Sequestration and Use (CCSU). But we have reached the limits of our hunter-gatherer unidirectional utilization of carbon-based energies and materials pillaging of nature, as our planets atmosphere and oceans can no longer absorb the excess carbon imbalance that we have created (Lackner, 2020). [65]

On the *use* side, nature is forcing us to close the cycle by taking over the production of carbon-based renewable "fuel" in a process of human- designed "photosynthesis" of synthetic hydro-carbon fuel production using renewable, currently mostly solar, energy, and human-designed renewable materials (initially mostly building materials: concrete, steel, and aluminum) from carbon fibers, graphene, and polymer composite building materials and renewable energy (Eisenberger, 2020, p. 18-22). Interestingly, one of many possible methods for addressing the other major link in this transition, biological or electro-chemical capturing of *hydrogen* using manageable levels renewable energy may be through closing the cycle for methane, the second largest GHG (Eisenberger, 2020a).

On the *sequestration* side, within a carbon-cycle framework, carbon is not a harmful pollutant but in conjunction with energy, a building block of life and of our material civilization. However, because of our one-way exploitation of its munificence we have been "storing", or dumping, too much of it in our atmosphere and oceans. We therefore need to either use it or store it somewhere else. In terms of sequestering, the issue not one of mitigation or adaptation through *flow* reduction, but rather a *stock* issue of cleaning up our planetary atmosphere and ocean dumpsite (Lackner, 2020).[66] As we are unlikely in the to be able to use enough of the

[66] https://www.youtube.com/watch?v=s5DEq-4ZpFU

stock of accumulated carbon that we need to remove from the atmosphere and ocean at a rapid enough pace to stabilize planetary climate, we are going to have to assist nature in sequestering it for long periods of time.[67]

Though we currently have dumped more carbon that we can possibly use in the atmosphere and ocean, in the future we may be able to adjust our use and sequestration, or carbon cycle management, in order to stabilize our climate and avoid geological “glacial” and “hot-house earth” periods driven by Milankovic and carbon cycle events (Broecker and Kunzig, 2009) (Eisenberger, 2020). Thus at some point we may be interested in “storing” carbon in an accessible way that will make it easy to utilize, but right now, to avoid catastrophe we need to remove and sequester what we cannot use in whatever way possible as quickly as we can.

Finally, in terms of general framing, as has been repeatedly pointed out, not just growth but *equity* is necessary to social transformation both for moral and political reasons. For this reason, sustainable energy use *and* social and economic transformations of the *relations of production* that increase environmental justice and overall equity and opportunity are central to the GGND vision. I have argued that for practical reasons of avoiding environmental catastrophe, we need to temporarily put aside a deep democratic socialist transformation of our *relations of production*, and focus on rapid transformation of our *forces of production* to implement Arctic Sea Ice triage and carbon-cycle restoration to a REME economy. But this does not mean that we need to abandon the equity focus of the GGND vision. In fact though focused on technology the REME vision also needs to, and does in Eisenberger’s framing, include a strong equity component of unleashing of human civilization from the limits and inequities of natural resource extraction economies and opening the opportunity of broad-based equitable global economic development based on almost unlimited renewable energy and materials use (Eisenberger, 2020, p. 3 – 14).

Though one may quibble with the notion that a REME economy will deliver a 6.1% growth rate for 50 years (Eisenberger, 2020, p. 13), the fact that for practical reasons we need to change our forces of production largely within our existing institutional infrastructure, and that we cannot wait for the much slower process of political and social transformation of our relations of production, as envisioned in some versions of the GGND, is I think irrefutable. In this sense Lackner’s practically oriented vision of an urgent “let’s just clean up the dump-site and solve this *waste management problem*” is correct. However, as a leftist it is hard to not resist the urge to view Eisenberger’s REME transformation from one-way carbon combustion and materials use “hunter gatherer” industrial civilization, to more complete HDCCRRE “cultivator” REME civilization, as possibly the opening to a world free of scarcity that allow an induce

[67] Based on calculations from recent data, 1,710 Gigatons of CO_2 need to be removed from the atmosphere to get back to 1989 level of 353 ppm. (K von Schuckmann et al., 2020) and (NOA, 2020): https://essd.copernicus.org/articles/12/2013/2020/ and https://www.esrl.noaa.gov/gmd/ccgg/trends/data.html in text below.

greater human *social relations of production* progress toward a democratic socialism or even democratic communism.

