Ocean and Biosphere Uptake of CO_2 - Expectations

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http://ccdatacenter.org/documents/CO2UptakeExpectations.pdf

Current climate models can be used to develop a formula which provides a rough estimate of the atmospheric CO_2 in 2100 based on CO_2 emissions from 2016-2100. And since there is a known relationship between climate sensitivity, equilibrium temperature, and radiative forcing, a formula can also be developed which allows a CO_2 "budget" to be estimated for an equilibrium temperature, climate sensitivity, and amount of non-radiative forcing in 2100.

- The ocean and biosphere currently absorb about 55% of anthropogenic CO_2 emissions[1]
- The amount absorbed varies greatly from year to year and will likely decrease later this century[2,3,4,5] (and climate models might overestimate the amount that will be absorbed)
- For the case where the net CO_2 emissions this century are over 200 GTC, the relationship between total CO_2 emitted from 2015 to 2100 and atmospheric CO_2 in 2100 is close to linear in both the MAGICC and C-ROADS models:

  "2100 CO2 PPM" = 0.2586 * CO2 Emissions 2016-2100 + 342.87

Net CO2 Emission (GTC)	200	250	300	350	400	450	500	550	600	650	700	750
2100 CO2 PPM	395	408	420	433	446	459	472	485	498	511	524	537
Added To Atmosphere	-20	7	35	62	90	117	145	172	199	227	254	282
Net Removed from Atmosphere	220	243	265	288	310	333	355	378	401	423	446	468
Percent Added to Atmosphere	-10	3		18	22	26	29	31	33	35	36	38

- This allows a CO_2 "budget" to be specified for an equilibrium temperature, climate sensitivity, and amount of non-radiative forcing in 2100[5,6,7] by using the formula:

  CO2 Budget = (278 * e((5.35 * Ln(1 + ET / CS) - NonCO2RF) /5.35) - 342.87)/ 0.2586

- If we can limit net emissions to about 250 GTC, the ocean and biosphere will absorb all of the emitted CO_2 and atmospheric CO_2 will eventually return to the current level[6,7,8]

- For the case where the CO_2 removed by CDR does exceeds the CO_2 emissions a polynomial equation works better[9]:

  "2100 CO2 PPM" = 0.0000522 * Emissions * Emissions + 0.20778 * Emissions + 347.0537
  (where Emissions = CO2 Emissions 2016-2100)

PPM Calculations based on Emissions (polynomial equation)										
Net CO2 Emissions (GTC)	-250	-200	-150	-100	-50	0	50	100	150	200
CO2 PPM	298	308	317	327	337	347	358	368	379	391
CO2 Removed	475	405	335	264	193	121	49			

- If all future CO_2 emissions are captured and sequestered and net CO_2 emissions become zero within 50-60 years, the ocean and biosphere will absorb about 120 GTC from the atmosphere and atmospheric CO_2 will eventually reach about 350 PPM[8]

1	
2	**Climate science: Ocean circulation drove increase in CO2 uptake** Sara E. Mikaloff Fletcher

Nature volume 542, pages 169–170 (09 February 2017) |

The ocean's uptake of carbon dioxide increased during the 2000s. Models reveal that this was driven primarily by weak circulation in the upper ocean, solving a mystery of ocean science

https://www.nature.com/articles/542169a

3 A scientist's final paper looks toward Earth's future climate
July 16, 2018

The exchange of carbon between the land, ocean and air plays a huge role in determining the amount of greenhouse gases in the atmosphere, which will largely determine Earth's future climate. But, there are complex interactions at play. While human-caused emissions of greenhouses gases are building up in the atmosphere, land ecosystems and the ocean still offset about 50 percent of all those emissions. As the climate warms scientists are unsure whether forests and the ocean will continue to absorb roughly half of the emissions – acting as a carbon sink – or if this offset becomes lower, or if the sinks become carbon sources.

https://climate.nasa.gov/news/2765/a-scientists-final-paper-looks-toward-earths-future-climate/

4 **Hyperactive soil microbes might weaken the terrestrial carbon sink**
1 Aug 2018
The rate at which carbon dioxide is lost from soil has risen faster than the rate at which it is used by land plants, because soil microbes have become more active — possibly weakening the land surface's ability to act as a carbon sink.

