Summer 2021 Newsletter

2B Technologies 2B Buzz

Air Pollution News

Global Poisoning by Carbon Dioxide?

Contributed by John Birks, 2B Technologies

Figure: Studies have shown that at CO_2 levels of 1,000 ppm and above, cognitive functions such as decision-making skills and performance on school exams are decreased. See: Coley *et al.*, Satish *et al.*, Allen *et al.*, Vehviläinen *et al.* and Jacobson *et al*. (2019).

Carbon dioxide (CO_2) is an atmospheric pollutant not often thought of as a toxin, at least not at the levels we inhale during our everyday activities. During at least the past 800,000 years and up until the Industrial Revolution of the nineteenth century, the average concentration of CO_2 in our atmosphere has never exceeded 300 ppm, averaging about 280 ppm in the 18th century. Compared to our current level of ~416 ppm this amounts to an increase of nearly 50%, and the atmospheric CO_2 concentration is continuing to increase at a level of about 2.3 ppm each year. Unless emissions decrease, we could easily double the concentration of CO_2 over that of the pre-industrial times by the end of this century.

Thus, the current level of atmospheric CO_2 is likely much higher than it was during the entire evolution of our species, and there has been little time (a few generations) for us as a species to have adapted to such a change. In fact, all of life on Earth is now experiencing CO_2 levels probably not experienced for millions of years. Until now, concerns about CO_2 emissions have been directed almost entirely on its climate effects. But evidence is beginning to suggest that increasing levels of CO_2 are also affecting human health as well. And, if humans are being affected, what about the millions of other species, both plants and animals?

Carbon dioxide is an extremely unreactive gas in the atmosphere, but it dissolves readily in water (think carbonated drinks) where it reacts with water to form carbonic acid (H_2CO_3), reducing the pH of that water:

$$CO_2 + H_2O <=> H_2CO_3 \text{ (carbonic acid)}$$
$$H_2CO_3 <=> HCO_3^- \text{ (bicarbonate ion)} + H^+ \text{ (hydrogen ion or proton)}$$

Fortunately, both the oceans and the human body are strongly buffered against those pH changes by the carbonic acid/bicarbonate/carbonate buffer system. Carbonate ions (CO_3^{2-}) scavenge protons released by carbonic acid to form more bicarbonate:

$$CO_3^{2-} \text{ (carbonate ion)} + H^+ <=> HCO_3^- \text{ (bicarbonate ion)}$$

Although strongly buffered, principally by this mechanism, as atmospheric CO_2 concentrations increase, the pH of both the oceans and human blood (and tissues and cells) do change slightly. Measurements show that the average pH of the ocean has decreased by nearly 0.1 pH units, from about 8.16 historically to about 8.07 now. Although this may seem like a small amount, since pH is a logarithmic function it represents a 23% increase in hydrogen ion concentration. And, it's enough, along with warming of the oceans and other factors, to contribute to bleaching and death of coral. The pH value of human blood, like the oceans, also is regulated, within the narrow pH range of 7.35 to 7.45, again principally by the carbonic acid/bicarbonate/carbonate buffer system. And the pH of blood controls the pH of interstitial fluids and the cytoplasm of individual cells. At a pH below 7.35, a person is said to be in acidosis, a serious medical condition.

> "We can never really get a breath of that "fresh air" that was available a century ago."

Besides the rising levels of CO_2 in outdoor air, we now spend most of our time indoors where CO_2 levels are frequently in the range 500-1,000 ppm, and in some cases 3,000 ppm or even higher, due to human respiration. This, combined with the fact that we can never really get a breath of that "fresh air" that was available a century ago, could have serious chronic health effects. And, as with other air pollutants there is likely to be a group of more vulnerable individuals such as the very young, very old and those with adverse medical conditions.

A recent article by Jacobsen *et al.* in the prestigious journal *Nature Sustainability* reviews the scientific literature on adverse health effects associated with acute and chronic CO_2 exposures in the range 1,000 to 5,000 ppm. These include inflammation, cognitive effects, bone demineralization, kidney calcification, respiratory acidosis, behavioral changes, physiological stress, hedonic feeding behaviors, oxidative stress and endothelial dysfunction. They point out that without limits on CO_2 emissions, we may eventually reach the thresholds for many acute (e.g., cognitive) and chronic health effects -- even with good indoor ventilation.

