Expectation Series - Introduction

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

Purpose

Climate change is the central issue of our time. It is a "wicked", multifaceted problem that has the potential to cause the collapse of our civilization and possibly result in the extinction of our species. This "Expectation Series" is an attempt to outline what we might expect from some of the major "climate factors", thereby providing a resource that can be used to "jog" one's memory of what to expect and why. Most of the "articles" are simply "bullet points" with detailed references, allowing the reader to quickly understand the basis of an "expectation". The articles should be viewed as a "work in process" as I will be revising them frequently as new material becomes available. Comments, suggestions, and corrections can be forwarded to me at bruce@chesdata.com.

Background

Many recent articles suggest (and I concur) that the IPCC (and other scientific organizations) are very conservative in their estimates for the expected temperature increase as the models used for their reports assume minimal natural emissions and likely underestimate climate sensitivity. But since most environmental organizations use the IPCC CO2 budget estimates for temperature increases of 1.5 °C and 2.0°C, the "general belief" is that we can "solve" climate change without sacrificing much by simply making slight changes to our lifestyles and by giving the politicians the "political will" to force our civilization to replace the consumption of fossil fuels with renewable energy in the next 30-60 years. Unfortunately the required changes are both more significant and costlier than most people realize.

Our climate strategy for the next 20-30 years will likely remain pretty much the same as it is today - work hard to mitigate greenhouse gas emissions where it makes economic sense and fund R&D to reduce carbon dioxide removal costs. In other words, let the "free market" determine how much CO2 is emitted or captured, with governments providing some incentives to reduce emissions (e.g., tax credits for renewables and carbon capture, renewable portfolio standards, carbon taxes, carbon caps, electric vehicle mandates, CAFE standards, power plant emission regulations, etc.). The problem is that it is likely too late to mitigate our way out of catastrophic climate change because (1) climate sensitivity is likely much higher than the models expect; (2) cumulative natural emissions will likely be in the 100-200 GTC range by 2100, and (3) non-CO2 radiative forcing will be very difficult to reduce to the levels expected by the models. As a result, a "mitigation only" approach would likely result in a temperature increase of 3 °C to 5 °C by 2100.

In order to meet the 2015 Paris Climate Agreement (which aims to keep "the global average temperature increase to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels") significant quantities of CO2 will almost certainly need to be removed from the atmosphere by either mechanical or biological means. And by anticipating that future generations will pay for CO2 removal, it then becomes possible to have emission scenarios that result in any temperature increase from 1°C to 2°C by "simply" removing the required amount of CO2. But many people see CO2 removal as a "moral hazard": by anticipating CO2 removal in the future we will skimp on mitigation now, and if CO2 removal does not work as planned (i.e., is too expensive) the result will be catastrophic climate change. Unfortunately, we are at the point where we must accept the moral hazard and plan for significant CO2 removal. But a major stumbling block to CO2 removal is its cost - although we are rich enough to be able to *afford* the necessary costs (likely several trillion dollars per year in the next 10-30 years) it is unlikely that politicians will be willing to raise taxes enough to actually *pay* for the necessary costs. And a possible "Catch 22" is that if carbon dioxide removal is to be affordable, costs might need to come down so much that it would make economic sense to emit CO2 now and remove CO2 later. And another problem is determining who pays to remove the CO2: 1) the U.S. (with 4% of world's population) is responsible for 25% of cumulative CO2 emissions; 2) India and China (with 35% of world's population) are responsible for about 8% of cumulative CO2 emissions; 3) India and China would like to emulate our life style; 4) how can we deny them what we have achieved? 5) shouldn't the U.S. (and other OECD countries) pay most of the CO2 removal costs?

