Global Climate Restoration for People, Prosperity and Planet:
$Trillions in Market Opportunities and Economics, Social, Environmental Benefits

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"We still need to shift from fossil fuels to clean energy. We still need to adapt to rising sea levels and an overheated planet ... Climate Restoration is not a substitute for mitigation (preventing or reducing greenhouse gas emissions) or adaptation (preventing or reducing damage from global warming)—but a timely and much-needed addition to them."

Foundation for Climate Restoration, Sept 2019 pg. 5.

I. The Three Pillars of Climate Transformation – Restoration, Adaptation, and Mitigation

Climate restoration—restoring atmospheric CO₂ levels to less than 300 to 350 parts per million (ppm) from our current 415 ppm within one generation by 2050—is the critical third pillar of climate transformation, alongside adaptation and mitigation. Until the last century, humans lived in a world where CO₂ levels were at most 300 ppm. The current international commitment to limit temperature rise to 2°C over pre-industrial conditions would still leave atmospheric CO₂ at well over 450 ppm in 2050 (IPCC, 2018: Global Warming of 1.5°C). Without restoration, adaptation and mitigation will not solve the climate crisis we are facing.

Market opportunities and broader political-economic dynamics will be a predominant driver of climate restoration, adaptation, and mitigation towards climate transformation. To simplify considerably, the world needs to know what the opportunities are for direct, tangible financial returns from market investments in climate action. The world also needs to know not only the size of these market opportunities but also the value of averted costs as well as the broader (often non-market or non-monetized) economic, social, and environmental benefits of climate action. Finally, the world needs to know the financial investment – both from public and private sources – that is needed to realize both the tremendous market opportunities as well as the broader economic, social, and environmental benefits of climate action.

The case that global climate action across the three pillars will prove immensely beneficial to the global economy is mounting. According to the 2018 Report of the Global Commission on the Economy and Climate (GCEC), if the world makes the right choices over the next 2-3 years we could unlock benefits worth US $26 trillion from now to 2030, create 65 million new low-carbon jobs, and avoid over 700,000 premature deaths from air pollution. While recognizing that current economic models cannot perfectly predict the future, analysis produced for GCEC found that the bold actions that could yield such large direct economic gains compared with business-as-usual likely represent a conservative estimate. The GCEC points out that we have a planetary window of opportunity created by other transitions taking place, such as urbanization and the 4th Industrial Revolution, transitions that need to be managed in any case and could be managed with a low-carbon approach. The world should make the shift in five key systems: energy, cities, food and land use, water, and industry (New Economy Climate Report 2018).
With respect to climate mitigation efforts, Stanford University researchers found that the overall economic benefits worldwide of keeping future temperature increases to 1.5°C are likely in the tens of trillions of dollars, with a majority of countries with over 90% of the world’s population benefitting (including the U.S., China and Japan as well as the lion’s share of countries in Africa, Asia, and Latin America). The projected benefits are more than 30 times greater than the most recent estimates of what it will cost to achieve the more ambitious 1.5°C goal. Inversely, the research projects that there would be a 15-25% reduction in world per capita output by 2100 with the 2.5°-3°C increase in average temperature that is expected given current national commitments, and an even greater reduction to 30% in world per capita output with global warming of 4°C (Nature, May 23 2018).

The Global Commission on Climate Adaptation (CGCA) found that the overall rate of return on investments in improved resilience is very high, with benefit-cost ratios ranging from 2:1 to 10:1, and in some cases even higher. Specifically, investing US $1.8 trillion globally in five areas from 2020 to 2030 could generate $7.1 trillion in total net benefits. Rebuilding shorelines, roads, sewers, power systems and other infrastructure in ways that will hold up to rising temperatures, surging sea levels, and other climate risks would yield $4 trillion in economic benefits. Revitalizing natural watersheds and upgrading infrastructure to reduce flood risks and ensure water supplies would generate another $1.4 trillion. Restoring mangrove forests that can protect coastal communities during storms contributes $1 trillion, improving practices for growing crops in arid regions adds $700 million, and building early warning systems that can help cities and citizens prepare in the face of coming storms and other events would contribute $100 million. (Global Commission on Adaptation, September 2019).
II. The Market Opportunities and Broader Benefits of Climate Restoration

