RICHARD WELLER

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+ GEOENGINEERING, CLIMATE SCIENCE, EARTH SCIENCE

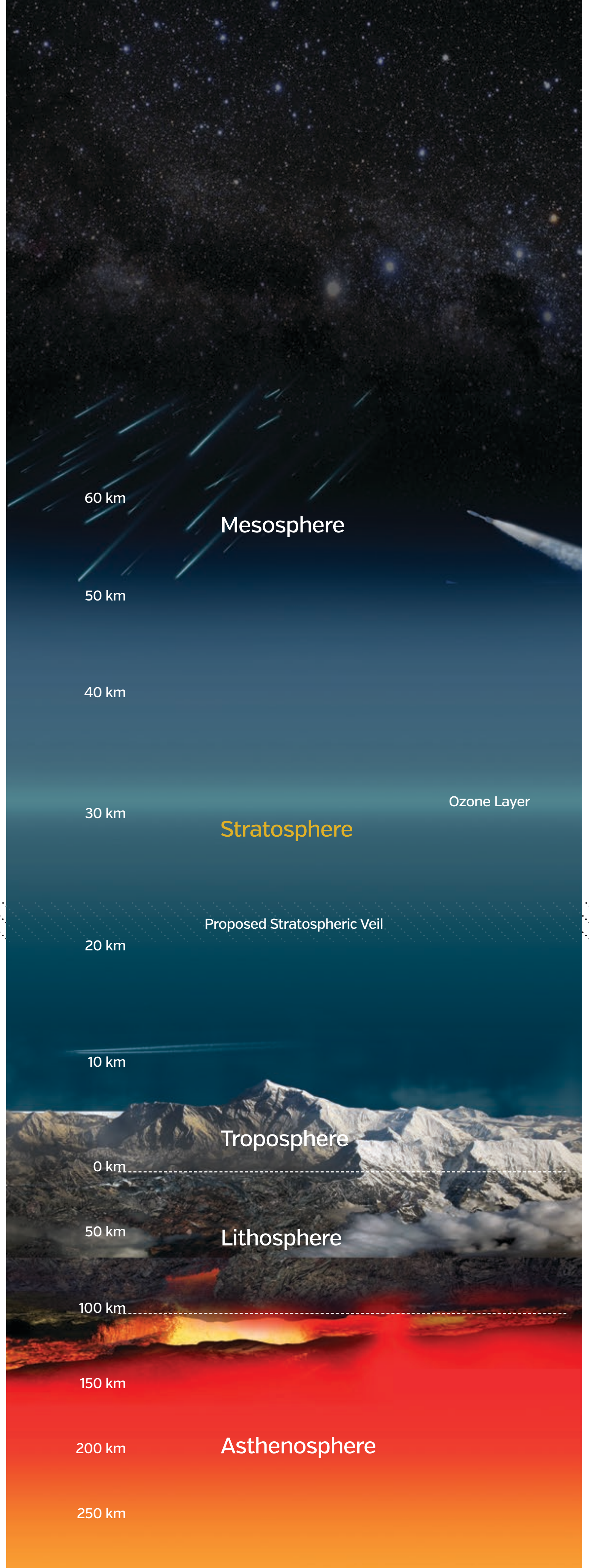
The environmental activist Stuart Brand famously quipped of the Anthropocene that since we have now become gods we "have to get good at it."[1] But what does it mean to be a good god? For Brand, and his colleagues in the Breakthrough Institute with whom he penned the 2015 *Ecomodernist Manifesto*, it means creating a "good Anthropocene."[2] This, they say, "demands that humans use their growing social, economic, and technological powers to make life better for people, stabilize the climate, and protect the natural world."[3] The fulcrum of that statement–the thing upon which the fate of both people and the so-called natural world now depend–is a stable climate. And it is the probability that humanity will consciously attempt to engineer such stability that elevates us from our Holocene status as mere mortals to the good gods of the Anthropocene.