Expectations

By 2030 the temperature increase is apt to be about 1.5°C and there might be no sea ice in the Arctic in September. Some climate scientists are worried that this might cause a really serious release of methane from the sub-sea methyl hydrates in parts of the Arctic, resulting in a temperatures to spike of 1-3°C in a few years. My guess is that, even without a "methane burp", between 2030 and 2040 the changes in the Arctic will drive changes to weather patterns that could easily disrupt food production (and a "methane burp" would simply make that happen sooner). This might cause famines in many parts of the world, disrupt global trade, and perhaps cause multiple advanced societies to collapse. And this likely a question of "When" and not "If". In other words, we are very likely already headed towards a "hothouse" Earth because we are not willing to make the sacrifices needed to stop global warming. So the only way to avoid a "hothouse Earth" is to employ some sort of solar radiation management in the coming decades.

The " Expectation Series" currently contains the following articles:

Climate Factors the Determine the Expected Temperature Increase		
1	Expectation Questions	What are the main questions that need to be answered to determine if world governments will likely be willing to fund the removal of CO_2 from the atmosphere at the scale needed to avoid serious climate disruption
2	Current Situation	Based on likely anthropogenic GHG emissions and climate feedbacks, we are almost certainly headed towards a "hothouse Earth" unless many gigatons of carbon are removed annually from the atmosphere
3	Anthropogenic CO_2 Emissions	Global CO_2 emissions from fossil fuels will likely remain the same through 2050 at about 10 GTC/year and atmospheric CO_2 could reach 480 PPM by 2050
4	Natural Emissions	Cumulative emissions through 2100 from natural feedbacks will likely be in the range of 120-200 GTC (not including methane from methyl hydrates).
5	Methane	"Global warming triggered by the massive release of carbon dioxide [from permafrost] may be catastrophic, but the release of methane from [methyl]hydrate may be apocalyptic".
6	Global Warming Feedbacks	The reaction of clouds to a warming atmosphere has been one of the major sources of uncertainty in estimating exactly how much the world will heat up from the accumulation of greenhouse gases
7	CO_2 Uptake	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
8	Climate Sensitivity	Recently it has been demonstrated that the models that best capture current conditions have a mean value of 3.7°C compared to 3.1°C by the raw model projections
Temperature Increase		
9	Temperature Increase	Likely increases: 1.5°C by 2030; 2.0°C by 2050; 4-5°C by 2100
10	Equilibrium Temperature Based on CO_2 Emissions	Tables were created to show the expected equilibrium temperature for various combinations of values for CO_2 emissions, non-CO_2 radiative forcing in2100, and climate sensitivity.
CO_2 Emission Budgets		
11	CO_2 Emissions Budget	There are several problems with presenting the IPCC's carbon budget in terms of "there is an XX% chance of meeting the NN° C temperature target if total emissions are less than MM GTC between now and 2100".
12	CO_2 Emissions Budget - Alternative Analysis	We essentially have exhausted the CO_2 budget for 1.5°C and 2.0°C
Carbon Dioxide Removal Costs		
13	CDR Costs	"Even if climate geoengineering techniques [,which includes carbon dioxide removal,]were ever actively pursued, and eventually worked as envisioned on global scales, they would very unlikely be implementable prior to the second half of the century".
14	CDR Costs - U.S.	Using Hansen's $450/tC as a rough estimate , we, in the U.S., should be spending about $1,900 per person per year (about $700 billion total) for the next 30-50 years to capture and sequester carbon

Other Consequences of Global Warming and CO2 Emissions		
15	Climate Change	It is quite possible that global warming will cause significant shifts in the Earth's entire atmospheric circulation patterns, which might lead to massive crop failures in the US.
16	Sea Level Rise	We could have between one and two meters of sea level rise by 2100
17	Ocean Acidification	Oceans could lose up to $1 trillion in annual value by 2100 due to acidification

Additional background material:
The Race of Our Lives, Revisited
What Lies Beneath
Job One for Humanity
Keeping track of activity: the Climate Progress Dashboard