Even though we need far more rigorous research and analysis, not to mention practical testing and scaling, of the market opportunities and the broader value of the economic, social, and environmental benefits of all three pillars of climate action, what we know about climate mitigation and adaptation is far more developed than our knowledge of climate restoration. I estimate the financial value of market opportunities of climate restoration could feasibly range between at least $1-3 trillion per year by 2030, while the broader economic, social, and environmental benefits of climate restoration are significantly greater (at least $3-5 trillion per year by 2030) based on a comprehensive review of the literature and dozens of interviews with scholars, market analysts, and other leading experts on natural and technological solutions for climate restoration.

The most systematic analysis of climate restoration market opportunities is the Comprehensive Road Map on carbon capture utilization (CCU) technologies produced by Lux Research for the CO₂ Sciences and the Global CO₂ Initiative published in 2016. This report not only projected how a subset of CCU market opportunities might scale under business as usual, but also how they might scale if the strategic actions in the road map are followed. The subset of CCU market opportunities they examined were building materials, chemical intermediates, fuels, and polymers. As figure 3 illustrates, the overall, annual revenue estimate of these combined markets could hit between $800 billion and $1.1 trillion by 2030, and over 10% of annual [global] CO₂ emissions can be captured in these solutions at the upper bound of this estimate.
And these represent only a subset of climate restoration market opportunities. Five “conventional pathways” and five “non-conventional pathways” were analyzed in a comprehensive recent review of “The technological and economic prospects for CO₂ utilization and removal,” published in Nature on November 6, 2019. This rigorous analysis finds that:

“Dependent on a multitude of technological, policy, and economic factors that remain unresolved, each of the conventional pathways—chemicals, fuels, micro-algae, building materials and CO₂-EOR—might utilize around 0.5 Gt CO₂ yr⁻¹ or more in 2050. We also estimate that between 0.2 and 3.2 Gt CO₂ yr⁻¹ could be removed and stored in the lithosphere or in the biosphere for centuries or more. The five non-conventional utilization pathways that we review here are BECCS, enhanced weathering, forestry techniques, land management practices, and biochar. Previous reviews have shown that these pathways offer substantial CO₂ removal potential: a recent substantive scoping review gives values of 0.5 to 3.6 Gt CO₂ yr⁻¹ for afforestation/reforestation, 2.3 to 5.3 Gt CO₂ yr⁻¹ for land management, 0.3 to 2 Gt CO₂ yr⁻¹ for biochar, and 0.5 to 5 Gt CO₂ yr⁻¹ for BECCS. Enhanced weathering offers a removal potential of 2 to 4 Gt CO₂ yr⁻¹ at costs of around $200 per tonne of CO₂. Not all of this potential involves utilization of carbon dioxide resulting in economic value, but the approximate scale of CO₂ utilized that is described below could be considerable. The break even costs per tonne of CO₂ utilized that we estimate here are low and are frequently negative.”
“Zero on the vertical axis is the present day ‘break even cost’ (in 2015 dollars), the point at which a technology is competitive with incumbents. Those below that line are already competitive. Those above the line would need a commensurate subsidy of some kind to compete. The width of the bars indicates the amount of CO₂ the technology could utilize annually by 2050 (based on projections and expert opinion). And the color of a bar indicates its TRL. The concrete pathways (aggregates and curing) are fairly close to cost-competitive and curing in particular has fairly large potential, especially when you consider that its CO₂ counts twice, once as emission reductions, once as permanent storage. Troublingly, the industrial CCU technology pathways with the most total potential to use CO₂ are the most expensive relative to incumbents.” (Vox.com, November 27, 2019).

