

# **An Assessment of Atmospheric Hydroxyl Levels and the Oxidative Capacity and Its Mitigation Given the Record Pollution Levels-Introduction to Hydroxyl Inundation**

Science Communication

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## Abstract

The hydroxyl radical (OH) is the primary naturally occurring oxidant in the atmosphere, playing a crucial role in removing pollutants 1,2. The production rate of hydroxyl radicals is finite, generally estimated to be in the range of  $1 \times 10^5$  to  $1 \times 10^7$  molecules per cubic centimetre 3,4. This rate corresponds to an abundance level of approximately 1 part per trillion (PPT), with hydroxyl radicals having an average lifespan of about 1 second. This leads to an average production or flux rate of around 620 formations at the 1 PPT level 5. Due to this finite production rate, hydroxyl radicals have a limited capacity for pollution removal.

In this letter, we calculate the total abundance of hydroxyl radicals about the current levels of criteria air pollutants, factoring in the NO<sub>x</sub>-initiated OH\* recycling mechanism. When the levels of pollutants exceed 100% of the hydroxyl abundance, it is proposed that this constitutes hydroxyl inundation. Our calculations reveal that the current levels of pollutants lead to an inundation exceeding 4,800% of the hydroxyl capacity. Including all adjunct oxidants in the calculation increases this inundation to over 900%.

This analysis underscores the significant imbalance between the available hydroxyl radicals and the current pollutant levels, highlighting a critical challenge in atmospheric chemistry and pollution management.

## Discussion

The hydroxyl radical, along with secondary oxidants, collaborates with the hydrologic system to mitigate pollution, which may provide some buffer against the onset of accelerating climate feedback. Currently, there is a disparity of 1 watt per square meter ( $1 \text{ W/m}^2$ ) between global climate models and actual observations<sup>6</sup>. Considering the substantial inundation of pollutants, this discrepancy might be contributing to the accelerated accumulation of greenhouse gases (GHGs), particularly methane, which has seen a 160% increase since the pre-industrial era<sup>10</sup>.

For comparison, another crucial component of the atmosphere, the ozone layer, has experienced a depletion of approximately 5-6%<sup>7</sup>. To date, no published study has comprehensively assessed total air pollutants to the atmosphere's oxidative capacity. This capacity encompasses secondary oxidants such as ozone (O<sub>3</sub>), hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), hydroperoxyl (HO<sub>2</sub>), and organic peroxides. A review of the literature indicates the parts per million (PPM) values of these oxidants, which, as shown in Table 1, do not significantly enhance the total oxidative capacity beyond the levels already documented.

This analysis suggests that the existing oxidative mechanisms in the atmosphere are currently overwhelmed by pollutant levels, underscoring the need for further research and action in atmospheric chemistry and environmental management <sup>8,9</sup>.

The climate sensitivity to current CO<sub>2</sub> levels has been adjusted by Hansen et al. (6), which includes a discussion about the potential impact of reduced sulfur emissions contributing to the additional 1W/m<sup>2</sup> in the planetary energy imbalance. It is hypothesized that the inundation of oxidants, particularly carbon-negative species, is exacerbating the rate of heat accumulation due to their depletion by unprecedented pollutant levels (4). CO<sub>2</sub> and methane concentrations are projected to rise beyond 2024, following the current trajectory. Notably, methane has the potential to drastically increase the inundation level of hydroxyl and other oxidants, potentially exceeding 40,000,000% from the current 35,365,572%. This significant increase could mark a critical tipping point, potentially triggering an accelerated, self-reinforcing wetland methane feedback loop. While a 100% or lower level of inundation did not trigger major warming feedbacks, a surge to approximately 35,400,000% inundation of the atmospheric oxidation system is likely to have a substantial impact, as indicated by the growing planetary energy imbalance observed in actual measurements<sup>12</sup>.

This scenario underscores the urgency of understanding and addressing the interconnected dynamics of atmospheric pollutants, greenhouse gases, and their cumulative effect on global climate systems.

Figure 1 illustrates an OH<sup>-</sup> (hydroxyl) anomaly indicative of a system heavily impacted by pollution, necessitating mitigation efforts. These mitigation strategies should consider enhancing hydroxyl levels in light of the current inundation evidenced by the data presented in Table 1. Interpretations asserting the adequacy of hydroxyl levels often rely on Nox (nitrogen oxides) pollution levels, which stimulate and boost hydroxyl formation. However, the detrimental effects of pollutants accompanying Nox on climate and health underscore the imprudence of this interpretation.

