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Article

Measuring the efficiency of greenhouse gases to absorb heat

Suraga Nallan[1], Jaqueline Gerson[2] ,
[1] Bret Harte Middle School, San Jose, California
[2] University of California, Berkeley, California

SUMMARY

Greenhouse gases are a very important part of the Earth's atmosphere that cause the Earth to warm enough to support life, but when they are too abundant can also cause global warming. To find out which greenhouse gas has the greatest effect on temperature, we measured the percent temperature change over time in three of the four major greenhouse gases (water vapor, carbon dioxide, and nitrous oxide) compared to regular air when exposed to the sun. We measured this by putting a thermometer in bottles containing each of the gases. We hypothesized that carbon dioxide would have the greatest percent temperature change. Indeed, we found the temperature of the bottle containing carbon dioxide went up by 41.64%, which was higher than the other gases. We also observed that nitrous oxide had the lowest percentage change, which was 32.19%. Our results suggested that carbon dioxide has the greatest effect on temperature, which could have many ramifications. Carbon dioxide is present everywhere in the atmosphere. This means that the warming effect of carbon dioxide applies globally. Given that there is a large amount of carbon dioxide in the atmosphere and that carbon dioxide emissions are increasing, global warming will increase more leading to ice caps melting, resulting in harm to the environment and all life on Earth.

INTRODUCTION

Earth depends on the temperature being warm enough for wildlife and people to survive. Earth's temperature is regulated by Greenhouse gases. Greenhouse gases—specifically, water vapor, nitrous oxide (N2O), methane (CH4), and carbon dioxide (CO2)—absorb heat from the sun, trap some of it, and reflect the rest back into space (1). This is known as the greenhouse effect (1). This trapping of the heat is also what enables the Earth to be warm enough to support life (1).

Greenhouse gases must exist in balance with each other within the Earth's atmosphere; however, this balance is getting disrupted due to human activities. Water vapor is the gaseous state of water and the most abundant greenhouse gas in the atmosphere (2). The percentage of water vapor in surface air varies from 0.01% at -42°C (-44°F) to 4.24% when the dew point is 30°C (86°F) (2). Approximately 99% of it is contained in the troposphere (2). Water vapor condensation creates rain, snow, hail, and other types of precipitation (2). Unlike other greenhouse gases, water vapor is not considered dangerous. However, as global temperatures rise, so does the amount of water vapor in the atmosphere (3). There is a possibility that adding more water vapor to the atmosphere could produce a negative feedback effect, since having more water vapor causes more cloud formation (4). Clouds reflect sunlight and reduce the amount of energy that reaches the Earth's surface to warm it (4).

Nitrous oxide is a colorless gas with a slight metallic smell. Emissions of nitrous oxide have gone up by 30% over the past 40 years, mostly coming from food production and fertilizer use (5). The atmospheric concentration of nitrous oxide reached 333 parts per billion (ppb) in 2020, increasing by about 1.4 ppb a year after 2020 (6). Nitrous oxide has significant global warming potential as a greenhouse gas. On a per-molecule basis, over a 100-year period, nitrous oxide has 265 times the atmospheric heat-trapping ability of carbon dioxide (6). However, the atmospheric concentration of nitrous oxide is less than 1/1,000 of that of carbon dioxide, so its contribution to the greenhouse effect is less than one third that of carbon dioxide, and less than water vapor or methane (6). On the other hand, since 38% or more of the nitrous oxide entering the atmosphere is the result of human activity, control of nitrous oxide is considered part of efforts to curb greenhouse gas emissions (6).

Methane is flammable and usually used as a fuel. The concentration of methane in Earth's atmosphere is around 1.8 ppm and has risen by about 150% since 1750, mostly because of human activities (7). Both natural and human sources supply methane to Earth's atmosphere (7). Even though the concentration is small, it is an important greenhouse gas because it is such a potent heat absorber. Methane accounts for about 20% of the heating effects of all the greenhouse gases combined (7).

Carbon dioxide is an acidic colorless gas with a density about 53% higher than that of dry air (8). Carbon dioxide is the primary carbon source of life on Earth and the most significant long-lived greenhouse gas in the atmosphere (8). Atmospheric carbon dioxide is a trace gas, having a global average concentration of 415 ppm by volume (or 630 ppm by mass) as of the end of 2020 (8). Atmospheric carbon dioxide concentrations fluctuate slightly with the seasons, falling during spring and summer in the Northern Hemisphere. This happens because plants consume carbon dioxide during northern autumn and then go dormant or die and decay during winter (9). Concentrations of carbon dioxide also vary based on altitude, with higher concentrations found near the ground and lower concentrations as altitude increases. Additionally, in urban areas, concentrations are generally higher, and indoor carbon dioxide concentrations can reach ten times of normal background levels (9).

