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News & Highlights

Mitigating Climate Change Will Depend on Negative Emissions Technologies

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"Negative emissions technologies" (NETs) that remove and sequester carbon dioxide from the air will need to play a significant role in mitigating climate change, according to a report published late in 2018 by the US National Academies of Sciences, Engineering, and Medicine (NASEM) [1]. The report calls for the launch of a substantial research initiative to advance these technologies as soon as possible.

Since the beginning of the industrial era, human activities—primarily burning fossil fuels and flooding the atmosphere with carbon dioxide—have caused global average temperatures to rise approximately 1 °C. To avoid catastrophic climate change, 195 countries came together in 2015 to sign the landmark Paris Agreement, setting a goal of keeping global average temperatures from rising more than 2 °C, ideally less than 1.5 °C [2].

But the challenge is daunting. Reducing global greenhouse gas emissions by half over the next decade and hitting "net-zero" emissions by about 2050 will require heroic efforts, with only a two-thirds chance estimated for meeting the 1.5 °C goal [3]. It means every sector—electricity, transportation, industry, farming—of every economy in the world needs to achieve, on average, zero emissions by 2050. The world's foremost authority on mitigating climate change, the Intergovernmental Panel on Climate Change, has assessed the most economically viable routes to meeting the emissions goals set under the Paris Agreement. "There's not a single 1.5-degree pathway that works without removing at least some CO_2," said economist Sabine Fuss, head of the Sustainable Resource Management and Global Change working group at the Mercator Research Institute on Global Commons and Climate Change, a Berlin, Germany-based science policy think tank (Fig. 1) [4].

A 2017 meta-analysis concluded that NETs could capture the equivalent of 37 Gt of CO_2 per year at a cost below \$70 USD·t^{-1} [5], which would offset the current global CO_2 emissions of about

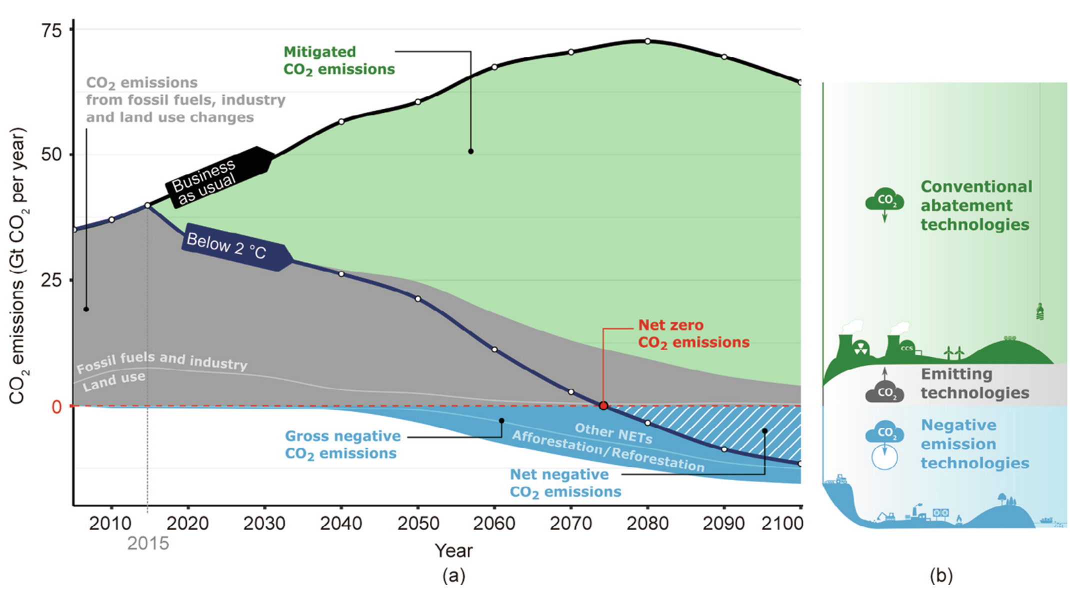

Fig. 1. Projections of emission reductions from conventional abatement technologies combined with carbon dioxide removal. (a) CO_2 emissions pathways from the scenario literature; (b) examples of technologies. Emissions will continue to rise in the absence of conventional abatement technologies ("Business as usual"). To have an at least two-thirds chance of keeping the global mean temperature rise below 2 °C relative to preindustrial levels, conventional abatement technologies will need to be combined with NETs. Under this "Below 2 °C" scenario, global net emissions levels become net negative around 2075 [4].

