

Coo-balls

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Abstract

Carbon dioxide (CO₂) is invisible, hiding the scale of our carbon dioxide pollution. So we propose a thought experiment: *Suppose CO₂ generated by burning fossil fuels was always emitted in “coo-balls” (colored ping-pong balls)?* (Pun between “coo” and “CO₂” intended, of course!) We ask, “How many coo-balls would be emitted?”

1. An average gasoline-powered car emits about one coo-ball every 26 cm (10 inches) of travel.
2. The burning of fossil fuels produces about 5×10^{17} coo-balls per year, enough to cover the entire surface of the earth (oceans and polar regions included) with a layer of tightly packed coo-balls once, with about 40% of the earth covered twice!
3. Since the beginning of the Industrial Revolution (1751), we have produced enough coo-balls to cover the entire surface of the earth (oceans and polar regions included) to a depth of six or seven feet!

1 Introduction

Climate change is real [4]; the primary cause is the CO₂ pollution caused by the burning of fossil fuels.

Yet CO₂ is invisible; it’s accumulation in the atmosphere can easily go unnoticed or be ignored.

We suggest as a thought-experiment an alternate reality. We find this mode of thought useful for appreciating the vast scale of our CO₂ problem; perhaps you will find it useful too.

We imagine that the tail-pipe of every gas-powered car emits not invisible CO₂, but colored “coo-balls” (colored ping-pong balls or similarly sized small hollow balls) containing CO₂. (We disregard the weight of the coo-ball shell, and pay attention to only the weight of the CO₂ it contains.)

Every so often, a coo-ball would drop out of the tail-pipe and fall on the road, to be blown around by the wind, and possibly end up in “coo-ball drift” (like a snow drift) near a building or floating in the ocean.

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One can imagine what a colorful sight that would be! A car might emit many coo-balls at a stoplight, and fewer on the highway.

An airplane passing overhead would emit a continuous shower of colored coo-balls (about 1 coo-ball for every centimeter of flight) that fall slowly to earth.

How many coo-balls would be emitted every mile?

How would these coo-balls affect daily life? Would there be a few of them here and there to be blown around, or would there be many?

We find claim (2) of our abstract quite startling: *our current emissions are more than enough to cover the earth in coo-balls **every year*** — the scale of CO₂ emissions is far beyond what I naively expected!

See Figure 1.

For the reader's convenience, the derivation of the claims in the Abstract is given in the Appendix.

2 Discussion and Conclusions

This note is primarily intended to illustrate the *vast scale* of the CO₂ problem we are faced with.

It is of course just a metaphor, and this paper provides no concrete steps for addressing CO₂ pollution, nor does it help in understanding the connection between CO₂ pollution and climate change. The coo-ball metaphor also does not represent the fact that the oceans absorb 30–50% of the CO₂ emitted.

While removing CO₂ directly from the atmosphere using DAC (Direct Air Capture, a form of carbon dioxide removal (CDR)) is an interesting technical challenge, the scale of what needs to be done is seen via this metaphor to be intimidating! We should perhaps focus almost all of our efforts on emissions reduction rather than carbon dioxide removal.

At one point we were thinking of “coo” as similar to styrofoam packing peanuts rather than ping-pong balls. Interestingly, a packing peanut weighs almost the same (0.066 grams) as the amount of CO₂ inside a ping-pong ball. Thus, one could re-do all of the above (and/or make visuals) using styrofoam packing peanuts rather than ping-pong balls. The math is quite similar, although packing peanuts are a little smaller than ping-pong balls.

Since a person emits about 0.034 grams of CO₂ per breath, we can imagine a person spitting out a coo-ball with every other breath or so. (This is amusing but not relevant to our discussion, as we are concerned with CO₂ generated from fossil fuels.)

Perhaps an appropriate organization could award a gold-plated coo-ball embossed with the number n to those causing a reduction in CO₂ emissions of 10^n coo-balls worth. (So, reducing CO₂ emissions by a gigatonne would earn a gold-plated coo-ball with the number 1.5×10^{13} .)

Somebody should please make a video for this! (See <https://www.youtube.com/watch?v=G15-UhVHVWw> for ping-pong balls in motorcycle exhaust!)



Figure 1: A child with too many coo-balls. (C)IStockPhoto 2014

I hope that this note provides you with some motivation and understanding for working on the CO₂ problem at an appropriate scale.

This problem *can* be addressed with quick execution of a good plan (see [1, 2]).

3 Related work

We acknowledge our debt to Dr. Seuss and his wonderful book “*Bartholomew and the Ooblek*.”

Other works making CO₂ emissions visual and/or more comprehensible:

- <https://blogs.scientificamerican.com/life-unbounded/the-crazy-scale-of-human-carbon-emission/>
- <https://www.theworldcounts.com/challenges/climate-change/global-warming/global-co2-emissions>
- <https://climate.nasa.gov/news/3020/how-much-carbon-dioxide-are-we-emitting/>
- <https://www.wired.com/story/big-business-burying-carbon-dioxide-capture-storage/>

Appendix

This Appendix provides the derivations of our claims.

Ping-pong balls

We assume that a coo-ball has the size of ping-pong ball. A standard ping-pong ball has diameter 4cm (1.57 inches) and a volume of 33.51 cubic centimeters (2.04 cubic inches).

Other candidates for coo-balls, such as ball pit balls, may be slightly larger. We have also considered using styrofoam packing peanuts as “coo-balls” (or maybe just “coo” in that case, since they are no longer spherical).