Table 1. 2023 Atmospheric OH Radical Demand Analysis

Calculator of *OH Needs		
Air Shed Constituents in ppm 2023		
CAP	ppm	comments
CO	0.871	
Sox	0.0004	
CH4	0.192499	
PM 2.5	0.312	
O3	0.1	
Nox	0.0126	
CO2	423	423 ppm-noted but excluded from deficit tally
VOC	0.32	
SGHG basket	0.427134905	
<b>Total Reactants</b>	<b>425.2356339</b>	PPM
(*OH Flux		
	ppm	
PPM (*OH natural	0.00072	720x in 12hours based on 10 <sup>6</sup> molecules/cc
added PPM (*OH	0	1.1 , 2.2, 1.5,3
AVG Nox Boost	0.0004824	67% Pollution based OH* triggering
Total OH* flux	0.0012024	
H2O2	0.12	
O3	0.1	
HO2	0.00001	
<b>Total Flux</b>	<b>0.2224148</b>	<b>PPM</b>
DEFICIT OF OH		
	<b>2.235</b>	<b>PPM</b>
<b>% INUNDATION OH*</b>	<b>35365572</b>	<b>%</b>
Deficit of all oxidants		
	<b>2.013</b>	<b>PPM</b>
<b>% INUNDATION All</b>	<b>191190</b>	<b>%</b>

Table 1 displays a table titled "Calculator of  $\cdot\text{OH}$  Needs", which seems to be related to atmospheric chemistry, specifically for the year 2023. It lists various constituents of an air shed in parts per million (ppm) and includes a section for comments. The table is divided into several sections:

**1. CAP (presumably 'Criteria Air Pollutants'):** Lists standard air pollutants such as CO (Carbon Monoxide), SO<sub>x</sub> (Sulfur Oxides), CH<sub>4</sub> (Methane), PM 2.5 (Particulate Matter with a diameter of 2.5 micrometers or less), O<sub>3</sub> (Ozone), NO<sub>x</sub> (Nitrogen Oxides), VOC (Volatile Organic Compounds), and a combined category of 'SGHG basket', which could refer to a basket of greenhouse gases. The concentrations range from 0.0871 ppm for CO to 0.423143905 ppm for the SGHG basket, with a note mentioning that NO<sub>x</sub> is 423 ppm-noted but excluded from the deficit tally.

**2. Total Reactants:** Summarize the total reactants in ppm.

**3. (OH) Flux:** This section seems to deal with the hydroxyl radical ( $\cdot\text{OH}$ ), which is a critical species in atmospheric chemistry, often acting as a "detergent" due to its ability to react with various pollutants. It lists PPM ('Parts Per Million'), AVG ('Average') NO<sub>x</sub> Boost, Total  $\cdot\text{OH}$  flux, and individual components such as H<sub>2</sub>O<sub>2</sub> (Hydrogen Peroxide), O<sub>3</sub> (Ozone), and  $\cdot\text{OH}$ . There is a specific mention of '720x in 12 hours based on 10<sup>8</sup> molecules/cc' for the  $\cdot\text{OH}$  natural added PPM, suggesting a calculation based on the typical concentration of  $\cdot\text{OH}$  molecules in the atmosphere.

**4. Total Flux:** Shows the total flux of  $\cdot\text{OH}$  in PPM.

**5. Deficit of OH / INUNDATION OH:** Indicates a deficit of hydroxyl radicals in the atmosphere, with values in ppm and percentage. This suggests that the calculation is designed to assess how much additional  $\cdot\text{OH}$  is needed to achieve a certain level of atmospheric cleanliness or reactivity.

**6. % INUNDATION All:** This shows a very high percentage, possibly indicating the extent of the need for  $\cdot\text{OH}$  in the air shed.

The table serves as a sophisticated tool for calculating the need for hydroxyl radicals in the air shed, reflecting the complex interactions of atmospheric chemistry. It is essential for environmental scientists and policy makers who monitor and manage air quality. The data could inform strategies for reducing air pollution through chemical reactions that mitigate harmful constituents.

If the adjunct oxidant population inundation reaches 2,000,000%, or the hydroxyl population inundation reaches 50,000,000%, the pollution removal effectiveness of the oxidative layer/system will be even more problematic. This would involve an effective methane level rise to about 2180-2280 ppt,  $\pm 40$  ppt, which is what should be watched. These values are suggestive of a highly resilient system reaching/passing a potentially dangerous milestone and tipping point.