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37.1 Gt a year estimated in a 2018 study [6]. More recently, Minx et al. reviewed 2092 documents related to seven different NETs (Fig. 2) [7], projecting how much CO_2 they could remove from the air and at what cost [7].

Afforestation—the planting of new forests—and reforestation are the least expensive options, with a cost ranging from below ten to tens of US dollars per tonne of CO_2 removed. A 2019 study by Baston et al. [8] calculated that new trees can, theoretically, be planted on nearly 1×10^9 hm^2 of land, bringing the total area of Earth that can support trees to 4.4×10^9 hm^2. Once mature, the additional 500 billion trees could create storage for 200 Gt of carbon. However, among the issues raised for this strategy are that it takes trees 50–100 years to mature and many of the trees would need to be planted in snowy northern regions that currently reflect much solar radiation back into space [9]. And there are other concerns as well. "Land-based solutions like afforestation worry me," said economist Jan Minx, Fuss's colleague at the Mercator Research Institute and head of the Applied Sustainability Science working group. "Land is actually pretty scarce, and we'll need it to feed people. And with a change in governance or a continued increase in forest fires due to a warming climate, the trees can be easily lost again, and the carbon immediately released back into the atmosphere."

On the more expensive end of the NET options is direct air capture (DAC), which covers a range of engineered systems that remove CO_2 from the air and bury it underground in old oil and gas reservoirs or saline aquifers. The cost of DAC, which has been tested at small scales, is on the order of hundreds of US dollars