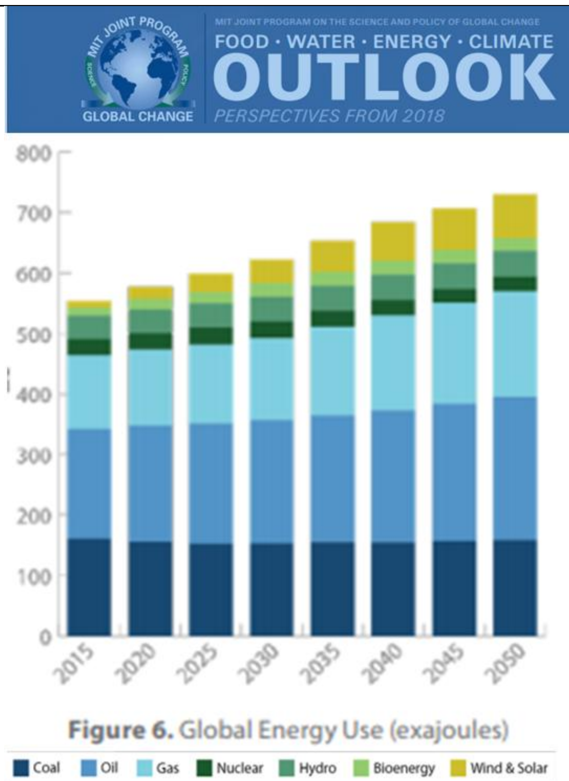
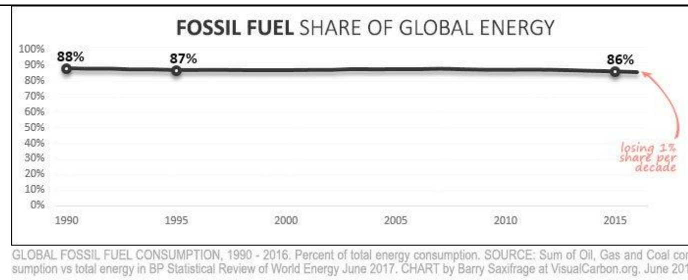


Figure 6. Global Energy Use (exajoules)

https://globalchange.mit.edu/sites/default/files/newsletters/files/2018-JP-Outlook.pdf (Page 10)



MIT Outlook 2018 has fossil fuel share of global energy decrease from 84% (93 exajoules) in 2015 to 78% (114 exajoules) in 2050
https://globalchange.mit.edu/sites/default/files/newsletters/files/2018-JP-Outlook.pdf (Page 10)

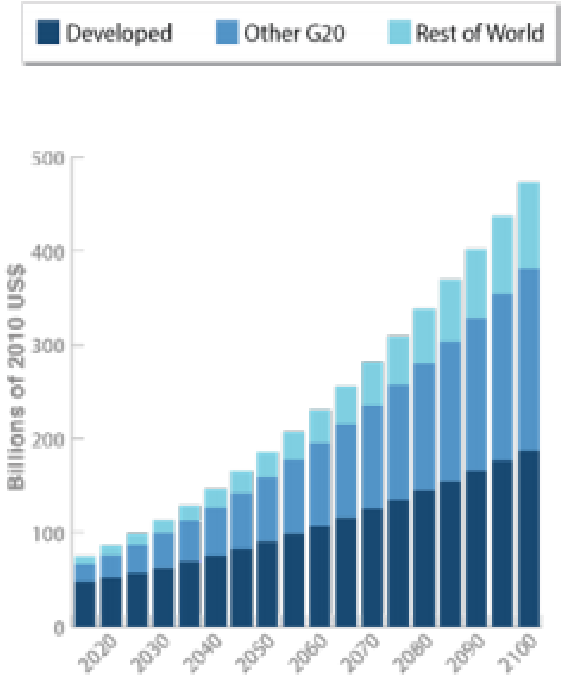


Figure 3. World GDP

https://globalchange.mit.edu/sites/default/files/newsletters/files/2018-JP-Outlook.pdf (Page 7)