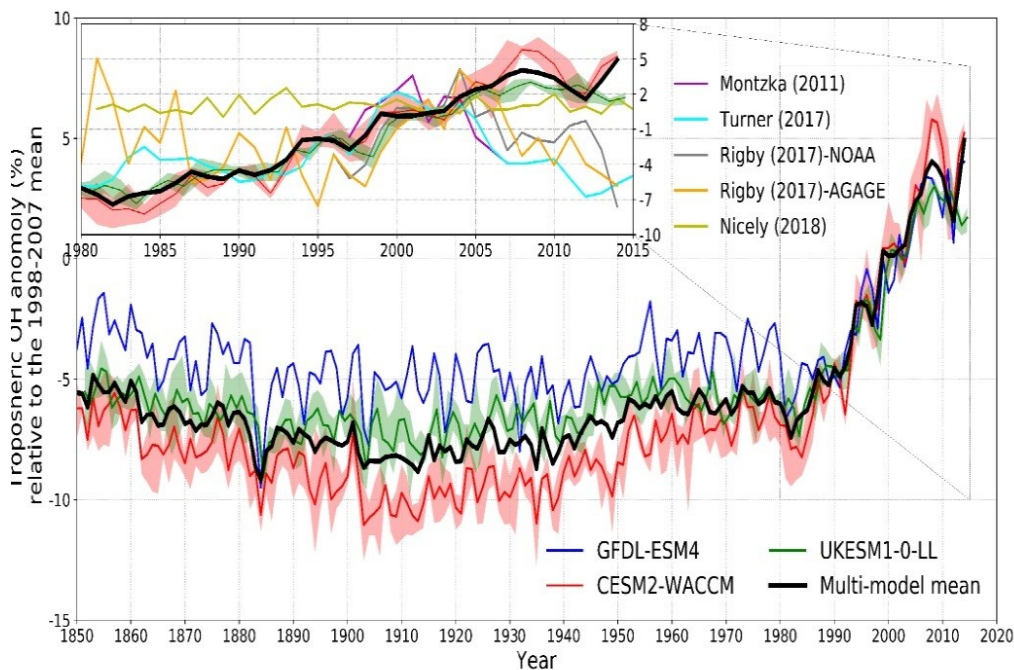


Figure 1. reprinted for discussion with credit to <sup>4</sup>.

Reprinted: Figure 2. Time evolution (1850-2014) of global annual mean tropospheric OH, expressed as a percentage anomaly relative to the 1998-2007 mean value for UKESM1-0LL (green),

Figure 1 presents a graph depicting the relative change in hydroxyl (OH) concentration in the atmosphere over time, from approximately 1850 to 2020. This is likely related to research in atmospheric chemistry or climate science. The graph plots the anomalies in OH concentration, measured as deviations from a mean value established from 1850 to 1980.

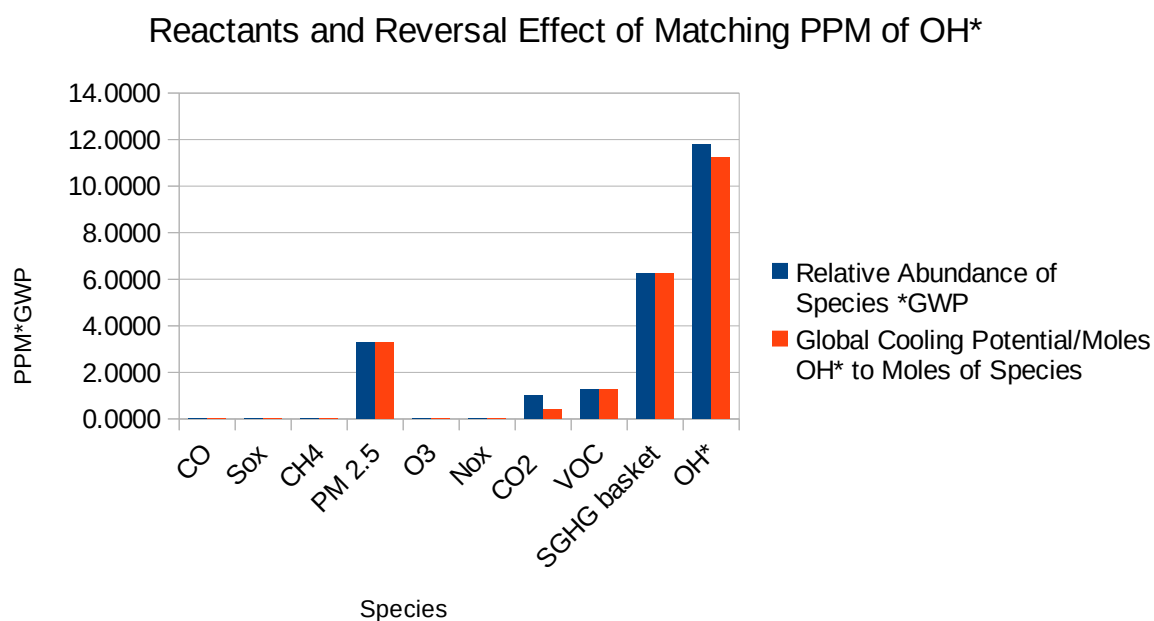
Several datasets are overlaid, including observations and outputs from various atmospheric models:

- **Observational Data:** Lines representing Montzka (2011), Turner (2017), Rigby (2017)-NOAA, Rigby (2017)-AGAGE, and Nicely (2018) likely reflect measurements or recalibrations of historical OH concentrations based on different methodologies or assumptions.

- **Model Outputs:** GFDL-ESM4, CESM2-WACCM, and UKESM1-0-LL are acronyms for different Earth System Models, which simulate atmospheric chemistry and physics. These models' outputs show the projected or simulated levels of OH concentration over time.

- **Multi-model Mean:** A line representing the mean of multiple models, providing a consensus estimate of OH concentration anomalies.

The shaded areas around some of the lines indicate uncertainty or the range of variability within the data or model outputs. The graph indicates a significant increase in the variability and concentration of OH radicals in recent decades, particularly evident from the 1980s onward. This could be due to various factors, including increased emissions of pollutants or changes in the atmosphere's chemical composition due to climate change. The sharp rise at the end of the series suggests a notable change in OH levels, potentially important for understanding atmospheric cleaning capacity and the degradation of pollutants.



**Figure 2.** Comparative Analysis of Species' GWP and the Mitigating Impact of OH\*

The provided image features a bar chart titled "Reactants and Reversal Effect of Matching PPM of OH<sup>-</sup>". This chart compares two different metrics across various atmospheric species: the relative abundance of species (expressed as a percentage of Global Warming Potential, or GWP) and the global cooling potential per moles of hydroxyl radicals (OH<sup>-</sup>) to moles of the species.

The species represented on the x-axis include CO (Carbon Monoxide), SO<sub>x</sub> (Sulfur Oxides), CH<sub>4</sub> (Methane), PM 2.5 (Particulate Matter that is 2.5 micrometers or smaller in diameter), NO<sub>x</sub> (Nitrogen Oxides), CO<sub>2</sub> (Carbon Dioxide), VOC (Volatile Organic Compounds), a combined category of SGHG basket (presumably a collection of Super Greenhouse Gases), and OH\* itself.

Two sets of data are represented in the chart:

**1. Blue Bars:** These indicate the relative abundance of each species in terms of their contribution to global warming, likely normalized to the GWP of CO<sub>2</sub>. The height of each blue bar corresponds to the GWP metric for each species.

**2. Red Bars:** These represent the global cooling potential, suggesting the amount of OH<sup>-</sup> needed to react with the respective species to potentially reverse their warming effects. This is expressed in terms of the ratio of moles of OH<sup>-</sup> required to the moles of the species present.