While greenhouse gases are necessary to warm the planet, too much can be a bad thing. Greenhouse gases started increasing in the Industrial Revolution (10). Before the Industrial Revolution started in the mid-1700s, the global average amount of carbon dioxide was about 280 parts per million (ppm) (11). When the Industrial Revolution started, factories began releasing more and more carbon dioxide into the atmosphere. As the years went on, carbon dioxide emissions only increased. As of now, the amount of carbon dioxide in the atmosphere is nearly 415 ppm (8, 12). This represents a 47% increase since the beginning of the Industrial Age (12).

Increases in atmospheric concentrations of carbon dioxide and other long-lived greenhouse gases such as methane, nitrous oxide and ozone have strengthened global absorption and emission of infrared radiation, causing a rise in average global temperature since the mid-20th century (9). Carbon dioxide is of greatest concern because it exerts a larger overall warming influence than these other gases combined (13). The more carbon dioxide in the atmosphere, the more heat that will get absorbed, which increases the Earth's temperature. The Earth getting warmer is an effect known as global warming. Because of global warming, ice caps are melting leaving thousands of animals without homes. For example, the polar bear population has dramatically decreased over the past few years due to global warming (14). If this trend continues, polar bears, along with many other animal species, may become extinct. The extinction of polar bears would disrupt many food chains, leading to unhealthy reductions of other species (15). This reduction in biodiversity will be detrimental to humans as well as animals and plants (16).

These four greenhouse gases are quite dangerous. We hypothesized that carbon dioxide would increase in temperature the most because it's the most significant long-lived greenhouse gas. To test our hypothesis, we trapped greenhouse gases in bottles and measured the temperature change over a 2–3-hour time period when exposed to the sun. We found that carbon dioxide increased most in temperature and nitrous oxide increased the least.

RESULTS

We measured the effectiveness of each greenhouse gas at trapping heat by measuring the temperature over time of bottles filled with carbon dioxide, nitrous oxide, and water vapor. We filled one bottle with air, which served as the control group. We placed all bottles in direct sunlight for 2 hours and 40 minutes and measured the temperatures at regular intervals. Then, we analyzed the change in temperature in each bottle to find which one had the greatest change in temperature.

The greenhouse gas that had the highest temperature change throughout all four trials of the experiment was carbon dioxide, which had the highest change in three of the four trials. In the first trial, the temperature of the bottle containing carbon dioxide went up by 27% from 85.3°F to 108.7°F over the course of the experiment, which was about 8% more than the overall results for the other gases over the same time period (**Figure 1**). In trial 2, the bottle containing carbon dioxide went up in temperature by 58%, from 68.9°F to 108.9°F, with the next bottle (containing water vapor) increasing by only 45%, from 74.5°F to 105.6°F (**Figure 2**). However, in trial 3, the bottle containing water vapor had the highest percentage increase in temperature. It went up by 53%, from 75.9°F to 116.2°F, while the bottle containing carbon dioxide only went up by 49%, from 73.6°F to 110°F. This was still more than the percentage increase in temperature of the other gases

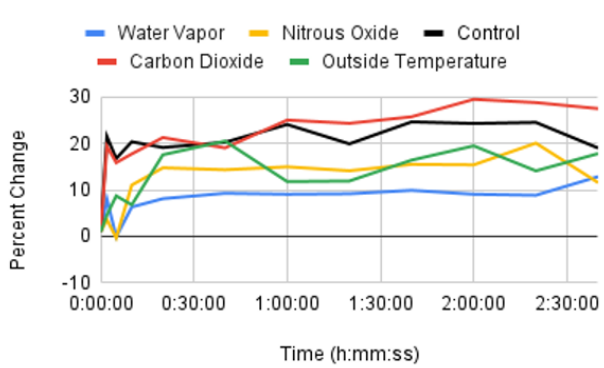

Figure 1: Change in temperature of each gas over time in trial 1. Each line represents the percentage change in temperature over time in the greenhouse gases, control group, and outside temperature.