Technologies for geoengineering a stable climate are typically organized into two major categories: solar radiation management (SRM) and carbon dioxide removal (CDR). SRM technologies apply directly to the atmosphere (heaven), whereas CDR technologies apply directly to the land and the oceans (earth). Organized according to this dualistic divinity of heaven and earth, this article briefly summarizes and discusses the risks of both.

The Intergovernmental Panel on Climate Change stresses that stabilizing temperature increase to below two degrees Celsius, "will require an urgent and fundamental departure from business as usual." But as global population swells, the world urbanizes, and billions attempt to lift themselves out of poverty by whatever means possible, significant reductions in greenhouse gas emissions this century seem unlikely. Indeed, the European Union's Directorate-General for Climate Action has already concluded that the sum total of emission reduction measures proposed by the 189 individual nations who have prepared National Climate Plans under the (COP 21) Paris Agreement will not be enough to achieve the agreement's primary aim of holding carbon dioxide emissions below a two degree increase.

And even if we were to stop using fossil fuels today, the excess of carbon and other greenhouse gases already in the system means stabilization would not emerge of its own accord for some time. At their own immemorial rates, the geosphere, biosphere, hydrosphere and atmosphere, which together comprise the earth system, will absorb and adjust to our excesses and stable patterns will once again emerge; but by then the landscape in which global civilization is so deeply rooted will have shifted. As Harvard physicist and environmentalist David Keith writes, "carbon casts a long shadow onto the future: a thousand years after we stop pumping carbon into the air the warming will still be about half as large as it was on the day we stopped."

In the interim, climate instability is variously predicted to heighten both the intensity and frequency of destructive and deadly weather events which, in combination with



inexorable sea level rise and temperature increase, will force the mass-migration of most species, inciting both political and ecological chaos. If those species, including humans, cannot adapt productively to these new conditions of instability, they will perish. Alternatively, in a bid to hold onto the world as we know it for a little longer, and buy some time to wean ourselves off fossil fuels once and for all, then stability–or what we may now recall fondly as Holocene weather–could, some think, be geoengineered.

As we know and trust them, engineers are especially risk averse professionals who design the world's mechanical structures and systems. Generally speaking they do so according to Newtonian physics with certitude regarding the performance and capacity of that which they make. Bridges span rivers, buildings stand up, and planes stay in the air. Geoengineers on the other hand propose to intervene directly in the workings of the earth system itself and for the first time in cosmological history they will attempt to reverse engineer an entire planet. A loose and unofficial collection of (overwhelmingly male) scientists and inventors, geoengineers are the vanguard of the Anthropocene, an epoch paradoxically defined (and confounded) by the fact that we have unwittingly and it seems very badly, already reengineered the planet.

SRM Heaven

Heavenly geoengineering concerns the control of global temperature through solar radiation management (SRM) and therefore addresses the symptoms rather than causes (carbon emissions) of anthropogenic climate change. Ideas for SRM include global dimming via orbiting sun-shades, increasing the earth's albedo by multiplying the density and brightness of clouds over the ocean, painting cities white, covering glaciers in white plastic and finally, the injection of sulfates (aerosols) into the stratosphere to deflect sunlight back into space. It is the latter, referred to as a 'veil,' that seems to rise to the top in cost-benefit and risk analyses and most consistently receive the imprimatur of prominent figures in the field.

Comprised of sulfuric acid suspended in tiny water droplets some 20 kilometers above the earth, the veil is relatively easy to manufacture. According to Keith, sulfur has "a near million to one" capacity to offset the effects of carbon dioxide. That is, one ton of sulfur suspended in the stratosphere deflecting sunlight back into space can offset the global warming effects of one million tons of carbon emissions. Because the sulfur falls to earth over the course of a year or so, the veil requires constant replenishment, which Keith has calculated at around one million tons per annum by the year 2070. And if that sounds frightening, bear in mind that humanity currently pumps around 50 million tons of sulfur dioxide as pollution into the lower atmosphere, killing around a million people every year. In any event, as its proponents are quick to point out, even if the act of loading sulfur into the earth system is not technically speaking reversible, the veil can always be lifted.