"The terrestrial land surface has a crucial role in the global carbon cycle, providing feedbacks to changes in atmospheric levels of carbon dioxide and associated climate change[1]. Increases in atmospheric CO_2 concentrations and in soil and air temperatures worldwide over the past several decades have been paralleled by an increase in the metabolism of organisms at the land surface — as demonstrated by enhanced rates of CO_2 uptake, mainly by plants through photosynthesis, and of CO_2 loss from plants and soil microorganisms, mostly owing to respiratory processes[2–6]. In a paper in *Nature*, Bond-Lamberty *et al.*[7] report that the rate of increase of CO_2 loss is outpacing that of CO_2 uptake by plants. The authors attribute the imbalance in these rates of increase to enhanced activity of microbes that obtain nutrition by decomposing or mineralizing organic matter in soil. If the observed trend continues, then respiration by microbes could contribute substantially to global warming by releasing CO_2 from organic matter that has previously been stored in soil for decades to millennia."

GR: On the other hand more nutrients will be released meaning more photosynthesis and CDR, countering (some?) CO2 loss? If soil CO2 rises won't that enhance the weathering of minerals, natural or added, and counter (some?) CO2 loss? What does biochar do under elevated soil T? +/- soil moisture has to be a big factor.
https://www.nature.com/articles/d41586-018-05842-2

5 Note that global warming is shifting many forests from carbon sinks to carbon sources, thus increasing natural emissions and reducing the CO2 uptake in the biosphere:
What Lies Beneath (download PDF from https://www.breakthroughonline.org.au/) (Page 25)

At the moment about one-third of human-caused CO2 emissions are absorbed by trees and other plants. But rapid climate warming and unusual rainfall patterns are jeopardising many of the world's trees, due to more frequent drought, pest outbreaks and fires. This is starting to have profound effects on the Earth's carbon cycle. In 2009, researchers found that 2°C of warming could cut in half the carbon sink of tropical rainforests.81 Some tropical forests — in the Congo, and in Southeast Asia — have already shifted to a net carbon source. The tropics are now a net carbon source, with losses owing to deforestation and reductions in carbon density within standing forests being double that of gains resulting from forest growth.82 Other work has projected a longterm, self-reinforcing carbon feedback from midlatitude forests to the climate system as the world warms.

There has been an observed decline in the Amazon carbon sink. Negative synergies between deforestation, climate change, and widespread use of fire indicate a tipping point for the Amazon system to flip to non-forest ecosystems in eastern, southern and central Amazonia at 20–25% deforestation. Researchers say the severe droughts of 2005, 2010 and 2015-16 could well represent the first flickers of this ecological tipping point, and say the whole system is oscillating.84

6 Based on model runs for C-ROADS (PC)[7] and MAGICC[8] (where the total emissions were between 200 GTC and 700 GTC) the following values were obtained (and see scatter chart below):

	MAGICC (No O2 removals)				C-ROADS			
CO2 Emissions (GTC)	657	465	327	258	683	358	557	219
2100 CO2 PPM	505	457	420	403	527	439	492	410

This can be represented by the formulas

"2100 CO2 PPM" = 0.2586 * CO2 Emissions 2016-2100 + 342.87

CO2 Emissions 2016-2010 = 3.867 * "2100 CO2 PPM" - 1325.87

Note: Values from other climate model will likely result in a slightly different formula

Using this formula and "standard climatic formulas" a formula for a CO2 budget based on CO2 emissions was derived:

RF=Radiative Forcing; ET = Equilibrium Temperature; CS=Climate Sensitivity; Ln=Natural Logarithm