The most practical way to solve our climate crisis within a reasonable (climate dictated) timeframe is to:

a) Immediately implement immediate *climate triage* to prevent the Arctic Sea-Ice from melting as discussed in Section II) above.
b) Restrict and quickly eliminate further "carbon dumping" by setting up a mandatory "dumping fee" or "cap and trade" market for all carbon dumped into the atmosphere or ocean with a cap that very rapidly goes to zero. Hahnel (2012) (2012a) (2013) has pointed out that a global cap and trade market with equitable, net-emissions, caps for all countries based on responsibility and capacity as proposed for example by the Greenhouse Development Rights Framework (2007)[68], policed by national governments would address most of the regulation and governance issues brought by critics such as Tokar (2010) and Bond (2012). Hahnel's major point, that applies to similar issues raised regarding Article 6 of the Paris Agreement, is that as national carbon emissions can be measured quite accurately, individual countries could be held responsible for their emissions regardless of whether traded "carbon offsets" (this issue is less likely to occur with "carbon removal" trading) are real or not.[69] A global cap and trade market like this would also increase the efficiency and scope of drawing down GHGs and lead to a large transfer of funding and investment to developing countries. Similar, national and state public compliance, and private voluntary carbon removal markets, can and are critical to developing protocols and creating markets for CCSU.
c) Since even a "zero cap on carbon emissions" is not adequate, we need to also directly subsidize and expand the funding of large-scale Carbon Direct Removal (CDR) and Carbon Storage and Sequestration, and Use (CSSU) markets. Sources of funding for this could be: the unique power of the US federal government to directly pay for global GHG drawdown by issuing and lending dollars (as in the Marshall Plan), additional carbon high-income and wealth, and rentier, taxes that would stimulate GGND economic development (Baiman, 2020). Use these funds to pay public, non-profit, or private entities to remove carbon from the atmosphere or ocean and either produce sustainable energy or materials from it, or successfully sequester it or equivalent

[68] http://gdrights.org/about/
[69] For more discussion: https://youtu.be/T_PGiZzUggU

amounts of carbon by using carefully monitored public or private carbon sequestration certificates[70] and "dump sites" or sequestering facilities where this could be done[71].

d) Position governments and private industry as buyers of carbon negative products, and of stored and sequestered carbon[72]. A keyway to do this would be to pass laws and regulations mandating the use of carbon neutral or zero negative construction materials, fertilizer, fuel, feed stock, food and other goods and services.

The objective would be to turn carbon drawdown, including CDR and CSSU, into major profit opportunities so that this these activities would develop into a major economic sector, and to use public policy to directly fund GGND REME and CCSU related jobs and infrastructure programs that would address climate change and global and economic equity and real (rather than rentier) production of goods and services (Baiman, 2020).[73] As Lackner has pointed out, minimum price for ambient (atmospheric or oceanic) carbon drawdown would become the effective "carbon tax" in a publicly enforced no carbon dumping compliance regime, and the public subsidy price for large-scale additional carbon drawdown and climate restoration.[74] Thus the more efficient DAC CDR becomes, the more pressure on point-source emitters like for-profit fossil fuel producers and users, who currently have an incentive to stall and delay and deny, to rapidly develop less costly (than DAC CDR) zero emissions technologies.