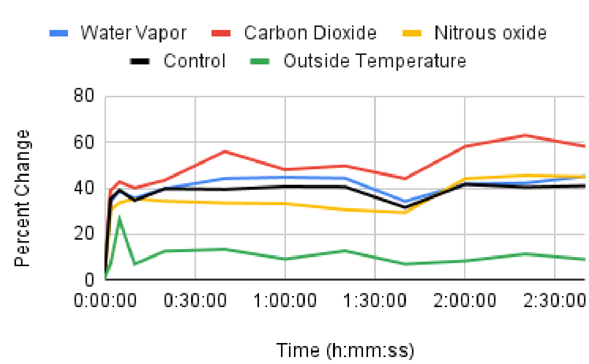

Figure 2: Change in temperature in each gas over time in trial 2. Each line represents the percentage change in temperature over time in the greenhouse gases, control group, and outside temperature.

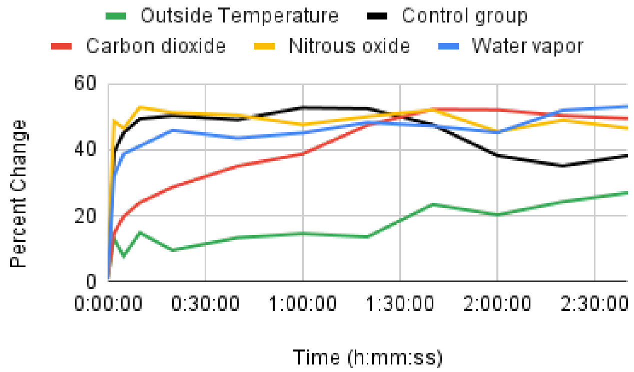

Figure 3: Change in temperature in each gas over time in trial 3. Each line represents the percentage change in temperature over time in the greenhouse gases, control group, and outside temperature.

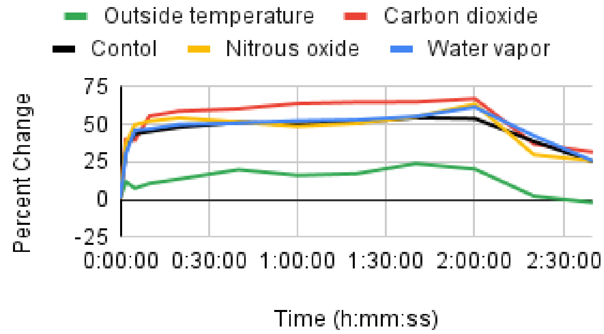

Figure 4: Change in temperature in each gas over time for trial 4. Each line represents the percentage change in temperature over time in the greenhouse gases, control group, and outside temperature.

(**Figure 3**). In trial 4, the bottle containing carbon dioxide went up by 31%, from 71.5°F to 94.1°F, which was about 6% more than all the other gases increased over the same time period (**Figure 4**). The average temperature change over all four trials for the bottle containing carbon dioxide was 41.64%.

Across the experiment, the bottle with the lowest temperature change was the one containing nitrous oxide. In trials 1, 2, and 3, the bottle with nitrous oxide went up the least in comparison to all the bottles containing a greenhouse gas (**Figure 5**). Across all four trials, nitrous oxide went up by an average of 32%, which was 2% lower than the average of the bottle containing water vapor and 9% lower than the average of the bottle containing carbon dioxide (**Figure 6**). The control group (the bottle containing regular air) went up in temperature the least amount across all trials (by 30%).

In trial 1, the percent temperature change of the bottle containing water vapor was 7% in the first 20 minutes, and then stayed mostly level at 9% until 2 hours and 20 minutes had passed, when it jumped up to 12%. Nitrous oxide went up by only 3% in the first 20 minutes, and then stayed level at 14%, until 2 hours and 20 minutes had passed, when it went to 20% and then back down to 11% in another 20 minutes. Carbon dioxide stayed in the 15-20% range for less than half of the experiment, and then jumped up to 24% and stayed there for the rest of the experiment (**Figure 1**). In trial 2, water vapor stayed in the 35-40% range, and then jumped up to 45% after 2 hours and 40 minutes had passed. Nitrous oxide stayed in the 30-35% range for the majority of the experiment, and then went up to 45% and stayed there for the rest of the experiment. Carbon dioxide stayed at 40% at the start of the experiment, and then fluctuated between the 50-60% range for the majority (**Figure 2**). In trial 3, water vapor steadily increased from 32% to 53% during the experiment, fluctuating slightly. Nitrous oxide stayed in the 46-50% range. Carbon dioxide started at 14%, and then increased to 50% (Figure 3). In trial 4, water vapor went slowly from 30% to 61%, and then quickly went down to 46%, then 25%. Nitrous oxide started out at 37% and then fluctuated between high 40s and low