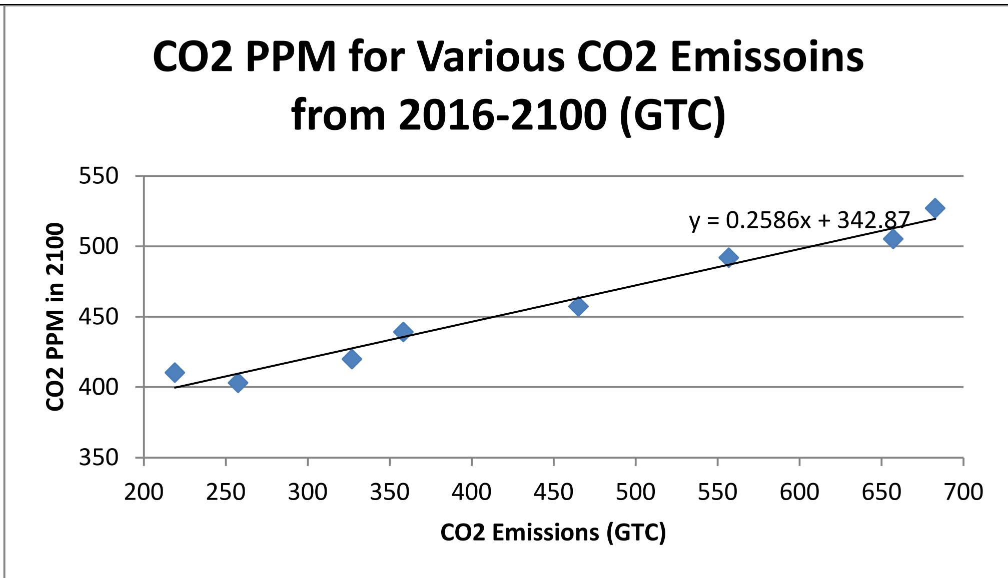
A. RF = 5.35 * Ln(1 + ET / CS)
CO2RF + NonCO2RF = 5.35 * Ln(1 + ET / CS)
CO2RF = 5.35 * Ln(1 + ET / CS) - NonCO2RF

B. CO2 RF = 5.35 * LN(CO2 PPM/278)

C. B=A
5.35 * LN(CO2 PPM/278) = 5.35 * Ln(1 + ET / CS) - NonCO2RF
LN(CO2 PPM/278) = (5.35 * Ln(1 + ET / CS) - NonCO2RF)/5.35
CO2 PPM/278 = e((5.35 * Ln(1 + ET / CS) - NonCO2RF) /5.35)
CO2 PPM = 278 * e((5.35 * Ln(1 + ET / CS) - NonCO2RF) /5.35)

D. Use data from models to develop a linear relationship between emitted CO2 and atmospheric CO2[1,2,3]
CO2 Budget = 3.2883 * CO2 PPM -1060.6
CO2 PPM = 0.3024 * CO2 Budget + 323.82

E. D = C
0.2586 * CO2 Budget + 342.87= 278 * e((5.35 * Ln(1 + ET / CS) - NonCO2RF) /5.35)
0.2586 * CO2 Budget = 278 * e((5.35 * Ln(1 + ET / CS) - NonCO2RF) /5.35) - 342.87
CO2 Budget = (278 * e((5.35 * Ln(1 + ET / CS) - NonCO2RF) /5.35) - 342.87)/ 0.2586



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7 Used CROADS results to provide data points for deriving a formula for a CO2 atmospheric PPM based on CO2 Emissions

Constants	
GTCO2 per GTC	3.664
GTC per PPM of atmospheric CO2	2.12

Temp	2.3	2	2	1.5
Clim Sens	3	3	3	3
Ref Year	2015	2015	2015	2015
StartYear	2015	2015	2015	2015
%Change	-50	-50/-99	-70	-99
By year	2100	2050/2100	2100	2100
PPM 2015	404.39	404.39	404.39	404.39
PPM	527.13	439.23	491.96	410.335
Net Added	953.4196	270.6406	680.2303	46.19344
Removed	1548.6	1042.7	1360.5	756.4
Total	2501.995	1313.371	2040.74	802.6225
Net Added	260	74	186	13
Removed	423	285	371	206
Total	683	358	557	219
PPM	527	439	492	410

