Dear Ed,

It is trivially true that changes to the average atmospheric CO2 level must be equal to the difference between the processes which add to that level and the processes which subtract from it.

1 ppmv CO2 (molecular wt 44.01) has mass 8.053 Gt, of which 12/44-ths or 2.196 Gt is carbon. (Note: I have a hard time remembering such numbers, so I have a [crib sheet of conversion factors](https://www.sealevel.info/conversion_factors.html) on my web site.)

We have good economic data for the global production & use of fossil fuels, so we can trivially calculate anthropogenic emissions from those sources. But everything else is harder.

It's not too bad on the emissions side, because it is generally acknowledged that fossil fuels are the main source of anthropogenic CO2 emissions. So even if estimates of the other sources (concrete, land use changes, etc.) are badly botched, we still will be "in the ballpark" for our anthropogenic emissions estimates. Those emissions are currently estimated to be a little over 10 Gt carbon per year, equivalent to almost 5 ppmv CO2 per year.

The various processes which remove CO2 from the air (mainly terrestrial greening, and dissolution in seawater) have rates which are governed by many factors, but those factors are surely dominated by just one: the average atmospheric CO2 level.

Note that simple physics & chemistry cannot possibly govern the removal rate, because the most important factors are probably biological.

Note also that those processes *cannot* be significantly affected by the emission *rate* of "fossil" (anthropogenic) CO2. There simply is no plausible physical mechanism for such a coupling. It is the CO2 *level*, not the CO2 emission rate, which primary governs the CO2 removal rate.

Now, as it happens, the CO2 removal rate has generally been very close to half the anthropogenic CO2 emission rate, for many years, with the result that CO2 levels have increased only about half as fast as would have happened w/o the negative feedbacks that remove CO2 at an accelerating rate (which apparently came as a big surprise for [Hansen *et al*](http://sealevel.info/hansen1988_retrospective.html) (1988), and is one of the main reasons their predictions 30 years ago were so far off). As CO2 emission rates have increased, CO2 levels have also unsurprisingly increased, and as CO2 levels have risen, CO2 removal rates have also unsurprisingly risen. The one really surprising thing about it is the *certainly coincidental* fact that CO2 removal rates have been consistently near half the anthropogenic CO2 emission rates.

Back in 1988, Hansen & his seven illustrious co-authors equated emissions with level increases, which means they assumed that rising CO2 levels would not cause an acceleration in the processes that remove CO2. But now a remarkable number of supposed authorities on climate change make the opposite mistake: they suffer from the delusion that CO2 removal rates are *governed* by the emission rates, and that it is some sort of *law* that "[half of the CO2 we emit stays in the atmosphere](https://www.google.com/search?q=%22half%22+AROUND%283%29+%28of%7Chuman%7Cemitted%7Cextra%7Cadditional%7Canthropogenic%29+AROUND%285%29+%22CO2%22+AROUND%2810%29+%22stays+in+the+atmosphere%22&filter=0)." That leads to imbecilic claims that anthropogenic CO2 emissions must be lowered to zero to stop the rise in CO2 levels, and to the idiotic notion of a "[carbon budget](https://www.carbonbrief.org/analysis-how-much-carbon-budget-is-left-to-limit-global-warming-to-1-5c)."  (Actually, if anthropogenic CO2 emission rates were merely halved, CO2 levels would completely cease rising, at least for quite a while.)

Okay, enough of *that* rant. Back to the subject at hand...

We can quite easily tabulate the CO2 removal rate as a function of atmospheric CO2 level. I didn't bother to do it exactly, because for back-of-envelope purposes there's no need for extreme precision.

We just need a few data points, and we can interpolate between them. Since we have [six decades of Mauna Loa CO2 measurement data](https://www.sealevel.info/co2.html), let's use six decadal averages: 1958-1968, 1968-1978, 1978-1988, 1988-1998, 1998-2008, 2008-2018.

I try very hard to avoid biasing my results according to my expectations, but it's just about humanly impossible. The only way to avoid it is to not *have* any expectations! So, I purposefully did *not* examine Roy's spreadsheet, before doing my similar (but cruder!) exercise. So I did not (yet) make use of his nice table of carbon emission levels. What I did was a lot rougher. Here's what I did.

I started with the assumption that we can approximate the historic CO2 emission rates as twice the rate of CO2 level increase, and thus that we can approximate the CO2 removal rate as equal to the rate of CO2 level increase. ("Version 2" will refine this by incorporating the actual emission data, copied from Roy's spreadsheet.)
So I made a little spreadsheet, with six rows for the six decades:
<http://sealevel.info/CO2_Residence_Times/simple_spreadsheet_relating_CO2_removal_rates_to_CO2_levels_v1.xlsx>
<http://sealevel.info/CO2_Residence_Times/simple_spreadsheet_relating_CO2_removal_rates_to_CO2_levels_v1.html>  <== exported as a web page

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Decade** | **Start level** | **End level** | **Avg level** | **E: increase/yr** | **F: Avg level-280** | **Ratio F/E** |
| 1958-1968 | 315.34 | 323.04 | 319.190 | 0.770 | 39.190 | 50.90 |
| 1968-1978 | 323.04 | 335.40 | 329.220 | 1.236 | 49.220 | 39.82 |
| 1978-1988 | 335.40 | 351.57 | 343.485 | 1.617 | 63.485 | 39.26 |
| 1988-1998 | 351.57 | 366.70 | 359.135 | 1.513 | 79.135 | 52.30 |
| 1998-2008 | 366.70 | 385.60 | 376.150 | 1.890 | 96.150 | 50.87 |
| 2008-2018 | 385.60 | 408.40 | 397.000 | 2.280 | 117.000 | 51.32 |
|  | **Averages:** | 1.551 | 74.030 | 47.73 |

For each decade:
column D has the average CO2 level over the decade,
column E has the average annual CO2 level increase during that decade,
column F has the average CO2 level minus 280 ppmv (i.e., the "CO2 elevation" above preindustrial).