Carbon dioxide

Carbon dioxide has a density of 0.00198 grams per cubic centimeter (3.34 pounds per cubic yard) at standard pressure and temperature; it is 50% denser than air.

CO₂ in ping-pong balls

Multiplying the ping-pong ball’s volume by the density of CO₂, we find that one ping-pong ball (one coo-ball) holds 0.066 grams of CO₂. One coo-ball’s worth of CO₂ is 0.066 grams.

Cars and planes

The average passenger vehicle emits 404 grams (0.89 pounds) of CO₂ per mile driven¹; this corresponds to emitting 6121 coo-balls per mile, or one every 26.3 cm (10.4 inches).

The above is the derivation of our first claim.

A similar calculation can be done for airplanes: a Boeing 777 airplane gets about 82 miles per gallon of aviation fuel per passenger, and has about 300 seats. This yields almost exactly one coo-ball every centimeter of flight. I can imagine such a stream of coo-balls drifting down on someone as an airplane passes overhead!

Total emissions

Humans generate about 34.8 gigatonnes (that's 34.8 billion metric tonnes) of CO₂ per year (data from 2020), or 3.48×10^{16} grams of CO₂ per year.

That calls for 5.27×10^{17} coo-balls per year.

Packing coo-balls

To provide some sense of the magnitude of such a number, we estimate the number of coo-balls that can be tightly packed into a single layer on the surface of the earth.

The optimal packing of coo-balls into a layer would be a hexagonal packing², which places each circle (the shape of the sphere when viewed from above) of radius $R = 2\text{cm}$ into its own hexagon of side length $2R/\sqrt{3} = 2.31\text{cm}$ and area $2\sqrt{3}R^2 = 13.87\text{cm}^2$.

Using such a hexagonal packing, we can pack $10^4/13.87 = 721.0$ coo-balls per square meter.

Coo-balls needed to cover the earth

The total area of the earth, including the land, oceans, and polar regions, is 5.1×10^{14} square meters.

It thus takes about 3.68×10^{17} coo-balls to cover the entire earth with a single tightly-packed layer.

We designate the amount of CO₂ in such a covering as a "coo-ball-layer". One coo-ball-layer contains 2.43×10^{16} grams of CO₂ or 24300 gigatonnes of CO₂.

Comparing with coo-balls generated per year

¹<https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle>

²https://en.wikipedia.org/wiki/Circle_packing

We see that the number of coo-balls generated per year (5.27×10^{17}) is about 43% larger than the number of coo-balls required to cover the entire earth with a single tightly-packed layer.

Every year humans generate about 1.43 coo-ball-layers worth of CO₂.

This completes the derivation of our second claim.

CO₂ generated by burning fossil fuels 1751–2014

We learn that between 1751 and 2014 fossil fuels put about 1480 billion tons of CO₂ into the atmosphere.³ So the 34.8 gigatonnes of CO₂ emitted in 2020 is just 2.35% $\approx 1/43$ of that.

The number of coo-balls needed to represent all CO₂ emissions since 1751 is thus about $43 \times (5.27 \times 10^{17}) = 2.26 \times 10^{19}$.

If we pack coo-balls tightly, one layer is about the height of a tetrahedron with edge length 4 cm: that is $\sqrt{2/3} \times 4 = 3.27$ cm.

So, the 2.26×10^{19} coo-balls needed to represent all of the CO₂ emissions since 1751 would need $(2.26 \times 10^{19}) / (3.27 \times 10^7) = 69.4$ layers. This many layers would have a total height of $69.4 \times 3.27 = 227.1$ cm (about 2 meters, or 6.59 feet).

Imagine the whole world covered with colored ping-pong balls to a height of seven feet!

This is effectively what fossil fuels have brought us!

This completes our derivation of the third claim in the abstract.

Alternative calculation Here is another computation, useful for “sanity checking” the previous claim.

The atmosphere of the earth would have a height of around 8.50 kilometers if it had uniform (sea-level) density.⁴

CO₂’s density in air (by volume) is about 415 ppm. If all of the atmosphere’s CO₂ were concentrated at the bottom, it would form a layer of about

$$8.50 \text{ km} \times 0.000415 = 3.53 \text{ m};$$

the difference between this figure of 3.53 m and the above figure of 2 m is attributable in part to the fact that the density of 415 ppm includes 280 ppm of CO₂ generated before 1750 by means other than the burning of fossil fuels.

(Check: spheres can be close-packed with a density of 0.74⁵, and $3.53 \times \frac{135}{415} / 0.74 = 1.55$, which is close enough to 2.0 for this note.)

³<https://blogs.scientificamerican.com/life-unbounded/the-crazy-scale-of-human-carbon-emission/>

⁴https://en.wikipedia.org/wiki/Atmosphere_of_Earth

⁵https://en.wikipedia.org/wiki/Sphere_packing

References

- [1] John Doerr. *Speed and Scale: An Action Plan for Solving Our Climate Crisis Now*. Penguin, 2021.
- [2] Seth Grodin. *The Carbon Almanac*. Penguin, 2022.
- [3] Randall Munroe. *What If?: Serious Scientific Answers to Absurd Hypothetical Questions*. Houghton Mifflin Harcourt, 2014.
- [4] Intergovernmental Panel on Climate Change (IPCC). Sixth assessment report. Technical report, 2022. <https://www.ipcc.ch/reports/>.
- [5] Dr. Seuss. *Bartholemew Cubbins and the Oobleck*. Random House, 1949.
- [6] Wikipedia. Carbon dioxide in Earth's atmosphere. https://en.wikipedia.org/wiki/Carbon_dioxide_in_Earth%27s_atmosphere.