We also should ask how the enhanced and rising levels of CO_2 affect other organisms that make up the complex ecosystem of which we are a part. Even if humans are only marginally affected, what about other mammals, birds, reptiles and insects that manage the delicate balancing of dissolved CO_2, bicarbonate, carbonate and pH within their cells? It's very likely that some species are far more sensitive to changes in ambient CO_2 concentrations than others. We know that plants, which are at the bottom of the food chain, grow faster now due to the "CO_2 fertilization" effect but that their leaves and stems have lower concentrations of several nutrients, including proteins (e.g., Idso and Idso, 2001). How does this affect bees and other insects? How does it affect mammalian herbivores? It may be that the direct effects of an increased atmospheric burden of CO_2 will have adverse consequences on ecosystems that rival those of climate change. We simply don't have enough information yet to know.

Allen *et al.* (2016) Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: A controlled exposure study of green and conventional office environments, *Environmental Health Perspectives*, **124**, 805-812. **Direct Link**

Coley *et al.* (2007) The effect of low ventilation rates on the cognitive function of a primary school class, *International Journal of Ventilation* **6**, 107-112. **Direct Link**

Idso and Idso (2001) Effect of atmospheric CO_2 enrichment on plant constituents related to animal and human health, *Environmental and Experimental Botany*, **45**, 179-199. **Direct Link**

Jacobson *et al*. (2019) Direct human health risks of increased atmospheric carbon dioxide, *Nature Sustainability*, **2**, 691-701. **Direct Link**

Satish *et al.* (2012) Is CO_2 an indoor pollutant? Direct effects of low-to-moderate CO_2 concentrations on human decision-making performance, *Environmental Health Perspectives*, **120**, 1671-1677. **Direct Link**

Vehviläinen *et al.* (2016) High indoor CO_2 concentrations in an office environment increases the transcutaneous CO_2 level and sleepiness during cognitive work, *Journal of Occupational and Environmental Hygiene*, **13**, 19-29. Direct Link

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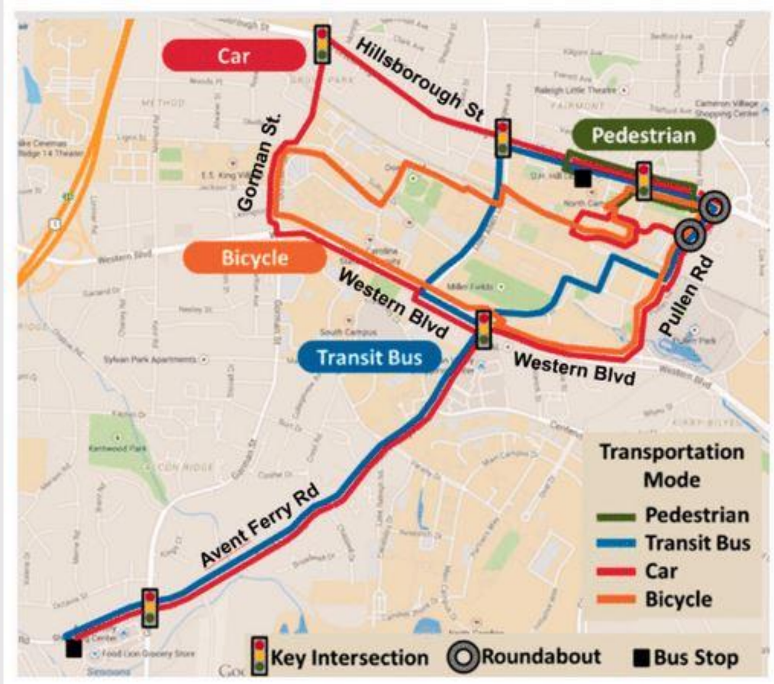
Case Study: The Personal Ozone Monitor (POM)