1 Stuart Brand, *Whole Earth Discipline* (London: Penguin, 2009) 1.

2 The Breakthrough Institute, "An Eco-Modernist Manifesto," http://www.ecomodernism.org (accessed December 27, 2016).

3 Ibid.

4 Rajendra K. Pachauri, *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Geneva: IPCC, 2014). Available at http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf.

5 European Commission, "Questions and Answers on the Paris Agreement," http://ec.europa.eu/clima/policies/international/negotiations/paris/docs/qa_paris_agreement_en.pdf (accessed June 1, 2016).

6 David Keith, *A Case for Climate Engineering* (Cambridge: MIT Press, 2013), 29.

7 Ibid., 6.

8 Ibid., 252.

9 Ibid., 70.

10 Ibid., 60.

11 Ibid., 16.

12 Dale Jamieson, "Ethics and Intentional Climate Change," *Climatic Change* 33, no. 3 (1996): 323–36.

13 Christopher J. Preston (ed.), *Engineering the Climate: The Ethics of Solar Radiation Management* (London: Lexington Books, 2014), 6.

14 Keith, *A Case for Climate Engineering*, 11.

15 Oliver Morton, *The Planet Remade: How Geoengineering Could Change the World* (New Jersey: Princeton University Press, 2015), 372–73.

16 Ibid.

17 See Mike Hume, *Can Science Fix Climate Change: A Case Against Climate Engineering* (Oxford: Polity Press, 2014); Clive Hamilton, *Earthmasters: The Dawn of the Age of Climate Engineering* (New Haven: Yale University Press, 2013).

18 Mike Hulme, "Reducing the Future to Climate," in Libby Robin, Sverker Sorlin & Paul Warde (eds), *The Future of Nature: Documents of Global Change* (New Haven: Yale University Press, 2013), 518.

19 Clive Hamilton, "*The Anthropocene as Rupture*," *The Anthropocene Review* 3, no. 2 (2016).

By diffracting sunlight back into space the great promise of the veil is that it could quickly reduce global temperature, forestall arctic sea-ice melt, and save communities and estuarine ecosystems from imminent sea-level rise. Stabilized or reduced temperatures also hold the prospect of avoiding predicted crop losses associated with global warming. Keith and other geoengineering heavyweights, such as Ken Caldeira from the Department of Global Ecology at Stanford, variously suggest that food supply in Africa and India could significantly increase by virtue of geoengineering. Keith concludes that even though a stratospheric veil cannot reduce the risk of humanity's transfer of carbon from underground reservoirs to the atmosphere "[i]t's hard to overstate the importance of geoengineering's ability to reduce risk for current generations as there are no other methods that can reduce these risks significantly in the next half century."

So what's the problem?

In 1996 Dale Jamieson, Professor of Environmental Studies and Philosophy at New York University, set out four standards that any geoengineering proposal must meet: they must be technically feasible, must have predictable consequence, must produce economic states preferable to the alternatives and, finally, must not violate any "well founded" ethical principles. These principles include democratic decision-making, avoiding irreversible change, and "learning to live with nature." Christopher Preston, Professor of Ethics at the University of Montana, claims that, to date, no geoengineering project has met these standards.

A stratospheric veil is technically feasible but predictions of its consequences range from potentially stopping the monsoon and putting more than a billion people at risk of starvation, to "a best guess" that it will "reduce the damage from climate change in most regions" but "make some regions worse off – perhaps by increasing drought." Sulfur particles may also damage the ozone layer and as they fall to earth they will compound pollution-related health problems and further acidify the oceans. Former editor of Nature Oliver Morton points out that the veil may also work too well and by cooling the planet, begin a new ice age.

Of course a veil would be constantly monitored and could be adjusted, but this leads perhaps to its biggest problem: the question how it would be regulated. Who sets the temperature? What of rogue states and military applications? And would it not be blamed for all the catastrophes we used to 'write off' as acts of God? Finally, as to the violation of the "well founded" ethical principle of "learning to live with nature," who is to say what this means when the nature of the Anthropocene is itself a cultural construct?