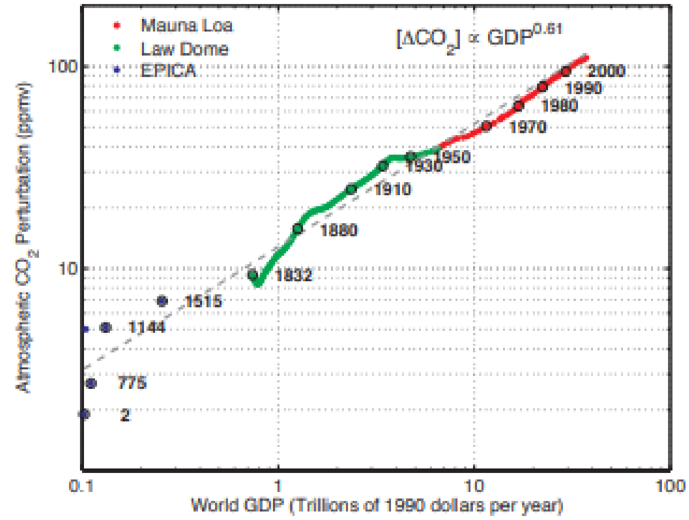
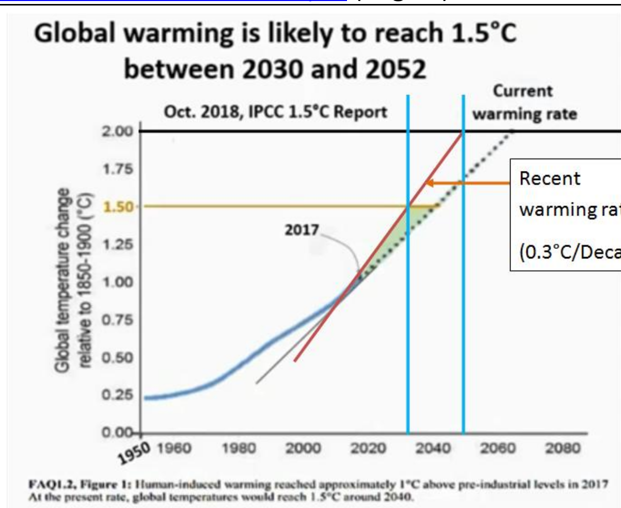


Fig. C1. Measured perturbations in atmospheric CO_2 concentrations from a baseline of 275 ppmv, compared with historical estimates of global GDP in inflation adjusted 1990 dollars, with associated year markers, and a linear fit to the data.

https://www.earth-syst-dynam.net/3/1/2012/esd-3-1-2012.pdf



(Figure is a slight modification of a screenshot from Peter Carter's "Global Warming Acceleration" YouTube video)

CO2 Budget 2016-2100 = (278 * e((5.35 * Ln(1 + ET / CS) - NonCO2RF) /5.35) - 342.87)/ 0.2586