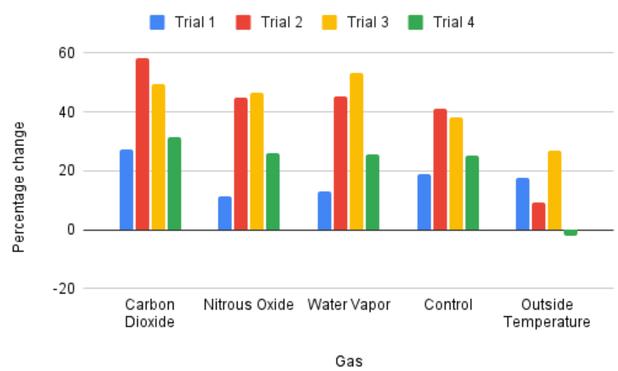

Figure 5: Change in temperature in each gas in all four trials. Each line represents the percentage change in temperature over time in the greenhouse gases, control group, and outside temperature.

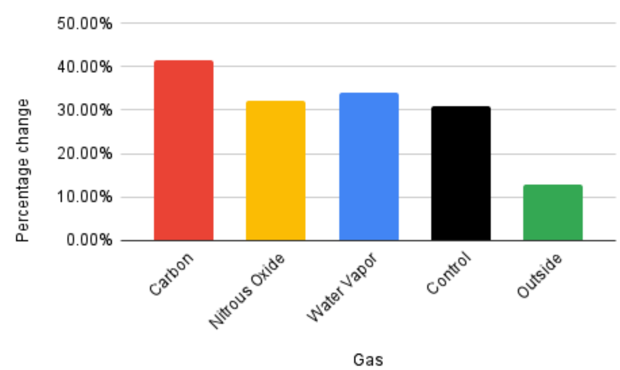

Figure 6: Overall change in temperature in each gas over all four trials. This shows the average change in temperature from the start to endpoint for each gas averaged over all four trials.

50s until reaching 63%, and then going down to 25%. Carbon dioxide started at 40%, and then gradually increased to 66%, and then went down to 31% at the end (**Figure 4**). Throughout all four trials, the control bottle temperature increased by about 30%.

We compared the overall temperature change in all 4 trials in each greenhouse gas to the other greenhouse gases, along with the control group and outside temperature by a two-sample, two-tailed t-tests. The t-test was done for the averaged data for each and every combination of gas, control, and outside temperature to each other, so there were 25 comparisons overall. Carbon dioxide was the only greenhouse gas that showed a significant difference in temperature change ($p = 0.02$).

DISCUSSION

In this experiment, we found that, overall, the bottle containing carbon dioxide had the greatest percentage of change in temperature throughout all four trials, and the bottle containing nitrous oxide had the least percentage of change in temperature throughout all four trials (**Figure 6**). This finding is in agreement with recent research that found carbon dioxide has contributed to the warming effect around 10 times more than nitrous oxide (5).

In all the experiments, the percent change in temperature in the control group (air) was smaller than that of all the other gases (**Figure 5 and 6**). This is because the control group contained regular air, so it included a variety of gases, most of which are not greenhouse gases. Greenhouse gases are the only gases that trap heat, and the control group only has a tiny amount of greenhouse gases compared to the other bottles (1). Additionally, the temperature change in the outside temperature was much smaller compared to all the other gases (**Figures 1-6**). This is because the molecules outside were not in an enclosed area, so it would take a lot more to heat them up and cause a noticeable temperature change.

We found that our data largely did not have any statistical significance. Only carbon dioxide was shown to have a significant effect on temperature ($p = 0.02$). This is likely because of our small sample size, n=4 for each gas tested. While we did observe a difference in the change in temperature between the greenhouse gases, more trials should be conducted to confirm whether any difference in temperature is significant, or not.

Our results indicated that carbon dioxide has the greatest effect on temperature and nitrous oxide has the least. As carbon dioxide had the greatest effect, it is the greenhouse gas that we should be most careful of. There is a large amount of carbon dioxide in the atmosphere, more than any other greenhouse gas, and emissions of carbon dioxide have been increasing (17, 18). If carbon dioxide traps more heat than all the other greenhouse gases, it may contribute a lot more to global warming. If emissions don't go down, global warming may increase even more (19). This will result in more frequent and severe weather, higher death rates, dirtier air, higher wildlife extinction rates, more acidic oceans, and higher sea levels (20). Our results also suggest that nitrous oxide has the smallest effect on temperature out of the other greenhouse gases. Nitrous oxide emissions are minimal, mostly coming from fertilizer and certain factories, so given these two things, nitrous oxide will not be much of a problem compared to carbon dioxide (21). However, it's still a greenhouse gas and should not be completely overlooked.

