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Reply to: Practical constraints on atmospheric methane removal

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REPLYING TO K.S. Lackner *Nature Sustainability* https://doi.org/10.1038/s41893-020-0496-7 (2020)

As a pioneer of direct-air capture of CO_2 (ref. [1]), particularly in passive systems, Lackner is well positioned to comment[2] on our proposal to remove methane (CH_4) and other non-CO_2 gases industrially from the atmosphere[3]. Here, we respond briefly to his points.

Lackner is right to highlight[2] the cost and energy requirements of processing large volumes of air to remove dilute CH_4 (~1,865 ppb). We acknowledged this challenge in our original paper[3]. However, his estimate that it would require an “energy bill that is three orders of magnitude larger for a ton of methane” (compared with 220 MJ per ton of CO_2) seems premature, absent more specific engineering designs for CH_4 conversion or capture. The minimum thermodynamic work required to separate methane from air scales logarithmically with concentration, not linearly, and is less than double that of CO_2. His estimate of electricity costs of ¢3 kWh^{-1} is fairly high today, let alone decades from now; processes such as CH_4 removal may also be a productive way to use solar and other renewable energy when supply exceeds demand, as already occurs at midday for some solar power generation. Furthermore, there may be ways to reduce the energy requirements of any given design. Air with CH_4 at concentrations higher than background would reduce energy needs, as we noted in our paper[3]. Using natural winds or existing blowers of exhaust gases could also drive down the energy needs. Nonetheless, passive systems, as championed by Lackner[1], do have some benefits over more energy-intensive systems with blowers.

Another advantage to be considered when comparing the costs of CH_4 and CO_2 removal is that methane can be used directly as a fuel or chemical building block if it is captured rather than converted and released back into the atmosphere. There are few viable large-scale processes that use CO_2 as a feedstock at present, thus reducing its post-capture value. Engineering demands may conspire to make CH_4 removal costs prohibitive. Time will tell—and research on catalyst performance, sorbents and engineering designs will all be important.

Our perspective differs from Lackner’s[2] on a few other issues. Using a framework of processing “the entire atmosphere in less than a decade”[2], as Lackner states, CH_4 removal appears (and perhaps is) more ambitious than proposed CO_2 removal, particularly when CH_4 is found at background concentrations two orders of magnitude lower than CO_2. On a mass basis, however, the total amount of CH_4 removed would be orders of magnitude smaller than for CO_2 removal. Concentrations of CH_4 could be restored to pre-industrial levels of ~750 ppb by removing ~3.2 of the 5.3 Gt CH_4 currently in the atmosphere[3]. In contrast, ~40 $GtCO_2$ are released yearly from anthropogenic activities[4], with 10 $GtCO_2$ removed yearly and hundreds of gigatons of CO_2 proposed to be removed cumulatively in many negative emissions scenarios.

Lackner also points out that “turning down the faucet” (that is, CH_4 mitigation) to a bathtub may be a better strategy than “bailing” (that is, methane removal from the atmosphere)[2]. We agree. Mitigation of a greenhouse gas is almost always better than removing it after its release into the atmosphere: a drop of ink is easier blotted from a pen than extracted after it drips into a bathtub or a glass of water. However, not all CH_4 mitigation efforts are technologically or economically tractable. We envision ‘permanent’, ongoing CH_4 removal to offset the most intransigent and expensive emissions from the energy sector and, more likely, food production—including emissions from ruminants and rice farming. In fact, it may be impossible to eliminate global CH_4 emissions this century and hence stabilize the atmosphere without continued CH_4 removal, even when atmospheric restoration is achieved[3].

Lackner also raises the possibility of curtailing other natural emission sources of CH_4, rather than removing CH_4 from the atmosphere[1]. As noted in our paper[3], any source of methane that results in higher-than-background concentrations in air would lower the energy requirement and cost of methane removal. Top-down estimates suggest that natural CH_4 emissions total ~230 Tg of CH_4 compared with ~330 Tg CH_4 from anthropogenic sources[5]. However, most natural sources come from wetlands (~170 Tg CH4), with smaller contributions from freshwater ecosystems, natural geological seeps and fires[5]. Modest CH_4 mitigation from geologic seeps and fires seems more practical than mitigating larger and more diffuse wetland and freshwater sources.

Finally, Lackner suggests reasons to consider nitrous oxide (N_2O) removal as an alternative to CH_4 removal, a point we highlighted several times in our paper[3], including the possibility of coupling N_2O and CH_4 removal. With an atmospheric lifetime of ~116 years (ref. [6]), N_2O is longer lived than CH_4 and far more potent than both CH_4 and CO_2 on a mass basis. For many reasons, research on N_2O removal seems warranted. However, N_2O has the disadvantage of being even more dilute in the atmosphere (~330 ppb) than CH_4. Current conversion processes often produce pollutants NO and NO_2 from N_2O, not just N_2 and O_2 (for example, ref. [7]).

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Finally, N_2O conversion does not have the extensive industrial research programme already in place today for oxidizing methane to methanol (CH_3OH).

We believe that CH_4 removal will eventually be practical and is likely to be deployed for decades to come. Our goal[3] was, and remains, to stimulate research in the neglected field of negative emissions for methane, nitrous oxide and other gases beyond CO_2 alone.

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Author contributions

All authors contributed to the ideas expressed in the paper. R.B.J. drafted the initial response.

Competing interests

The authors declare no competing interests.

Additional information

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