CO2 Budget 2019-2100 = CO2 Budget 2016-2100 - 35

Temp Increase: 1.5 °C

Non-CO2 RF (W/m-2)	Climate Sensititivity 2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0
0.0	520	447	386	334	290	252	218	188	162	138	117	98	81	65	50	37
0.1	485	414	354	303	259	222	189	160	134	111	90	71	54	38	24	11
0.2	451	381	322	272	229	192	160	132	106	83	63	45	28	12	-2	-15
0.3	418	348	291	242	200	164	132	104	79	57	37	18	2	-13	-27	-40
0.4	385	317	260	212	171	135	104	77	52	30	11	-7	-23	-38	-52	-64
0.5	352	286	230	183	143	108	77	50	26	5	-15	-32	-48	-63	-76	-88
0.6	321	255	201	154	115	81	51	24	0	-21	-40	-57	-72	-87	-100	-112
0.7	290	225	172	126	88	54	24	-2	-25	-45	-64	-81	-96	-110	-123	-135
0.8	259	196	143	99	61	28	-1	-27	-49	-70	-88	-105	-120	-133	-146	-157
0.9	229	167	116	72	34	2	-26	-51	-74	-94	-112	-128	-143	-156	-168	-180
1.0	200	139	88	45	9	-23	-51	-76	-98	-117	-135	-151	-165	-178	-190	-202
1.1	171	111	61	19	-17	-48	-75	-100	-121	-140	-157	-173	-187	-200	-212	-223
1.2	142	84	35	-6	-42	-72	-99	-123	-144	-163	-180	-195	-209	-222	-233	-244
1.3	115	57	9	-31	-66	-96	-123	-146	-166	-185	-202	-217	-230	-243	-254	-265
1.4	87	31	-16	-56	-90	-120	-145	-168	-189	-207	-223	-238	-251	-264	-275	-285
	CO2 Budget 2019-2100 (Emissions - GTC)															

Temp Increase: 2.0 °C

Non-CO2 RF (W/m-2)	Climate Sensititivity 2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0
0.0	789	691	610	541	482	431	386	346	311	280	252	226	203	181	162	144
0.1	749	653	573	506	448	398	354	315	280	249	222	197	174	153	134	116
0.2	710	616	538	471	414	365	322	284	250	220	192	168	145	125	106	89
0.3	672	579	502	437	381	333	291	253	220	190	164	139	117	97	79	62
0.4	634	543	468	404	349	302	260	223	191	162	135	112	90	70	52	36
0.5	597	508	434	371	318	271	230	194	162	133	108	84	63	44	26	10
0.6	561	474	401	339	286	241	201	165	134	106	81	58	37	18	0	-16
0.7	525	440	368	308	256	211	172	137	106	79	54	31	11	-8	-25	-40
0.8	490	406	336	277	226	182	143	109	79	52	28	6	-14	-33	-49	-65
0.9	456	374	305	247	197	153	116	82	52	26	2	-20	-39	-57	-74	-89
1.0	423	341	274	217	168	125	88	55	26	0	-23	-45	-64	-81	-98	-112
1.1	390	310	244	188	139	98	61	29	1	-25	-48	-69	-88	-105	-121	-136
1.2	357	279	214	159	112	71	35	3	-25	-50	-72	-93	-111	-128	-144	-158
1.3	325	249	185	131	84	44	9	-22	-49	-74	-96	-116	-135	-151	-166	-181
1.4	294	219	156	103	58	18	-16	-47	-74	-98	-120	-139	-157	-174	-189	-202
	CO2 Budget 2019-2100 (Emissions - GTC)															

- Yellow cells show combinations of CS and NonCO2 RF for a post 2018 budget of around 190 GTC (roughly that put forward by the IPCC and National Academy of Science and adjusted for 2016-2019 emissions[4]).
- Orange cells show combinations of CS and NonCO2 RF for a post 2018 anthropogenic budget of around 70 GTC (assuming natural emissions of roughly 120 GTC[5])
- Green cells show the total CO2 budget for a value of climate sensitivity slightly below that which was demonstrated by the models that best capture current conditions[6,7]
- Purple cells show the CO2 budget for the non-CO2 radiative forcing for RCP 4.5[8]

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

Cheat Sheet: What you need to know from the National Academies report on carbon removal **Direct air capture closer to paying off than we had thought:** "The major barrier to large-scale direct air capture is the high current cost. If made less expensive, direct air capture technologies could be scaled up to remove very large amounts of carbon." (page 248) While direct air capture (DAC) systems are reported as costing greater than $500/t CO2 today, the report provides incredibly detailed calculations that show that DAC costs could reasonably fall to ranges between $100-$300/ton CO2 when deployed at greater scale. https://medium.com/@carbon180/cheat-sheet-what-you-need-to-know-from-the-national-academies-report-on-carbon-removal-6090ecac9877	