Local Travel: "How You Get There" Affects Your Personal Pollutant Exposure

Study Looks at Transit by Car, Bus, Bicycle, and on Foot

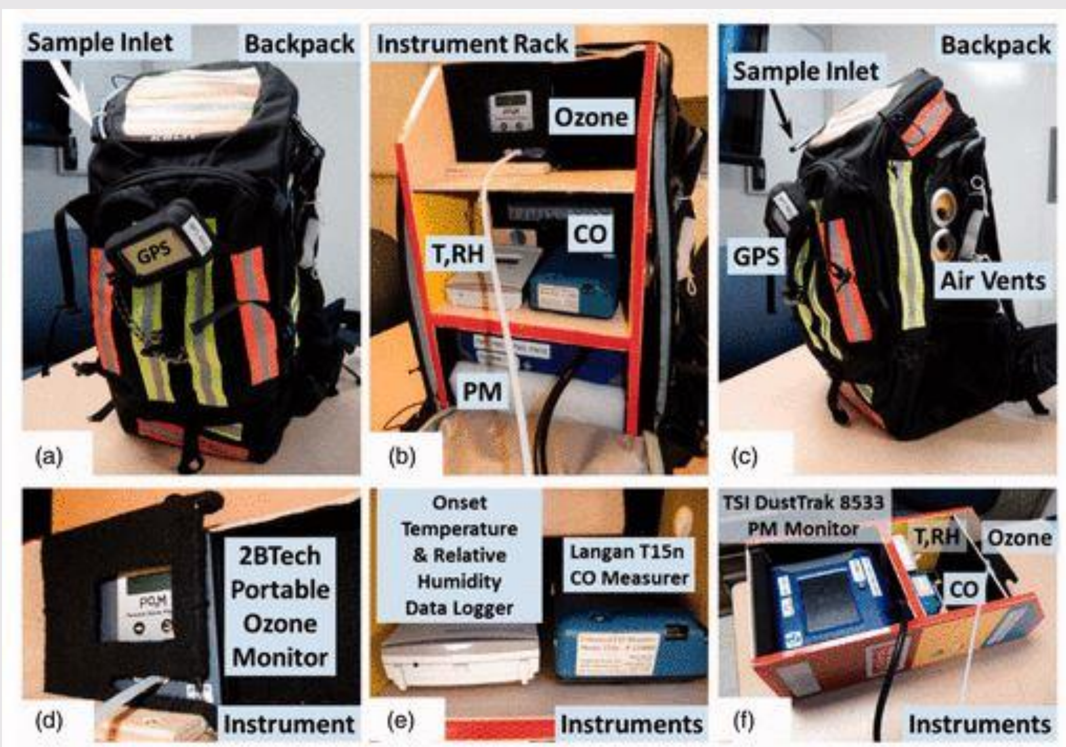
A new study shows that if you go on a 30-minute trip by foot or on a bicycle, you'll experience higher ozone and particulate matter than if you hop the bus or travel by car-- but you'll have less carbon monoxide to contend with. How that exposure varies by season and time of day was also investigated in one of the few available systematic studies of the personal pollutant exposure experienced in various "transportation microenvironments."

H.C. Frey and colleagues mapped out four time-equivalent (30-minute) routes in the vicinity of North Carolina State University for comparison of the transit modes. They completed the routes within 2-hour periods at 11 am and 4 pm on several different weekdays during all four seasons.



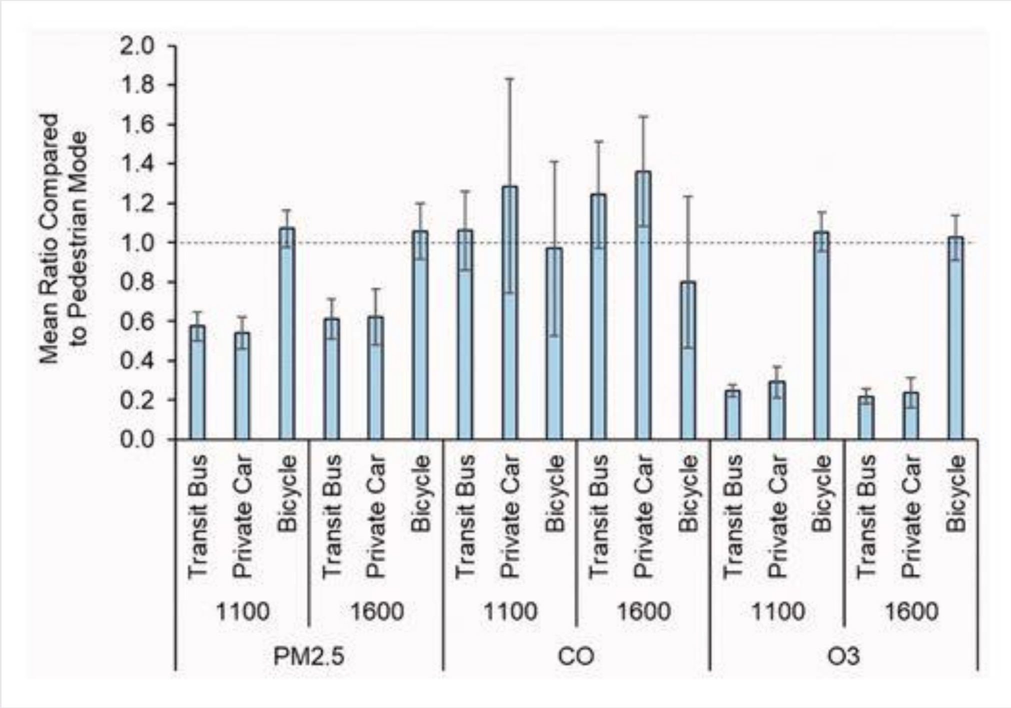
The 30-minute routes used for comparison of pollutant exposure (ozone, CO, particulate matter) during four different transit modes. [Figure Credit: *Transportation Research Record*, Frey et al., 2020.]