Carbon capture from natural solutions including reforestation and regenerating land -- especially degraded farm land -- could further reduce 1-11 GT of CO₂/year. Approximately 900 million hectares of the nearly 2 billion hectares of land around the world that has been degraded by human misuse. An estimated investment of $300 billion is needed to employ simple, age-old practices to lock millions of tons of carbon back into an overlooked and over-exploited resource: the soil. Returning that land to pasture, food crops or trees would convert enough carbon into biomass to stabilize emissions of CO₂, the major greenhouse gas, for 15-20 years, giving the world time to adopt carbon-negative solutions (Scenarios for the UNCCD Global Land Outlook – PBL Netherlands Environmental Assessment Agency, 2017).
The broader economic, social, and environmental benefits of reforestation and regenerating farmland could certainly run into the trillions of dollars of value people and planet. The revitalized areas could benefit local communities and host countries through increased food supply, tourism and other commercial uses. At the UN Conference on Desertification in September 2018, 196 countries plus the European Union agreed to a declaration that each country would adopt measures needed to restore unproductive land by 2030. Kenya, for example, plans to plant 2 billion trees on 500,000 hectares to restore 10% of its forest cover, but it is also working on ways to adapt to the changes in climate by developing indigenous vegetables and livestock, while simultaneously embracing hybrid crop and livestock varieties.

![Dry Belts Change in aridity 2010-2050](image)

Sources: PBL Netherlands Environmental Assessment Agency, United Nations Convention to Combat Desertification
Note: Data shown are “Middle of the Road” scenario (SSP2), indicating the continuation of current trends.

But as the authors in the November 6, 2019 Nature paper state, “many technologies are in the very early stages of development, and cost optimization via research and development could substantially change these estimates.” The scale of market opportunities is indeed advancing rapidly. For example, technologies being developed to capture CO₂ from the air have been constrained by the cost of capture and the ability to harvest the gas at scale. “Mechanical trees” invented by Klaus Lackner of Arizona State University and his colleagues are being deployed commercially by Silicon Kingdom Holdings (SKH), addressing both issues: bringing the cost of CO₂ capture comfortably below $100 per metric ton at scale — the lowest in the industry — making it both commercially viable and impactful for reducing global warming. SKH plans to deploy clusters of the columnar mechanical trees. A cluster comprises 12 columns and can remove 1 metric ton of CO₂ per day. SKH will deploy the technology in a pilot CO₂ farm targeting 100 metric tons per day of CO₂. The technology will then be deployed to full-scale CO₂ farms in multiple locations, each capable of removing 3.8 million metric tons of CO₂ annually.
The scale up of carbon negative concrete could remove an additional trillion tons of CO₂ from the atmosphere over 30 to 40 years while avoiding environmental degradation caused by quarrying fresh limestone aggregates. A prime example is that of Blue Planet and building materials. Blue Planet has developed a commercially viable way to capture and permanently sequester CO₂, as CO₃ in the crystalline state, within limestone aggregate products sold for use in concrete. Producing limestone aggregates provides a scalable solution in the carbon-removal space because there is a well-established immediate commercial market for construction aggregates. Indeed, this market could be large enough to remove and sell all the world’s excess CO₂ by 2050.

Blue Planet’s first commercial scale production plant, San Francisco Bay Aggregates, is currently under development in Pittsburg, CA, and will service the Bay Area, Los Angeles and U.S. west coast with aggregate products. Blue Planet has partnered with Kamine Development Corporation (KDC) Sustainable Infrastructure, a family business dedicated to building scalable infrastructure to solve the critical challenge of climate change and improve sustainability globally. The partnership will focus initially on completion of San Francisco Bay Aggregates, then on scaling and deploying Blue Planet’s revolutionary carbon sequestering technology across multiple plants. Additionally, as of January 2020, Blue Planet is in discussion with a wide range of industrial emitters, including cement and steel plants, and other international project development companies about deploying plants on a worldwide basis.

The development of CarbonStar™ represents another breakthrough – a simple, quantifiable global standard (a quantifiable measure on a continuum that is verifiable and can be independently validated by auditors like EnergyStar) for carbon intensity of cement and concrete, with the potential to expand the scope in the future to other building materials such as steel and glass. CarbonStar™ is being proposed as a new standard for the International Standards Organization (ISO) that would immediately allow simple comparison of the carbon intensity of similar products and provide a benchmark for issuing carbon sequestration credits. CarbonStar™ would benefit the entire set of industries and organizations advancing innovative CO₂ sequestering methods, including regulatory bodies, the building industry, building owners, and other key stakeholders.