Year	Global CO2 Removal			
2000	16.38622	16.38622	16.38622	16.38622
2001	16.56536	16.56536	16.56536	16.56536
2002	16.74213	16.74213	16.74213	16.74213
2003	16.97652	16.97652	16.97652	16.97652
2004	17.281	17.281	17.281	17.281
2005	17.60205	17.60205	17.60205	17.60205
2006	17.87633	17.87633	17.87633	17.87633
2007	18.12115	18.12115	18.12115	18.12115
2008	18.3768	18.3768	18.3768	18.3768
2009	18.59464	18.59464	18.59464	18.59464
2010	18.84395	18.84395	18.84395	18.84395
2011	19.28144	19.28144	19.28144	19.28144
2012	19.66137	19.66137	19.66137	19.66137
2013	19.97188	19.97188	19.97188	19.97188
2014	20.23864	20.23864	20.23864	20.23864
2015	20.52114	20.52114	20.52114	20.52114
2016	20.78327	20.76449	20.77357	20.70859
2017	20.96781	20.89966	20.93196	20.70393
2018	21.1103	20.97678	21.04115	20.60224
2019	21.22033	21.01086	21.11129	20.43279
2020	21.3054	21.01005	21.151	20.20826
2021	21.36883	20.97969	21.16513	19.9405
2022	21.41044	20.92106	21.15484	19.63472
2023	21.43439	20.83923	21.12206	19.29952
2024	21.44131	20.73668	21.07114	18.94099
2025	21.43438	20.61583	21.0037	18.56507
2026	21.41483	20.47973	20.92166	18.17393
2027	21.38325	20.32964	20.82682	17.77238
2028	21.34183	20.16812	20.72072	17.36296
2029	21.29082	19.99548	20.60385	16.9491
2030	21.23191	19.81372	20.478	16.5328
2031	21.16398	19.62374	20.34355	16.11608
2032	21.08959	19.42843	20.20243	15.70019
2033	21.00994	19.22653	20.05634	15.28836
2034	20.92606	19.02153	19.90594	14.88063
2035	20.83749	18.81315	19.75133	14.47557
2036	20.74658	18.60262	19.59369	14.06993
2037	20.65256	18.39104	19.4341	13.66139
2038	20.55651	18.17786	19.27233	13.25128
2039	20.45724	17.9642	19.10855	12.84168
2040	20.35536	17.74944	18.94343	12.43381
2041	20.25319	17.53551	18.77765	12.02934
2042	20.15072	17.32294	18.61294	11.63182

2043	20.04652	17.11089	18.44661	11.23989
2044	19.94111	16.8997	18.28009	10.85573
2045	19.83444	16.68867	18.11378	10.48106
2046	19.72655	16.47787	17.946	10.11613
2047	19.6176	16.26874	17.77952	9.761387
2048	19.50757	16.06092	17.61168	9.417564
2049	19.39703	15.8536	17.44358	9.084143
2050	19.28552	15.6482	17.27657	8.760759
2051	19.17409	15.40117	17.11125	8.44909
2052	19.06513	15.09236	16.94811	8.15007
2053	18.95616	14.75343	16.78707	7.861927
2054	18.84739	14.39489	16.62556	7.583501
2055	18.73779	14.01783	16.4658	7.315658
2056	18.62774	13.62001	16.30619	7.057756
2057	18.51702	13.20388	16.14627	6.810171
2058	18.40578	12.77538	15.98737	6.574873
2059	18.29451	12.34072	15.82913	6.349125
2060	18.18322	11.90293	15.67157	6.135007
2061	18.0721	11.46558	15.51489	5.931486
2062	17.96133	11.03484	15.36051	5.737724
2063	17.85078	10.61102	15.20649	5.553456
2064	17.73997	10.19768	15.05242	5.37737
2065	17.629	9.795789	14.89948	5.212621
2066	17.5186	9.40451	14.74732	5.058511
2067	17.40744	9.025126	14.59629	4.912415
2068	17.29644	8.657232	14.44508	4.77531
2069	17.1856	8.302394	14.29464	4.647015
2070	17.07456	7.962522	14.14585	4.526315
2071	16.96429	7.637784	13.99742	4.412694
2072	16.85486	7.330318	13.85074	4.305342
2073	16.74492	7.039061	13.70446	4.203323
2074	16.63529	6.762394	13.55948	4.107183
2075	16.52599	6.499829	13.41452	4.017003
2076	16.41748	6.254687	13.27074	3.931515
2077	16.30774	6.025239	13.12777	3.849895
2078	16.19875	5.811582	12.98599	3.772825
2079	16.08999	5.612417	12.84433	3.699554
2080	15.98072	5.426558	12.70283	3.629382
2081	15.8713	5.250569	12.55997	3.560746
2082	15.75939	5.083028	12.41513	3.492486
2083	15.64716	4.925581	12.26964	3.425637
2084	15.53438	4.77739	12.12457	3.362111
2085	15.4226	4.63801	11.97913	3.29966
2086	15.31017	4.507048	11.83392	3.240029
2087	15.19851	4.38262	11.68954	3.181795
2088	15.08722	4.265635	11.54563	3.125403