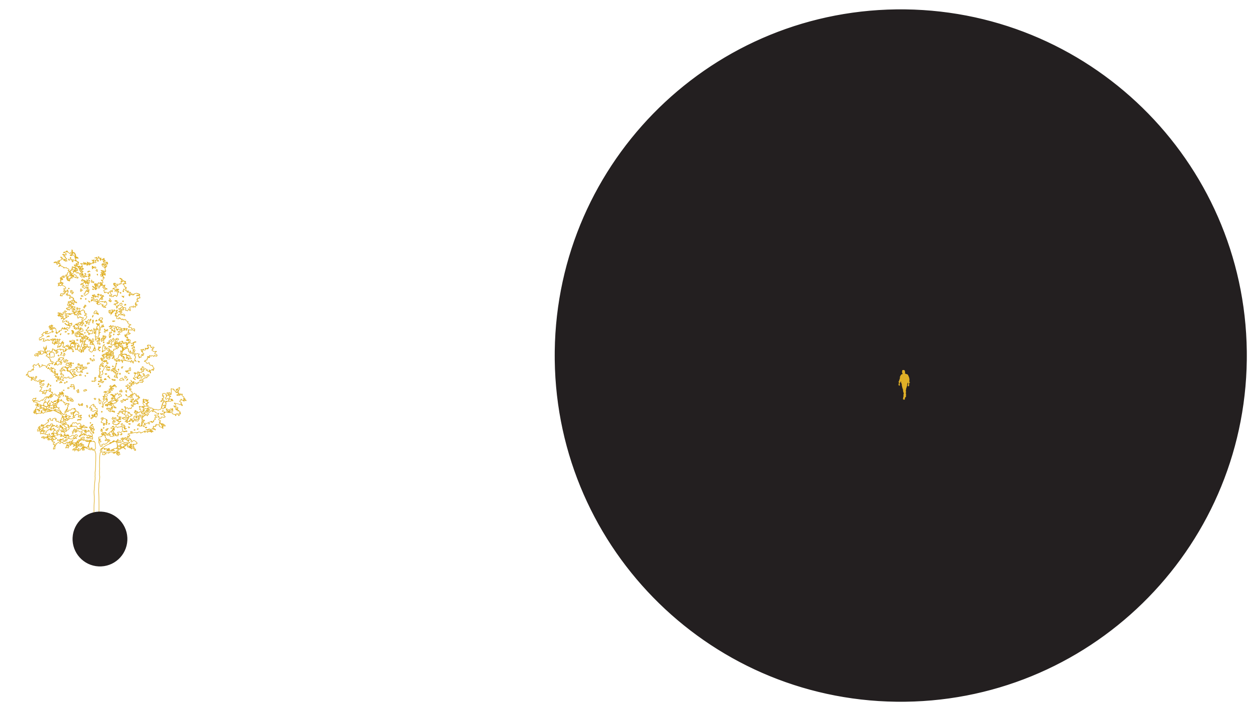
Whilst recognizing that the advent of geoengineering "changes what it is for humans to be humans and what it is for nature to be nature" and that for some it "takes human empire over the border of blasphemy," Morton goes so far as to discuss geoengineering as potentially a thing of beauty. He suggests that it could manifest a new understanding of nature as a co-evolutionary process, not a separate ahistorical thing. On the other hand, prominent critics such as Mike Hulme and Clive Hamilton, consider any such techno-fix to climate change a perpetuation of the pathological modernity that got us into this predicament in the first place. Such fixes, they argue, will have the negative effect of reinforcing the status quo. Hulme rails against geoengineering as a form of climate determinism arguing that it is "nurtured by elements of a Western cultural pessimism that promote the pathologies of vulnerability, fatalism, and fear" and that reducing climate change to a technical problem is stifling the "human creativity, imagination and ingenuity [that] will create radically different social, cultural and poltical worlds in the future." Similarly, for Hamilton climate change is not just an engineering problem, and nor is it just a continuation of cultural and environmental history; it is, as he puts it, "a rupture" requiring far more radical revisions of what it means to be human and, along with it, the fundamental reorganization of society.