Our experiment did have some limitations. Methane was not available for use, so we were unable to compare it directly to the other gases in our experiment. If methane was used, it may have shown a large increase in temperature as methane accounts for about 20% of the warming effect of all the other greenhouse gases combined (16). In addition, our trials lasted for 2 hours and 40 minutes to ensure that they were performed during full sunlight, 12:00pm-4:00pm (22). Increasing this time interval may have resulted in a different or greater temperature change. Additionally, if we used stimulated sunlight we would have been able to better control it so our results would measure the temperature change in the bottle instead of the overall temperature change. This would more accurately measure how much of an effect each greenhouse gas has. Lastly, in trial 1 the bottles kept getting tipped over because of the wind. While this was fixed in the later trials and we believe only had a minimal effect on results, it still could have had an effect.

In conclusion, greenhouse gases are very important to the well-being of the Earth, but too much of them are causing global warming. Our results indicate that carbon dioxide has the greatest effect on temperature. Carbon dioxide is also the greenhouse gas with the highest emissions level, so it will have a detrimental effect on our planet (3). Therefore, we must focus on lowering carbon dioxide levels in the atmosphere.

MATERIALS AND METHODS

The temperature change of the gases in plastic bottles was measured. Four 16.9 ounce bottles (Kirkland Signature Purified Drinking Water) were filled with either water vapor, carbon dioxide, nitrous oxide, or inside air (control). The temperature of the gases was recorded over the course of 2 hours and 40 minutes with thermometers placed inside the bottles. The temperature was measured at 0,2, 5, 10, and 20 minutes, and then every 20 minutes afterwards. The experiment was conducted four times (trials), in the month of August, between 12-4 pm, when there was the most sunlight (22).

The water vapor was made by boiling half a cup of water in a pot with a hole in the lid. The water vapor was then transferred to the bottle by straw. One end of the straw was placed directly on top of the pot lid, and the other end was placed inside the bottle. Once the water vapor was in the bottle, the cap was closed tightly. The carbon dioxide was made by waiting for dry ice (solid carbon dioxide) to sublimate. A small amount of dry ice (half a cup) was placed inside the bottle. Once the dry ice was in the bottle, the cap was closed tightly. Nitrous oxide was produced by whipped cream chargers (Creamright Ultra-Purewhip 50-Pack N2O Whipped Cream Chargers) and a canister that sprays it. The charger was secured on the canister. The canister was put upside down and the nozzle of the canister was placed inside the bottle. The nitrous oxide was pumped into the bottle. Exactly two bottles (16 oz) of nitrous oxide were put in the bottle for each trial. The control group was air, so nothing was put in the bottle.

The caps of the four bottles had holes in them so the thermometers could go through. When all four bottles were filled with their various gases and fitted with caps and thermometers (Taylor Precision Products Antimicrobial Waterproof Digital Instant Read Thermometer). Bottles were then put in a lidless, plastic, see-through box to ensure that they didn't fall over (trials 2-4). The box with the bottles was placed outside in direct sunlight. For trial 1, the bottles were not placed in the box, and a few bottles fell over during the experiment. When this happened, the bottles were put back upright in the same position.

The formula used to determine the percentage of temperature change over time was $[(T_t - T_0)/T_0*100]$ where T_t represents the temperature at time stamp t and T_0 represents the starting temperature (t=0).