2089	14.9763	4.154904	11.40102	3.070798
2090	14.86628	4.04959	11.25614	3.017897
2091	14.75809	3.951592	11.11278	2.968375
2092	14.65273	3.860617	10.97193	2.921728
2093	14.549	3.774696	10.83191	2.878056
2094	14.44529	3.693774	10.69261	2.835263
2095	14.34242	3.615727	10.55301	2.79409
2096	14.24118	3.542037	10.41449	2.753852
2097	14.13919	3.471851	10.2761	2.713935
2098	14.03861	3.404527	10.1388	2.676113
2099	13.93811	3.338949	10.0016	2.637983
2100	13.83763	3.276805	9.865486	2.60044
2100	13.83763	3.276805	9.865486	2.60044

8 Used MAGICC results to derive a formula for a CO2 atmospheric PPM based on CO2 Emissions

Starting with WRE350; 5-year emissions changed only for CO2 and deforestation

Values in report.dp Climate sensitivity = 3

Temperature to 1990 0.4208

2015 CO2 PPM 404.29

GAS file	WRE350_2020_3	WRE350_2020_6	WRE350_2020_9	WRE350_2020_12	300 PPM
2015 FF Emissions	9.72	9.72	9.72	9.72	9.72
Change/5 yrs	0.28	0.28	0.28	0.28	
Number of Years	5	5	5	5	
Change/5 yrs	-0.3	-0.6	-0.9	-1.2	
Number of Years	80	80	55.6	41.7	
2015 Defo Emissions	1.6	1.6	1.6	1.6	1.6
Change/5 yrs	0.2	0.2	0.2	0.2	
Number of Years	40	40	40	40	
2100 CO2 PPM	505.3	457.4	419.9	403.1	300.0
Temp 1990-2100	1.9	1.6	1.4	1.2	
Temp 1870-2100	2.3	2.0	1.8	1.6	
CO2 Emissions	657	465	327	258	-242
PM Increase	101	53	16	-1	-104
CO2 Atmos Increase	214	112	33	-3	-221
Pct Emiss to Atmos	32.6	24.2	10.1	-1.0	

Fossil Fuel CO2 Emissions

1995	6.45	6.45	6.45	6.45	
2000	6.99	6.99	6.99	6.99	

2005	8.12	8.12	8.12	8.12
2010	9.17	9.17	9.17	9.17
2015	9.72	9.72	9.72	9.72
2020	10	10	10	10
2025	9.7	9.3	9.1	8.8
2030	9.4	8.7	8.2	7.6
2035	9.1	8.1	7.3	6.4
2040	8.8	7.5	6.4	5.2
2045	8.5	6.9	5.5	4
2050	8.2	6.3	4.6	2.8
2055	7.9	5.7	3.7	1.6
2060	7.6	5.1	2.8	0.4
2065	7.3	4.5	1.9	0
2070	7	3.9	1	0
2075	6.7	3.3	0.1	0
2080	6.4	2.7	0	0
2085	6.1	2.1	0	0
2090	5.8	1.5	0	0
2095	5.5	0.9	0	0
2100	5.2	0.3	0	0