But if it is true that due to the loading of carbon since at least the late 18th century the climate is already a reengineered system, and one that will negatively impact the lives of many of the world's most vulnerable, then such philosophical critique at this point in time seems like sophistry. The conundrum of climate change is that we are damned if we do and damned if we don't. The most compelling argument for stabilizing temperature with a stratospheric veil is that it would buy us time: time for better research, time for energy transition, and time for spatial, political, *and* philosophical adaptation to this new reality.

CDR Earth

Geoengineering the heavens concerns temperature stabilization therefore it only addresses the thermal symptoms, not the causes of anthropogenic climate change. To broach the direct cause–that is, the excess of carbon in the earth system–we need to come down to earth and consider carbon dioxide removal (CDR) proposals.

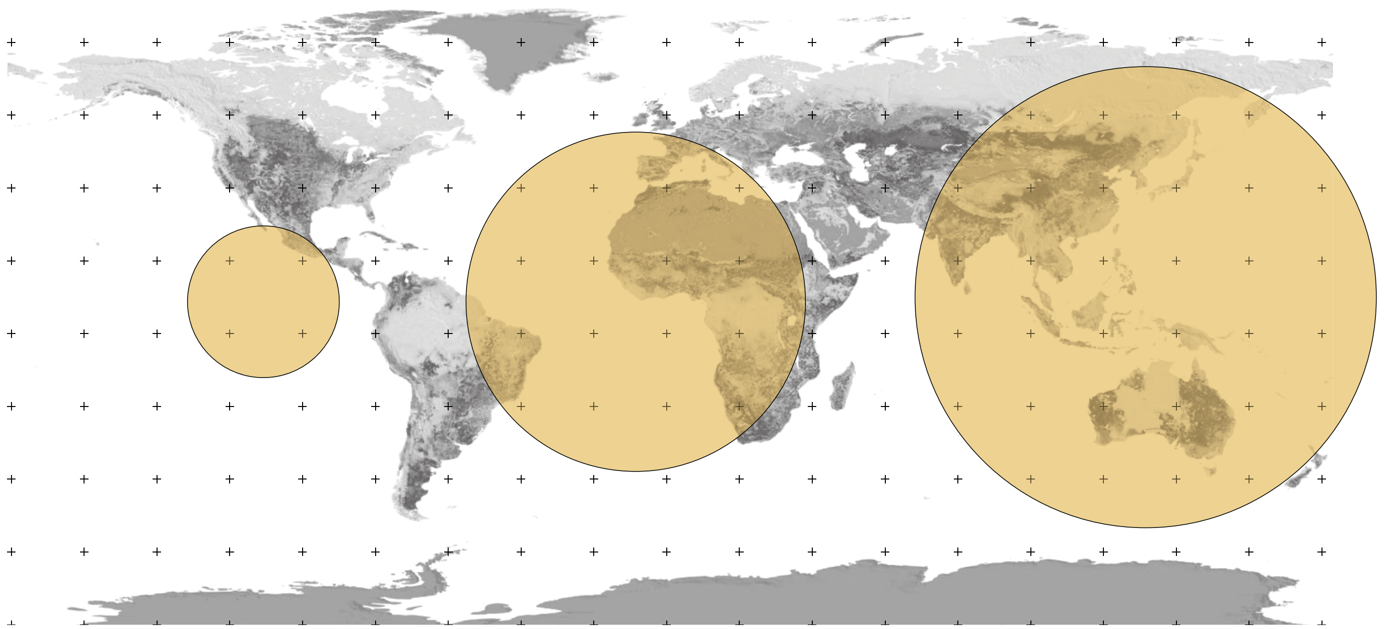
Proposed methods for 'mopping up' excess carbon in the earth system include adding iron to the oceans to cause phytoplankton blooms, converting agricultural waste to bio-char before it decomposes and releases carbon, filtering carbon from industrial outlets, speeding up what trees do by mechanical carbon capture from the air, and establishing vast forests to 'naturally' sequester carbon. Apart from chemically manipulating the oceans, which is akin to manipulating the stratosphere, all these ideas are relatively low-risk and may all, therefore, have a role to play. Here, however, I focus on carbon sequestration through forestry and relate it to other land use pressures that will shape the global landscape this century.