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REFERENCES

1. Mobius, Ariel. "How Do Greenhouse Gases Trap Heat in the Atmosphere?" *MIT Climate Portal*, climate.mit.edu/ask-mit/how-do-greenhouse-gases-trap-heat-atmosphere.
2. "WeatherQuestions.com." *WeatherQuestions.com*: What Is Water Vapor?, 2020, weatherstreet.com/weatherquestions/What_is_water_vapor.htm
3. "Steamy Relationships: How Atmospheric Water Vapor Amplifies Earth's Greenhouse Effect." *NASA*. 08. Feb. 2022, climate.nasa.gov/ask-nasa-climate/3143/steamy-relationships-how-atmospheric-water-vapor-amplifies-earths-greenhouse-effect/. 23. Dec. 2022
4. "It's Water Vapor, Not the CO2." *American Chemical Society*, 2021, www.acs.org/content/acs/en/climatescience/climatesciencenarratives/its-water-vapor-not-the-co2.html.
5. Stanford University. "Why Laughing Gas Is a Growing Climate Problem." *Stanford News*, 7 Oct. 2020, news.stanford.edu/2020/10/07/laughing-gas-growing-climate-problem/.
6. US Department of Commerce, NOAA. "Global Monitoring Laboratory - Carbon Cycle Greenhouse Gases." *GML*, 1 Oct. 2005, gml.noaa.gov/ccgg/trends_n2o/
7. UCAR, Center for Science Education. "Methane." Methane | *UCAR Center for Science Education,* 2021, scied.ucar.edu/learning-zone/how-climate-works/methane.
8. Eggleton T (2013). A Short Introduction to Climate Change. *Cambridge University Press*. p. 52. ISBN 9781107618763. Archived from the original on 23 July 2021.
9. US Department of Commerce, NOAA. "Global Monitoring Laboratory - Carbon Cycle Greenhouse Gases." *GML*, 1 Oct. 2005, gml.noaa.gov/ccgg/trends/gl_data.html.
10. "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." Greenhouse Gases' Effect on Climate - *U.S. Energy Information Administration (EIA)*, 2021, www.eia.gov/energyexplained/energy-and-the-environment/greenhouse-gases-and-the-climate.php.
11. Lindsey, Rebecca. "Climate Change: Atmospheric Carbon Dioxide: NOAA Climate.gov." Climate Change: Atmospheric Carbon Dioxide | *NOAA Climate.gov*, 14 Aug. 2020, www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide.
12. Buis, Alan. "The Atmosphere: Getting a Handle on Carbon Dioxide – Climate Change: Vital Signs of the Planet." *NASA,* 3 Mar. 2020, climate.nasa.gov/news/2915/the-atmosphere-getting-a-handle-on-carbon-dioxide/
13. US Department of Commerce, NOAA. "NOAA/ESRL Global Monitoring Laboratory - the NOAA Annual Greenhouse Gas Index (AGGI)." *GML*, 1 Oct. 2005, gml.noaa.gov/aggi/.
14. Vander Meiden, Laura. " Climate Change to Cause Polar Bear Population Declines." *Shark Research & Conservation Program (SRC*) | University of Miami, Aanstett Sharkresearch.azurewebsites.net/Wp-Content/Uploads/2018/07/Um-Shark-Research-Logo-2018-New.png, 16 Dec. 2015, sharkresearch.rsmas.miami.edu/climate-change-to-cause-polar-bear-population-declines/.
15. Sidhu, Zubair. "Facts about Polar Bears and What Would Happen If They Went Extinct." *Prezi.com,* 2012, prezi.com/tyxt6p5q7luz/facts-about-polar-bears-and-what-would-happen-if-they-went-extint/.
16. European Parliament. "Biodiversity Loss: What Is Causing It and Why Is It a Concern? | News | European Parliament." *Europa.eu,* 2020, www.europarl.europa.eu/news/en/headlines/society/20200109STO69929/biodiversity-loss-what-is-causing-it-and-why-is-it-a-concern.
17. Ritchie, Hannah, and Max Roser. "CO2 Emissions." *Our World in Data*, 11 May 2020, ourworldindata.org/co2-emissions.
18. American Museum of Natural History. "Rising CO2: AMNH." *American Museum of Natural History, 2020*,

www.amnh.org/explore/ology/climate-change/rising-co2.
19. April 07, 2021 Amanda MacMillan Jeff Turrentine. “Global Warming 101.” *NRDC*, 17 Aug. 2021, www.nrdc.org/stories/global-warming-101.
20. Denchak, Melissa. “Are the Effects of Global Warming Really That Bad?” *NRDC*, 21 Apr. 2021, www.nrdc.org/stories/are-effects-global-warming-really-bad.
21. Shankman, Sabrina. “What Is Nitrous Oxide and Why Is It a Climate Threat?” *Inside Climate News*, 7 Dec. 2020, insideclimatenews.org/news/11092019/nitrous-oxide-climate-pollutant-explainer-greenhouse-gas-agriculture-livestock.
22. Old Farmer's Almanac. “What Is the Hottest Time of Day? 3 P.m., or Noon?” *Old Farmer's Almanac*, 2021, www.almanac.com/fact/what-is-the-hottest-time-of-dayr.