Deforestation				
1990	1.1	1.1	1.1	1.1
1995	1.1	1.1	1.1	1.1
2000	1.1	1.1	1.1	1.1
2005	1.1	1.1	1.1	1.1
2010	1.3	1.3	1.3	1.3
2015	1.6	1.6	1.6	1.6
2020	1.4	1.4	1.4	1.4
2025	1.2	1.2	1.2	1.2
2030	1	1	1	1
2035	0.8	0.8	0.8	0.8
2040	0.6	0.6	0.6	0.6
2045	0.4	0.4	0.4	0.4
2050	0.2	0.2	0.2	0.2
2055	0	0	0	0
2060	0	0	0	0
2065	0	0	0	0
2070	0	0	0	0
2075	0	0	0	0
2080	0	0	0	0
2085	0	0	0	0
2090	0	0	0	0
2095	0	0	0	0
2100	0	0	0	0

8 MAGICC 300 PPM emissions and removals

Year	Removed	FF Emissions	Deforest
2010	0	8.9	1.08
2015	0	9.86	1.6
2020	0	9.86	1.6
2025	20	9.86	1.6
2030	20	7.89	1.28
2035	20	5.92	0.96
2040	20	3.94	0.64
2045	20	1.97	0.32
2050	0	0	0

Total FF	5Yr Emissions	5Yr Removals
9.98		
11.46		
11.46	57	0
11.46	57	50
9.17	52	100
6.88	40	100
4.58	29	100
2.29	17	100
0	6	50
2015-2100	258	500
Net:	-242	

9 Based on model runs for and MAGICC[7] (where the total emissions were between -250GTC and 700 GTC) the following values were obtained (and see scatter chart below):

	MAGICC				
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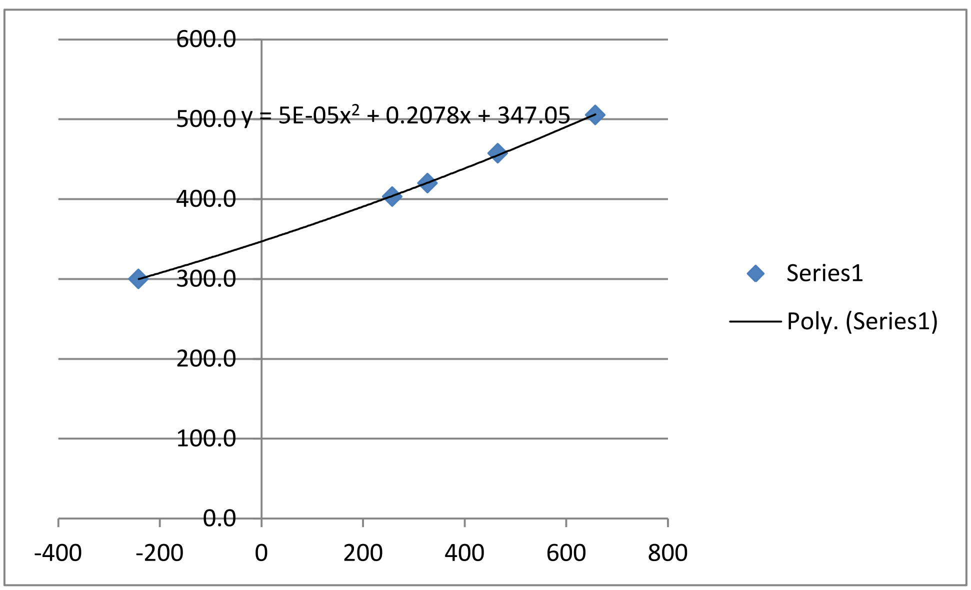

PPM Calculations based on Emissions (polynomial equation)										
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