We need to immediately fund, pilot, and deploy Arctic Sea-Ice saving climate *triage* to avoid crossing the first critical Arctic Sea-Ice loss global climate tipping point, and utilize large scale public infrastructure and jobs program roll-outs coupled with existing competitive for-profit markets embedded in government compliance regulations and taxes and subsidy regimes to incentivize the development of a competitive and efficient CDR and CCSU sectors for private and public utilities and other applications is necessary to scale up fast enough to address change and progress toward the REME economy of the future (Chichilnisky 2020) (Eisenberger, 2020).[75]

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[70] NORI (a company for which Lackner is listed as an advisor) has been designing certificates of carbon removal. In this 2018 interview with Lackner they were trying to couple their carbon removal certificate with a cryptocurrency token, but there is does not appear to be a cryptocurrency link (that Lackner was, in my view, skeptical about in this the 2018 interview) in recent (11/24/2020) scan of the NORI website that talks about blockchain recording of certificates but not a cryptocurrency: https://youtu.be/G9zPJDAKLHw .

[71] Though, as carbon dumpsites would require even more extensive environmental and quality control regulation and monitoring than ordinary dumpsites, it might, be more efficient, accountable and feasible as these would probably require large upfront risk and investment, for these to be, as with ordinary dump sites, public facilities.

[72] Based on calculations from recent data, 1,710 Gigatons of CO2 need to be removed from the atmosphere to get back to 1989 level of 353 ppm. (K von Schuckmann et al., 2020) and (NOA, 2020): https://essd.copernicus.org/articles/12/2013/2020/ and https://www.esrl.noaa.gov/gmd/ccgg/trends/data.html in text below.

[73] Lackner has estimated that DAC would have to be on the scale of about 1/10th the current global automobile sector for carbon neutrality and larger for draw-down - see Section 3 of paper.

[74] https://youtu.be/G9zPJDAKLHw

[75] Lackner has suggested employing "reverse auctions" whereby the government solicits bids on the lowest (publicly guaranteed) price per ton of carbon for removing say a hundred million tons of carbon per year from the

Bibliography

Alfred Wagener Institute. 2019. A warming Arctic produces weather extremes in our latitudes. *Science Daily*. May 28.

Baiman, Ron. 2020. Financial bailout spending would have almost paid for thirty years of global green new deal climate: Triage, Regeneration, and Mitigation. *Review of Radical Political Economics* 52(4) 616-625.

Bond, Patrick. 2012. *The politics of climate justice: paralysis above, movement below*. Scottsville, South Africa : University of Kwazulu-Natal Press.

Bryce, Emma. 2020. Can the forests of the world's oceans contribute to alleviating the climate crisis? BreenBiz. Jul. 16. Accessed at: https://www.greenbiz.com/article/can-forests-worlds-oceans-contribute-alleviating-climate-crisis

Cao Y. F. et al. 2015. Assessment of sea ice albedo radiative forcing and feedback over the Northern Hemisphere from 1982 to 2009 using satellite and reanalysis data. *Journal of Climate* 28(3) 1248-1259.

Coghlan, Andy. 2018. A warm-water time bomb could spell disaster for Arctic sea ice. *New Scientist*. Aug. 29. https://www.newscientist.com/article/2178160-a-warm-water-time-bomb-could-spell-disaster-for-arctic-sea-ice/#ixzz6iMIiwzDS

Chichilnisky, Graciela and Peter Bal. 2020. *Reversing Climate Change:How Carbon Removals can Resolve Climate Change and Fix the Economy*. Singapore: World Scientific Publishing Co. Pte. Ltd.

Dorman, Peter. 2020. The climate crisis and the green new deal: the issue is the issue after all. *Challenge* April 219-233.

Eisenberger, Peter. 2020. Renewable energy and materials economy: the path to energy security, prosperity and climate stability. Submitted to *Physics and Society*: https://arxiv.org/pdf/2012.14976.pdf

________________. 2020a. Appendix – the transition to REME. *WordPress.* Accessed at: https://elkcoastinstitute.org/2020/05/28/publications/

Fiekowsky, Dan, Carole Douglis and Susan Lee. 2019. Climate restoration: solutions to the greatest threat facing humanity and nature today. *The Foundation for Climate Restoration*. Sep. Accessed at: https://foundationforclimaterestoration.org/wp-content/uploads/2019/11/20191030_f4cr4_white-paper.pdf

atmosphere in order to induce rapid development of technological innovation, learning by doing, and economies of scale for DAC.