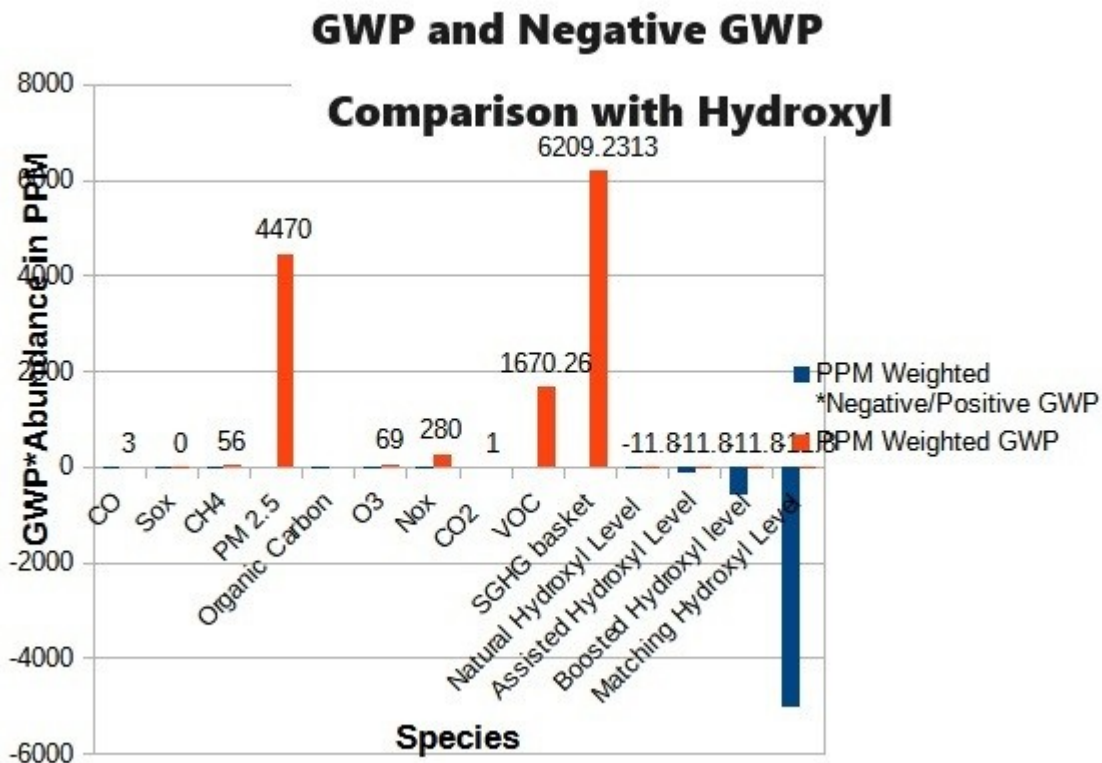
From the chart, it appears that CO<sub>2</sub> and the SGHG basket have the highest relative GWP, while OH<sup>-</sup> has a significant global cooling potential, indicating its importance in mitigating the impact of these species on global warming. The chart underscores the critical role of OH<sup>-</sup> in the atmosphere as a cleansing agent that can react with various pollutants, potentially reversing some of their warming effects. The visual representation provides a clear comparison of the warming potential of various species against their reactivity with OH<sup>-</sup>, which is a key factor in atmospheric chemistry and climate change mitigation strategies.

Hydroxyl radicals (OH<sup>-</sup>) are often referred to as the "governor of atmospheric pollution" or the "principal atmospheric cleanser or detergent." The critical concentration of hydroxyl radicals, as reflected by parts per million (PPM) inundation relative to atmospheric pollutants presented in Table 1, raises significant concerns. It signals an urgent need for remedial actions akin to those that have successfully preserved the ozone layer. Notably, the CO<sub>2</sub> data depicted in Figure 2 underscores the actual sequestration capability of hydroxyl radicals. This is particularly relevant given recent studies indicating that 59% of CO<sub>2</sub> sequestered in soils re-emits back into the atmosphere, where it had initially been deposited by precipitation<sup>14</sup>.

The evolution of oxygen on Earth and the consequent enhancement of the oxidative capacity/system, which augmented the availability of free energy, has led to several profound consequences. These have relevance to the current state of atmospheric pollution and the broader environmental crises. The large-scale effects of increased oxidative capacity include global cooling, enrichment of soil minerals and biodiversity, improvements in the averages of productive precipitation<sup>15</sup>, heightened air quality<sup>16</sup>, and an increase in the Albedo of clouds and skies due to enhanced oxidation of volatile organic compounds (VOCs) over land<sup>17</sup>.