The last column is the ratio of the "CO2 elevation" (column F) to the rate of increase (column E).

Note that the last column doesn't vary much.

Using the crude approximation that the rate of increase has, historically, been very roughly equal to the removal rate, I wrote a little Perl program, which estimates the removal rate as a function of the CO2 level, by interpolating between those six data points:

<http://sealevel.info/CO2_Residence_Times/calc_est_co2_removal_rates.pl.txt>

#!/usr/bin/perl

# linear interpolation:

# takes five inputs, and produces one output. The five inputs are:

# $x is the main input, which is expected to be between $x1 and $x2

# $x1 is the lower bound of the input range

# $y1 is the return value if $x = $x1

# $x2 is the upper bound of the input range

# $y2 is the return value if $x = $x2

sub interpolate {

 local($x,$x1,$y1,$x2,$y2) = @\_;

 local($xrange) = $x2 - $x1;

 local($yrange) = $y2 - $y1;

 local($result) = (($x - $x1) / $xrange) \* $yrange + $y1;

 return $result;

}

# estimate CO2 removal rate in ppmv/yr as a function of CO2 level in ppmv

sub removal\_rate {

 local($co2level) = shift;

 local($removalrate) = 0;

 local($co2elevation) = $co2level - 280;

 local($ratio) = 47.73;

 if ($co2level <= 280) {

 $removalrate = 0;

 } elsif ($co2level < 319.19) {

 $removalrate = $co2elevation / 50.90;

 } elsif ($co2level <= 329.220) {

 $removalrate = &interpolate( $co2level, 319.19, 0.770, 329.20, 1.236 );

 } elsif ($co2level <= 343.485) {

 $removalrate = &interpolate( $co2level, 329.20, 1.236, 343.485, 1.617 );

 } elsif ($co2level <= 359.135) {

 $removalrate = &interpolate( $co2level, 343.485, 1.617, 359.135, 1.513 );

 } elsif ($co2level <= 376.150) {

 $removalrate = &interpolate( $co2level, 359.135, 1.513, 376.150, 1.890 );

 } elsif ($co2level <= 397.000) {

 $removalrate = &interpolate( $co2level, 376.150, 1.890, 397.000, 2.280 );

 } else { # > 398

 $removalrate = $co2elevation / 51.32;

 }

 return $removalrate;

}

# SIMULATE DECLINE IN CO2 LEVEL IF EMISSIONS SUDDENLY WENT TO ZERO

$co2level = 410;

$year = 2019;

while ($co2level > 300) {

 printf("$year %5.1f\n", $co2level);

 $year += 1;

 $removalrate = &removal\_rate( $co2level );

 $co2level -= $removalrate;

}

I then ran a simulation: starting at year 2019, with CO2 at 410 ppmv, of what would happen to CO2 levels if anthropogenic CO2 emissions suddenly ceased; this is the output:

<http://sealevel.info/CO2_Residence_Times/simulation_output_01.txt>

2019 410.0

2020 407.5

2021 405.0

2022 402.5

2023 400.2

2024 397.8

2025 395.5

2026 393.3

2027 391.1

2028 388.9

2029 386.8

2030 384.7

2031 382.6

2032 380.6

2033 378.6

2034 376.7

2035 374.8

2036 372.9

2037 371.1

2038 369.3

2039 367.6

2040 365.9

2041 364.2

2042 362.6

2043 361.0

2044 359.5

2045 358.0

2046 356.4

2047 354.9

2048 353.4

2049 351.8

2050 350.2

2051 348.7

2052 347.1

2053 345.5

2054 343.9

2055 342.3

2056 340.7

2057 339.2

2058 337.7

2059 336.2

2060 334.8

2061 333.4

2062 332.0

2063 330.7

2064 329.4

2065 328.2

2066 327.0

2067 325.9

2068 324.8

2069 323.8

2070 322.8 **<== two-thirds of the anthropogenic CO2 is gone in 51 years**

2071 321.8

2072 321.0

2073 320.1

2074 319.3

2075 318.5

2076 317.8

2077 317.0

2078 316.3

2079 315.6

2080 314.9

2081 314.2

2082 313.5

2083 312.9

2084 312.2

2085 311.6

2086 311.0

2087 310.4

2088 309.8

2089 309.2

2090 308.6

2091 308.0

2092 307.5

2093 306.9

2094 306.4

2095 305.9

2096 305.4

2097 304.9

2098 304.4

2099 303.9

2100 303.5

2101 303.0

2102 302.5

2103 302.1

2104 301.7

2105 301.2

2106 300.8

2107 300.4

2108 300.0

Note the result: 2/3 of the anthropogenic CO2 gone from the atmosphere in 51 years (very similar to Dick Lindzen's "50 years" and not far from Roy Spencer's "70 years").

It's my bedtime, now, but when I refine this by incorporating real CO2 emission numbers, and from them the more precisely calculated removal rate numbers, I'll let y'all know.

The files (including a Windows command-line Perl executable, and a "run\_simulation.bat" file to run the simulation at a Windows command prompt), are here:
<https://sealevel.info/CO2_Residence_Times/allfiles.zip>

Warmest regards,
Dave