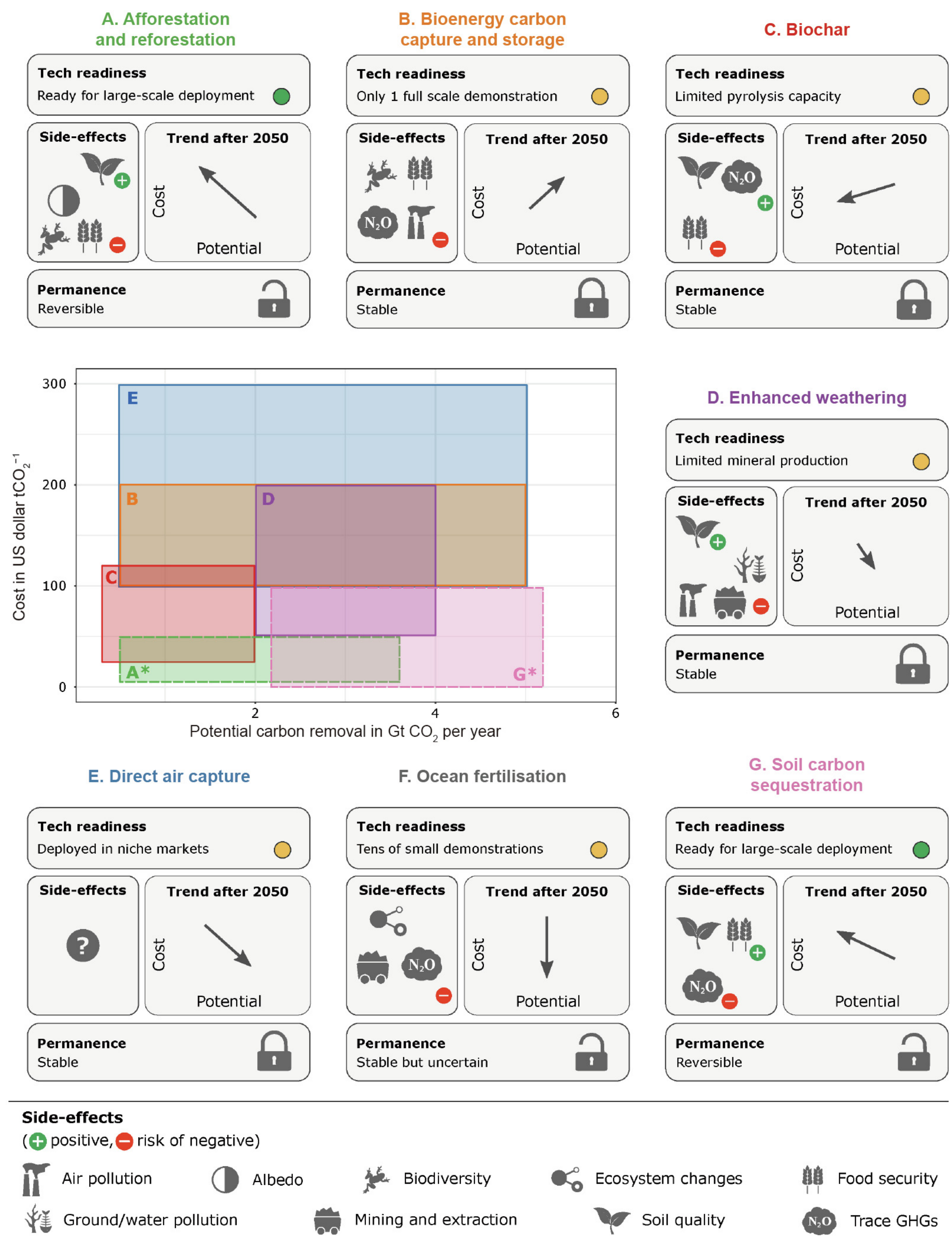

Fig. 2. NETs and their major features including costs, carbon-removal potential, permanence of storage, as well as development status, and a partial list of side-effects [7]. tCO_2^{-1}: per tonne of CO_2; Tech: technology; GHGs: green house gasses.

or more per tonne of CO_2 removed, with one 2019 study suggesting the technology could consume as much as a quarter of global energy supplies by 2100 [10]. But this technology has the potential for removing the most CO_2 of any NET. "DAC's big advantage is that it could be more scalable than other technologies," said Minx, who was a reviewer of the final 2018 NASEM report and whose work, along with that of Fuss, was cited extensively in the report. "It's a bit like solar where, in principle, modules can be put anywhere."

Somewhere in between afforestation and DAC in terms of cost and carbon-scrubbing potential is bioenergy with carbon capture and storage (BECCS). This technology involves burning plant matter, or biomass, in power stations to generate electricity. Instead of being released into the atmosphere, however, the emitted CO_2 is pumped underground, at an estimated cost between \$100 and \$200 $USD{\cdot}t^{-1}$ of CO_2 removed. The technology works but would need to be scaled up substantially to be relevant. There are 17 large-scale carbon capture and storage plants in operation today, with an annual capacity for removing about 4×10^7 t of CO_2 from entering the atmosphere [11], less than 0.01% of the carbon emitted each year.

The NET that Fuss, Minx, and colleagues identify as currently the most cost-effective is soil carbon sequestration, a process that enriches the CO_2 in soils by adjusting agricultural practices. This sequestration can be enhanced with regenerative agricultural practices such as no tilling and crop rotation. Robin Batterham, professor of chemical engineering at the University of Melbourne, said that while it makes economic sense to pay farmers to implement these practices, the challenges are first convincing farmers to upend decades-old habits and figuring out a cost-effective way to track farmers' efforts. Not everyone agrees about the amount of carbon this process can retain, however, with a 2016 study concluding that the potential impact of soil carbon sequestration has been overestimated by about 40% [12].

Assessing the total potential of all NETs is not as simple as adding them together. They are all in various stages of development and some of them compete with one another for land, water, bioenergy, and other resources. For example, some 1.5 °C-model pathways require a land mass anywhere from two to five times larger than India to grow the biomass necessary for BECCS [13,14].

Minx said NETs can be thought of as a portfolio, with each deployed according to a schedule that considers cost, potential effectiveness, availability, safety, and permanence. For example, land-based options, which are currently available, relatively cheap, and more easily reversible, could be deployed right away. Then, more technical options, such as BECCS and DAC that can remove much more carbon, can be phased in once the technology has matured. "In the 1.5 °C scenarios, those technologies need to work at a gigatonne scale, and we are nowhere near reaching that," Minx said. "Innovation usually takes much longer than people think and some of the most scalable NETs are still in the research and development phase."

In any case, "the best current solution may be decarbonizing the economy as quickly as possible to avoid putting more CO_2 in the atmosphere in the first place," said Fuss. "Then you don't have to take out as much in the end."

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