Harnessing substantial quantities of hydroxyl radicals from the existing oxygen column by utilizing atomic oxygen radicals and water to form hydroxyl would be a revolutionary development. If this process could be scaled effectively, it could simultaneously eliminate all pollutants and initiate a cooling process more than twice as fast as the removal of CO<sub>2</sub> alone, as illustrated in Figure 3. The atmospheric oxygen column, with an approximate mass of 10<sup>15</sup> tonnes, and the amount of oxygen needed to generate sufficient hydroxyl radicals to remove 35 gigatonnes (GT) of atmospheric CO<sub>2</sub> and other greenhouse gases (GHGs) is 22.1 GT of OH<sup>-</sup>. This derives from the overall reaction  $2O + 2H_2O = 4OH$ , requiring an equal split of oxygen from both air and water. This process represents a one-time draw-down of 10.4GT of oxygen from the atmosphere and water, which is merely one-millionth of the current atmospheric oxygen content. In contrast, the CO<sub>2</sub> emissions from combustion processes

between 2000 and 2013 have consumed approximately 27.7 GT of atmospheric oxygen annually. Cumulatively, this equates to 360 GT of O<sub>2</sub> during that period, constituting 0.000036 of the total atmospheric oxygen<sup>19</sup>. Such a reduction is accelerating the depletion of the oxygen column, the very source of our planet's vital oxidative capacity.



**Figure 3.** Comparison of Global Warming Potential and Hydroxyl-Driven Negative GWP Across Various Atmospheric Species.

The Figure 3 features a bar graph titled "GWP and Negative GWP Comparison with Hydroxyl", where GWP stands for Global Warming Potential. This graph presents a comparative analysis of various atmospheric species' GWP against their potential for mitigation through reaction with hydroxyl radicals (OH<sup>-</sup>).

The x-axis categorizes different atmospheric species, such as CO (Carbon Monoxide), SO<sub>x</sub> (Sulfur Oxides), CH<sub>4</sub> (Methane), PM 2.5 (Particulate Matter less than 2.5 micrometers), NO<sub>x</sub> (Nitrogen Oxides), CO<sub>2</sub> (Carbon Dioxide), VOC (Volatile Organic Compounds), and SGHG basket (potentially a grouping of Super Greenhouse Gases). Additionally, it includes categories for natural hydroxyl levels, assisted hydroxyl levels, and matching hydroxyl levels.

The y-axis measures the abundance in parts per million (PPM), with positive values indicating a warming potential and negative values representing a cooling or negative GWP, which is the mitigating effect of hydroxyl radicals.

Key points from the graph:

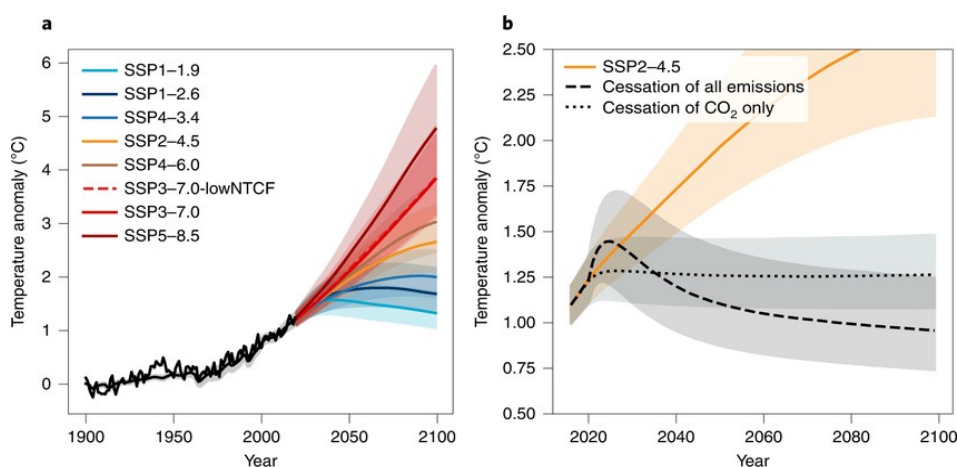
- The CO<sub>2</sub> and SGHG basket categories exhibit the highest GWP, with CO<sub>2</sub> notably at 6209.2313 PPM and SGHG basket at 1670.26 PPM, suggesting their substantial contribution to atmospheric warming.
- Conversely, the bars representing "Natural Hydroxyl Level", "Assisted Hydroxyl Level", and "Matching Hydroxyl Level" have negative values (-11.8 PPM each), indicating the potential of hydroxyl radicals to counteract the warming effect of greenhouse gases.
- The "PPM Weighted GWP" is shown in red, reflecting the warming impact, while the "PPM Weighted 'Negative/Positive GWP'" is shown in blue, indicating the cooling or mitigative potential.