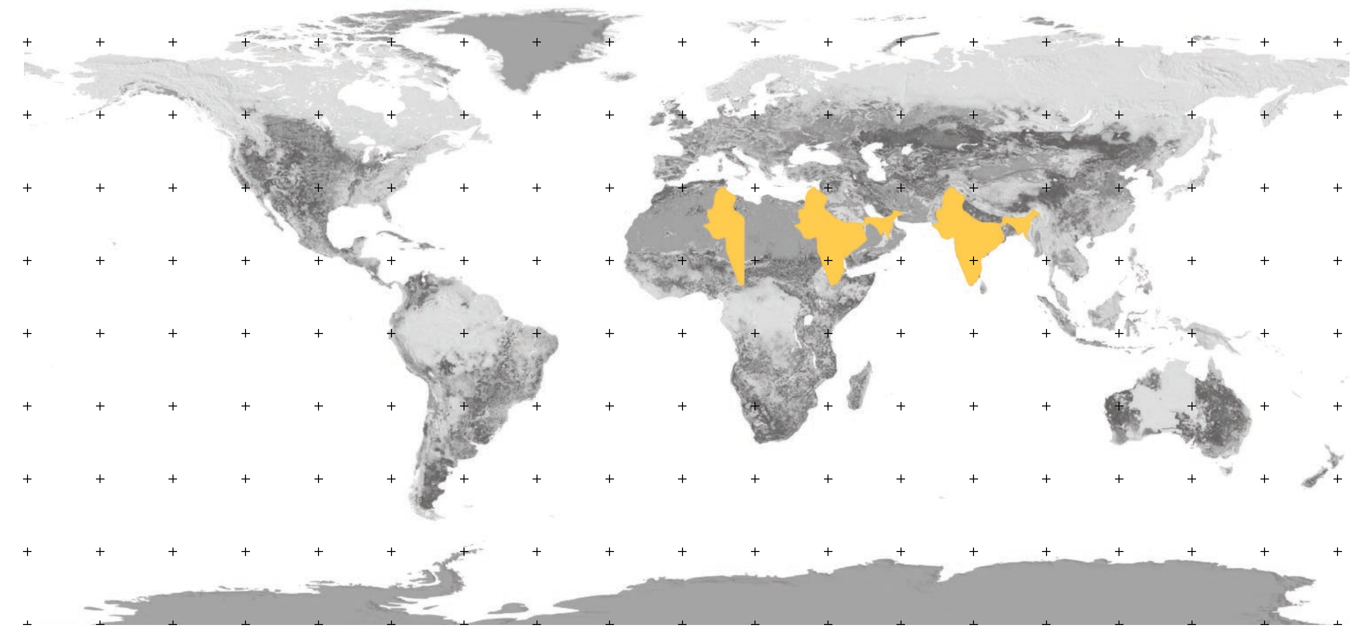


Land clearance for agriculture and urban growth is one of the biggest contributors to carbon emissions. As global populations urbanize and more people shift toward high-protein diets, more land must be cleared for crops and livestock. Humanity extracts one-third of its protein from livestock: this requires 3.38 billion hectares (38%) of the earth's ice-free land in order to graze and produce the feed crops necessary to sustain livestock. It is the largest single land use on the planet. Livestock then erode and compact soil, pollute water with nitrous oxide and ammonia, and expel 37% of all methane into the atmosphere. High crop yields are only made possible through the liberal application of industrially manufactured fertilizers and pesticides, themselves drawn from fossil fuels and expelling carbon in the (Haber-Bosch) process of their production. Most problematic is that reactive nitrogen run-off from industrialized agriculture causes extensive eutrophication of inland waterways and the proliferation of 'dead' (hypoxic) zones in the oceans. If carbon weren't the hot issue, nitrogen would be.