Though the researchers looked like the typical backpack-carrying student on the 2-hour journeys, it was no ordinary backpack! It was outfitted with instruments for measuring ozone (2B Tech's **Personal Ozone Monitor-POM**), carbon monoxide, particulate matter ($PM_{2.5}$), temperature, and relative humidity. The POM can be seen in the figure below, at the top of panel b and in panel d. Despite its small size, the POM provides FEM-quality measurements of ozone with a precision comparable to much larger FEM ozone instruments.



The instrumented backpack used in the study. The 2B Tech Personal Ozone Monitor can be seen at the top of panel b and in panel d. [Figure Credit: *Transportation Research Record*, Frey et al., 2020.]

The study considered several aspects of the transit modes that affect pollutant exposure, such as proximity to the roadside of pedestrians and bicyclists, and the most common practice of travel by car and bus (windows closed, air recirulation on, heating or air conditioning on).



Pollutant concentrations for mid-day and afternoon transit by bus, car, and bicycle relative to pedestrian transit. [Figure Credit: *Transportation Research Record*, Frey et al., 2020.]

Perhaps not surprisingly, pedestrians and bicyclists experienced similar pollutant concentrations. For ozone and particulate matter, the exposure concentrations were largest for this pair of the four modes; CO exposure concentrations were lower, though. The other pair of modes, bus and car, were like each other but the relative pollutant exposures were flipped compared to the other mode pair--CO exposure was higher while the O_3 and PM exposure was lower. The season made a big difference for the exposure levels, except for CO (always high in the closed quarters of buses and cars). Time of day did not have a strong influence on results, but it was evident that exposure concentrations varied at specific locations along the routes (bus stops, intersections) and by distance from the roadway for travel by foot and bicycle.

Though the researchers point out that much more needs to be done on this little-studied topic, the results hint at possibilities for reducing pollutant exposures for pedestrians and bicyclists by optimizing transit designs for those modes.

Link to Published Paper

The 2B Tech Personal Ozone Monitor

Quantification of Sources of Variability of Air Pollutant Exposure Concentrations among Selected Transportation Microenvironments, H.C. Frey, D. Gadre, S. Singh, and P. Kumar, Transportation Research Record, **2674**, 395-411, 2020.

Employee Spotlight

Jonathan Beall: Building 2B Tech Instruments

2B Tech's instruments incorporate many technical innovations, and like any high-precision instrument for making measurements, they are a challenge to build and the details have to be done right. Jonathan Beall, a manufacturing assistant at 2B Tech for over four years, has mastered the skills to build nearly every instrument in 2B Tech's 20-plus lineup.

Jonathan has a keen interest in environmental issues, which led him to pursue a degree in Environmental Engineering at Dalhousie University in Halifax, Nova Scotia (B.E., 2013). Jonathan is from Canada originally, but he made his way to the U.S. and Colorado shortly after earning his degree. He worked in manufacturing (an educational robotics company) before coming to 2B Tech in 2017.

At first specializing in building our Model 106 ozone monitors, Jonathan quickly expanded his repertoire. In 2B Tech's building process, each builder usually takes an instrument from "start to finish" in the build. Jonathan finds that the approach enables him to use his problem-solving skills and makes the work challenging (in a good way!). That might be why he particularly likes building 2B Tech's smallest instrument, the handheld Personal Ozone Monitor (POM). The tight tolerances of the handheld POM require lots of dexterity and precision throughout the building process.

When he's not building instruments, Jonathan might be running or hiking the trails around Boulder, or creating music. He uses a variety of synthesizers to create music in the "electro" genre. Perhaps building on his lifelong interest in science, it's an experiment of a different sort, and Jonathan enjoys the process of coming up with a unique sound or generating a new ambiance. And in a way, it seems like it's an extension of the building expertise he uses every day at 2B Tech!

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