The graph underscores the significant role of hydroxyl radicals in atmospheric chemistry, particularly in their potential to mitigate climate change by neutralizing the warming effects of major greenhouse gases. This visual representation provides a stark contrast between the positive GWP of various species and the negative GWP, which represents the potential beneficial impact of increased hydroxyl radical concentrations in the atmosphere.

In Figure 3, the global cooling potential, also referred to as Negative Global Warming Potential (GWP), emerges as a crucial metric for evaluating and implementing corrective measures against climate change. As depicted in Figure 2, the GWP values are normalized, with carbon dioxide (CO<sub>2</sub>) serving as the baseline index of 1, aligning it with the GWPs of primary greenhouse gases (GHGs). However, Figure 6 in the study conducted by David S. Stevenson et al. in 2020<sup>4</sup> reveals that the assortment of pollutants that interact with hydroxyl radicals (OH<sup>-</sup>) is not exhaustively covered.

The importance of Negative GWP lies in its ability to quantify the potential of various species to counteract global warming effects. This quantification is essential for strategizing mitigation efforts. Notably, the scaling of GWPs relative to CO<sub>2</sub> as a unit allows for a standardized comparison across various GHGs, facilitating a more straightforward understanding of their relative impacts on climate change.

Expanding upon the work by Stevenson et al., it is imperative to include a comprehensive range of pollutants in the analysis of reactions with OH<sup>-</sup> to gain a full perspective on the atmospheric cleansing capacity of hydroxyl radicals. Such an inclusive approach would not only enhance our understanding of atmospheric chemistry but also strengthen the foundation upon which global climate remediation strategies are built.



**Figure 4.** Projected Global Temperature Anomalies Under Different Emission Scenarios. Graph a: Temperature Anomaly Projections by SSP Scenarios, Graph b: "Impact of Emission Cessation on Temperature Anomalies.

The Figure 4 contains two graphs (a and b) depicting projected global temperature anomalies relative to a historical baseline. Graph a presents a series of projections under different Shared Socioeconomic Pathways (SSPs), which are scenarios that reflect varying degrees of greenhouse gas emissions and socioeconomic conditions. The SSPs range from SSP1-1.9, a scenario that implies significant mitigation efforts to limit warming, to SSP5-8.5, a high-emission scenario leading to substantial warming. The colored bands represent the range of temperature outcomes for each scenario, reflecting the uncertainty in climate sensitivity and the effectiveness of mitigation strategies. Notably, there are two variations of SSP3-7.0, one of which includes a low technology carbon feedback (lowNTCF), indicating lower warming due to technological interventions. Graph b focuses on the near-term projections under SSP2-4.5, a middle-of-the-road scenario, and compares it with hypothetical situations where either all emissions or only CO<sub>2</sub> emissions cease. The solid orange line represents the temperature projection under SSP2-4.5, while the dashed and dotted lines represent the temperature trajectories following the cessation of all emissions and of CO<sub>2</sub> emissions alone, respectively. The cessation of all emissions results in a stabilization and then a gradual decline in temperature anomalies, while the cessation of CO<sub>2</sub> alone leads to a slower rate of increase but does not reverse the warming trend. These graphs are critical for understanding the potential impacts of different emission trajectories on global temperatures and the urgency of reducing emissions to mitigate climate change. They also illustrate the complex dynamics of climate response to different mitigation strategies, highlighting the importance of comprehensive action beyond just CO<sub>2</sub> reductions.

The Figure 5 presents an ensemble of constrained global temperature projections derived from the FaIR model. Panel a illustrates the temperature trajectories following various Shared Socioeconomic Pathways (SSPs), with historical data from the HadCRUT5 dataset integrated in black. This historical temperature record provides context for the modeled projections, anchoring them to observed climate trends.

Panel b offers a focused examination of temperature changes under the SSP2-4.5 scenario without any cessation of emissions, represented by the orange line. It contrasts this scenario with hypothetical pathways where only CO<sub>2</sub> emissions cease (depicted by the dotted line) and where all anthropogenic emissions are halted (illustrated by the dashed line, labeled ZECAnthro), starting at the onset of 2021. The shaded areas around the projections indicate a 66% confidence interval, stemming from a large ensemble of 6,729 posterior members, which underlines the robust statistical treatment applied in the study.

Global temperature anomalies are calibrated against the pre-industrial average from 1850-1900, serving as a baseline for measuring the degree of warming. This comparative approach underscores the varying impacts of different mitigation strategies and the potential pathways towards achieving international climate targets.