In 1990 the world had 4,128 million hectares of forest; by 2015 this area has decreased to 3,999 million hectares. According to the 2015 Soil Atlas, around 13 million hectares of forest are cleared every year, and of the world's primary forests around 40 million hectares have disappeared since 2000. Naturally occurring forests are in decline, planted forests are increasing. Though not always the case, forested lands are generally increasing in rich countries and decreasing in poor countries. Before modern agriculture, tropical rainforests covered about 1.6 billion hectares of the earth's surface. In his 2015 report to the Club of Rome on the state of the world's rainforests, Claude Martin estimates that one-half has been eradicated due to agriculture, logging, and mining, much of this occurring in the last few decades. A further one-quarter of the world's rainforests is, according to Martin, degraded. It is currently estimated that 4.9 million hectares of rainforest are lost each year. At this rate the earth's entire

Above: An average American produces 21.55 metric tons (47,510 lbs) of CO_2 equivalents a year. In contrast a single (average) tree can sequester 2.8 metric tons of CO_2 per year.





Above: [1] The world's current crop land. [2] The world's entire supply of arable land. [3] The land area required for food production for a global population consuming at the rate of average Americans (1.4 hectares per person).

Right: A forest the size of 2.5 Indias would be required to sequester the world's current excess of five billion tons of carbon per year.

rainforest biome–exempting the 9.8% (at 2008) under protection–will be eradicated in a little over 100 years from now. To do this would be to radically destabilize an already volatile earth system and sacrifice life's most prodigious biodiversity before it is barely documented. In return 'we' will get relatively small quantities of palm oil, soy beans, cocoa, and beef.

Against this trend of deforestation, the Paris Agreement urges the retention of existing carbon sinks (vegetated landscapes), which, if taken seriously, bodes well for the world's ecoregions and will encourage reforestation in accordance with Aichi target 15 of the United Nations' Convention on Biological Diversity. Target 15 states that "by 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification."

According to Morton there are about five billion tons of excess carbon in the earth system per year. If that carbon was to be sequestered through forestry, he concludes that it would require a forest of approximately seven million square kilometers. Morton doesn't explain how he reached this figure but if a single tree absorbs around 20 kilograms of carbon per year then 250 billion trees would be needed to sequester the five billion tons of excess carbon in the system. If those trees were planted on 10-meter centers, the forest would have a density of 31,250 trees per square kilometer, adding up to eight million square kilometers of new forest, about two-and-a-half times the size of India.

To consider the feasibility of such a forest, we must first find space for it in the Earth's total ice-free terrestrial area of 149,000,000 km2. First, we have to discount the 39,000,000 km2 of the world's existing forest, then 15,000,000 km2 of current crop land and 33,000,000 km2 of current grazing land. Further, we should also subtract the 26,000,000 km2 of potentially arable land which is not yet, but surely will be farmed if we are to feed a global population of 10 billion by 2100. This leaves a total of 36,000,000 km2 on which to develop our sequestration forest. The problem is, however, that 33% (49,000,000 km2) of the earth's terrestrial surface is desert – by definition land unsuited to forestry.

In this scenario, to complement the heavenly work of creating the veil, the earthly task becomes a matter of greening the deserts. It is important to note, however, that the performance of such a forest in the totality of the earth system is not at all well understood and therefore the true calculation of its size is the stuff of conjecture. For example, a complicating factor is that when carbon is sucked out of the atmosphere, as such a massive forest would certainly do, the oceans react proportionally by giving up more carbon. Morton, for one, concludes that "there are undoubtedly ways to encourage the storage of carbon in the biosphere through soil management, agronomy, and forestry… [b]ut such actions do not store carbon on the scale needed to put a serious dent in the fossil-fuel-driven trajectory of atmospheric carbon dioxide."

In addition to tensions between the expansion of the global food bowl and sequestration forestry the major impact on the earth system is the unprecedented scale and pace of urbanization. In 2015 the global population was estimated at 7.3 billion people. The United Nations forecasts that this will grow to 8.5 billion by 2030, 9.7 billion by 2050, and anywhere up to 13.3 billion by 2100. Given these forecasts and the rate at which the world is urbanizing it seems reasonable to expect something in the order of at least an additional three billion people living in cities this century. To facilitate this means the equivalent of 464 New York Cities are required. In terms of sheer construction, this means building 5.5 New Yorks per year between now and 2100. Because building entirely new cities in new locations is expensive, and because existing cities tend to resist densification, we can expect much of this new global development to be what is pejoratively known as sprawl. Supplying energy, food,

20 Phytoplankton construct themselves in part from carbon and upon their death fall to the ocean floor where their remains are absorbed into the carbonate rock cycle.