____. 2020. Climate restoration: solutions to the greatest threat facing humanity and nature today. *The Foundation for Climate Restoration*. Dec. Accessed at: https://foundationforclimaterestoration.org/wp-content/uploads/2020/12/20201218_f4cr_white-paper_updated.pdf

Flanner, M. G. et al. 2011. Radiative forcing and albedo feedback from the Northern Hemisphere cryosphere between 1979 and 2009. *Nature Geoscience* 4(3) 151-155.

Hahnel, Robin. 2012. Left clouds over climate change policy. *Review of Radical Political Economics* 44(2) 141-159.

___________. 2012a. Desperately seeking left unity on international climate policy. *Capitalism Nature Socialism* 23(4) 83-99.

___________. 2013. Rejoinder to Patrick Bond. *Capitalism Nature Socialism* 24(2) 116-121.

Hausfather, Zeke. 2019. Analysis: Why the IPCC 1.5C report expanded the carbon budget. *Carbon Brief*. Oct. 8.

Hudson, S. R. 2011. Estimating the global radiative impact of the sea ice albedo feedback in the Arctic. *Journal of Geophysical Research* 116.

Jehne, Walter. Regenerate Earth. 2017. Dubbo, NSW: Heathy Soils Australia. Accessed at: http://nzbiocharltd.co.nz/resources/Regenerate-Earth-Paper-Walter-Jehne%20%281%29.pdf

Keith, David. 2019. The Peril and Promise of Solar Geoengineering. Lecture at Harvard Museum of Natural History. Oct. 30. Accessed at: https://youtu.be/xWI2w2F1gMg

Keith, Dave et al. 2016. Stratospheric solar geoengineering without ozone loss. *PNAS* December 27, 2016 113 (52) 14910-14914; first published December 12, 2016; https://doi.org/10.1073/pnas.1615572113

King, David and Rick Parnell. 2020. Stopping climate change could cost less than fighting covid-19. *Washington Post*. Sep. 17.

Kostigen, Thomas M. 2020. *Hacking Planet Earth*. New York: Targer Perigee

Lackner, Klaus. 2020. Klaus Lackner on carbon capture, climate change, and physics - #40. *Manifold*. April 2: https://manifoldlearning.com/episode-040/

Lackner, Klaus et al. 2012. The urgency of the development of CO_2 capture from ambient air. *PNAS* 109(33) Aug. 14.

Lenton et al. 2008. Tipping elements in the earth's climate system. *PNAS* 102(6) Feb. 12.

MacMartin et al. 2017. Solar geoengineering as part of an overall strategy for meeting the 1.5°C Paris target. *Phil. Trans. R. Soc. A* 376. Oct. 16.

National Academy of Sciences. 2019. *Negative research technologies and reliable sequestration: a research agenda*. Washington, D.C.: The National Academies Press.

Pistone, Kristina, Ian Eisenman and Veerabhadran Ramanathan. 2019. Radiative heating of an ice-free Arctic ocean. *Geophysical Research Letters*. Jul 10.

Project Drawdown. 2017. *The most comprehensive plan ever proposed to reverse global warming.* New York: Penquin Books.

Rapier, Robert. Fossil Fuels Still Supply 84 Percent of World Energy — And Other Eye Openers From BP's Annual Review. *Forbes.* June 20. https://www.forbes.com/sites/rrapier/2020/06/20/bp-review-new-highs-in-global-energy-consumption-and-carbon-emissions-in-2019/?sh=d68448966a16

Tokar, Brian. 2010. *Toward climate justice. Perspectives on the climate crisis and social change*. Porgrunn, Norway: New Compass.

Wang, Seaver and Zeke Hausfather. 2020. ESD Reviews: mechanisms, evidence, and impacts of climate tipping elements. The Breakthrough Institute. April 21.

Watson, A. J. 1997. Volcanic iron, CO_2, ocean productivity and climate. *Nature* 385, 587–588. doi: 10.1038/385587b0