The data source is cited as "Estimating the timing of geophysical commitment to 1.5 and 2.0 °C of global warming" by Dvorak et al., highlighting the paper's contribution to the ongoing discourse on climate change and the importance of timely and decisive climate action to limit global temperature rise within internationally agreed thresholds.

Wei Li and colleagues (2021) propose enhancing atmospheric water vapor levels to augment the photolysis of hydroxyl radicals (OH<sup>•</sup>), which could be beneficial for atmospheric cleansing. Despite the potential merits of this method, concerns arise regarding water scarcity and the considerable costs associated with generating water vapor—a greenhouse gas that could exacerbate global warming. Additionally, pollution can create significant steric hindrance, which may reduce the reliability of this



approach. In contrast, the direct emission of pure hydroxyl radicals might offer a more dependable, controllable, and cost-effective means of reducing atmospheric pollutants. This strategy circumvents the complexities introduced by increased water vapor and directly targets the reduction of pollutants through a process that can be finely tuned to meet specific environmental goals.

## Conclusion

The combustion of fossil fuels over the past five decades has inflicted substantial harm on various planetary systems, including the degradation of the oxygen column. This degradation is of particular concern as it diminishes the stock of oxygen available for the Earth's oxidative capacity. Moreover, even well-intentioned efforts at CO<sub>2</sub> sequestration, while mitigating one aspect of climate change, may inadvertently worsen the loss of the oxygen column, rather than replenish it.

Amidst the discourse, there exists a scientific hypothesis suggesting that if humanity were to achieve net-zero emissions, the hydroxyl-hydrological cycle could potentially regenerate within a span of 35 years. However, scrutinizing the data in Table 1 reveals a substantial disparity between current levels of OH<sup>•</sup> and pollutants, casting doubt on the practicality of such a recovery based on the present PPM analysis.

The path to aligning with the regenerative capabilities of Earth's biomes involves drastically reducing combustion to a level that permits the natural conversion of CO<sub>2</sub> back into oxygen and carbon. Only then can we approach a level of technological intervention that effectively addresses the accumulation of legacy pollutants. Addressing the pronounced deficiency in the planet's oxidative capacity is essential, necessitating a reduction in pollution levels to align with the natural production of hydroxyl radicals. Concurrently, remedial strategies must be implemented to rectify the Earth's energy imbalance in a safe manner.

A comprehensive review of hydroxyl chemistry within the broader scientific literature indicates that the oxidation of methane by hydroxyl radicals typically leads to an unwanted byproduct—formaldehyde. Nevertheless, this issue is not insurmountable; it can be swiftly mitigated by introducing sufficient quantities of additional hydroxyl radicals to expedite the removal of formaldehyde, thereby resolving this isolated concern.

Wei Li et al <sup>21</sup>, present the approach of increasing atmospheric water vapor to increase the photolysis of OH<sup>\*</sup>, which is helpful aside from water scarcity and the notable cost of producing water vapor which is a potent greenhouse gas, is helpful. With pollution causing major steric hindrance problems, this is less reliable than emitting pure hydroxyl radicals, which would be more effective, controllable, and economical.

## Conclusion

Fossil fuel combustion during the most recent 50 years has become very damaging to many planetary systems and is damaging the oxygen column, which reduces the oxygen feedstocks for oxidative capacity. Even CO<sub>2</sub> sequestration, which is a form of abatement won't address the oxygen column loss—it will exacerbate it. There is also publicly voiced scientific speculation that If humanity achieves net zero, the hydroxyl-hydrological system can recover as quickly as in 35 years. Based on the above-noted Table 1. this does not appear feasible because of the large difference between OH<sup>\*</sup> levels and pollution levels in the PPM analysis. However, only significant cessation of combustion to a level that matches the planetary biome's ability to reverse CO<sub>2</sub> into oxygen and carbon will establish a technologically

supportable match to the legacy pollutants. This very large inadequacy of the oxidative capacity needs addressing by lowering pollution levels to match the in situ hydroxyl production capacity, in conjunction with remedial measures to ensure that the Earth's energy imbalance is safely corrected. A broad literature review of hydroxyl chemistry found only one undesired chemical species increase when it oxidizes methane to formaldehyde. This can, however, be quickly remedied by adding enough additional hydroxyl to remove it very quickly, thus, removing this single issue.

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