21 Future Directions International, "The Future Prospects for Global Arable Land," http://www.futuredirections.org.au/publication/the-future-prospects-for-global-arable-land/ (accessed June 24, 2016).

22 Food and Agriculture Organization of the United Nations, "Livestock's Long Shadow: Environmental Issues and Options" (Rome: 2006). Available at http://www.fao.org/docrep/010/a0701e/a0701e00.HTM.

23 Christine Chemnitz & Jes Weigelt (eds), *The Soil Atlas 2015* (Berlin: Heinrich Böll Foundation & Institute for Advanced Sustainability Studies, 2015), 15. Available at http://globalsoilweek.org/wp-content/uploads/2014/12/soilatlas2015_web_141221.pdf.

24 Claude Martin, *On the Edge: The State and Fate of the World's Tropical Rainforests*, Report to the Club of Rome (Vancouver: Greystone Books, 2015).

25 Toby A. Gardner, et al., "Prospects for Tropical Forest Biodiversity in a Human-Modified World," *Ecology Letters* 12, no. 6 (2009): 561–82.

26 S. Vaughan, *The State and Fate of Tropical Forests* (Winnipeg: International Institute for Sustainable Development, 2015). Available at http://www.iisd.org/sites/default/files/publications/state-fate-tropical-rainforests-commentary.pdf.

27 Convention on Biological Diversity, "Aichi Biodiversity Targets," https://www.cbd.int/sp/targets/ (accessed September 10, 2016).

water, and housing (not to mention the consumer pleasures of late capitalism) for so many additional people will need to be carefully designed so as not put the earth system at further risk of irreversible failure.

The UN reports that there is a 23% chance that global population will stabilize or fall before 2100. This would bring to an end a growth cycle which began when a global population of around four million nomads started to transition into settlements with the birth of the agricultural revolution. The critical question is what shape the earth system will be in by the time peak population is reached. Along with the Milankovitch cycles (the angular orbit of the earth in relation to the sun), the climate is affected by the chemical constituency of and interrelationships between the atmosphere, the oceans, and the land. The world's oceans and forests act as planetary lungs breathing carbon in and oxygen out: they distribute heat, water, and nutrients (indeed all the elements of the periodic table) via vast interwoven convection currents driven by incoming sunlight and the differential between the tropics and the poles. Understanding and being able to predictively model the dynamics of this planetary metabolism, and how "planetary urbanism" impacts it, is the future of geoengineering. It is also the future of humanity.

While landscape architects can't do much about the heavens, as intermediaries between the arts and sciences and between development and ecology, they can surely play a role here on earth. There is a vast landscape of risk before us.

28 Morton, *The Planet Remade*, 258.

29 NC State University College of Agriculture & Life Sciences, "Tree Facts," http://www.ncsu.edu/project/treesofstrength/treefact.htm (accessed December 1, 2016); Sarah Moos, "50,000 Trees," *Scenario 04:* Building the Urban Forest (2014), http://scenariojournal.com/article/50000-trees/.

30 Although this grazing land has some tree cover, it is not at the density required to meet the sequestration demand.

31 Morton, *The Planet Remade*, 262.

32 United Nations, Department of Economic and Social Affairs, Population Division, *World Population Prospects: The 2015 Revision, Key Findings and Advance Tables* (2015). Available at https://esa.un.org/unpd/wpp/Publications/.

33 Neil Brenner & Christian Schmid, *"Planetary Urbanization,"* in Matthew Gandy (ed.), Urban Constellations (Berlin: Jovis Verlag, 2011), 12.

Right: A world of 10 billion people living at the material standard of today's average American would produce 216 billion metric tons of CO_2.