CarbonStar™ would be recognized by government entities, such as treasury departments, ministries of finance and tax authorities that are administering CO₂ tax credits for the geological sequestration of CO₂, as well as cap-and-trade programs that need to review the amount of CO₂ sequestered for carbon allowance accounting. The Government of Canada, through the support of the Standards Council of Canada (SCC) and the Canadian Standards Association (CSA Group) is currently developing a technical specification to implement the first demonstration of CarbonStar™.

According to David Roberts of Vox, there are also numerous other market opportunities that are even more speculative and cutting-edge. “For example, CO₂ can be transformed into high-performance materials — carbon composites, carbon fiber, graphene — that could conceivably substitute for a whole range of materials, from metals to concrete. For instance, the team at C2CNT is using ‘molten electrolysis’ to transform CO₂ directly into carbon nanotubes, which are stronger than steel and highly conductive. They are already used in high-end applications like the Boeing Dreamliner and some sports cars. But as they become cheaper, there is almost no ceiling to the market opportunities. To take just another example, think of substituting carbon nanotubes for copper in electric wiring.”
Virtually every application of electricity, from the space station to electric vehicles to household appliances, would benefit from lighter-weight wiring that conducts better. And then there’s steel, the most commonly used metal in the world, responsible for between 7 and 9 percent of global CO2 emissions from fossil fuels. If carbon-based materials could be substituted for steel on any real scale, it could mean billions of tons of reduced carbon emissions.” (Vox.com, November 27, 2019).

Perhaps the most difficult to estimate in terms of market opportunities, let alone broader economic, social, and environmental benefits but nonetheless critical, are solutions in areas such as ocean fertilization, permaculture arrays with upswelling, and Arctic ice restoration. Pasture Partners estimates an internal rate of return on ocean fertilization of 20%. The Foundation for Climate Restoration estimates a 15% internal rate of return for permaculture arrays, and believes there are technologies like ice thickening that may have a market value by creating new industries (Foundation for Climate Restoration White Paper, 2019). Over the last decade Ice 911 has tested and developed material approaches that “could be used to make young, thick ice reflective. The team now focuses on using reflective hollow glass microspheres, chosen for its safety, effectiveness and practicality (L. Field et al in “Earth’s Future”, May 21, 2018).

Global financial markets and the private sector more generally are beginning to shift investment policies to enable humanity to achieve climate mitigation, adaptation, and increasingly, restoration. At COP25 in Madrid in December 2019, a record 631 investors managing over US $37 trillion signed the Global Investor Statement to Governments on Climate Change, which called on world governments to achieve the Paris Agreement’s goals, accelerate private sector investment into the low carbon transition, and commit to improve climate-related financial reporting. Goldman Sachs is overhauling its environmental policies, which includes pledging to spend $750 billion on sustainable finance projects over the next decade, as well as implementing stricter lending policies for fossil fuel companies.

On January 18, 2020, Microsoft joined the vanguard of climate restoration. The global company, which consistently ranks among the world’s five most financially valuable enterprises, committed to become carbon negative through a range of feasible investments and solutions by 2030. The plan includes converting to renewable energy sources, focusing on using electric vehicles, and expanding an internal carbon tax. The company’s ultimate goal is to remove from the environment by 2050 all of the carbon the company has emitted since it was founded in 1975. Microsoft will also launch a $1 billion fund to finance carbon reduction, capture, and removal technologies over the next four years.

It is this type of bold and audacious effort during this “decade of action” that will contribute to ensuring the survival and flourishing of humanity. What is needed now is a transformative, global, multi-stakeholder partnership to catalyze and connect the mounting initiatives on climate restoration. With this new global institution, climate restoration efforts can reach the scale necessary to be the critical third pillar in collaboration with the absolutely essential scaling of climate adaptation and mitigation efforts for people, prosperity and planet.