Carbon Emission Reduction Targets Based on Projected Global Average Temperature Rise and the Resulting Consequences

March 7, 2013

2°C (3.6°F)!

That is aspirational limit of the "group of eight" (G8) nations for global temperature rise as a consequence of greenhouse gas emissions.

That was 2009.

What does the G8 goal portend for the future?

What has happened toward achieving the G8 goal in the ensuing 3.5 years?

This brief has been developed to address these questions, drawing primarily on data[1] from the UK government commissioned 2006 *Stern Review - The Economics Of Climate Change*, *The Community Guide to Boulder's Climate Action Plan 2010/2011 Progress Report*, and the 2010 (US) National Academy of Sciences (NAS) – *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia*. It is an effort to connect the dots from an array of data sets to establish an understanding of where we are headed and where we need to go so to mitigate climate change and give readers a clear idea of the how our policy makers' actions (or inactions) impact climate change. This dot connection should enable readers to understand the appropriate targets for emission reductions in order to stabilize global temperature rise at an achievable and survivable level. Such targets can be broadly applied all emitting facets of our existence including new building emission standards (i.e. building codes), existing building emission standards, transportation plans, parking policies, etc.

Part I: What does 2°C mean and why is 2°C the G8 aspirational goal?

The narrative below examines the current science regarding likely temperature rise as a result of human greenhouse gas (GHG) emissions, how emissions cause temperature rise over time and how cumulative carbon is an appropriate metric for identifying probable global temperature increases.

2°C translates to about 1200 Gigatons (GtC) of accumulated carbon in the atmosphere since 1750, the start of the industrial age. A gigaton is 1 billion tons. Currently, the cumulative carbon is slightly under 600 GtC meaning humans have locked in about 1°C of current and future global temperature rise since 1750 (Figure 2).

2°C was adopted by the G8 as an aspirational goal primarily because that is all anyone could agree upon. More robust goals were proposed but not agreed upon.

Carbon dioxide's concentration has increased by more than 35 percent since 1750, and is now higher than at any time in at least 800,000 years. Annual emissions have increased by about a 3% average for the past decade. Current global emissions are about 10GtC per annum. Figure 4 indicates the current emissions trend line will reach the 2°C GtC equivalency by 2050 according to the NAS. The concentration of carbon dioxide could undergo a further doubling or tripling by the end of the century, greatly amplifying the human impact on climate (Figure 1, lower chart).

Because human carbon dioxide emissions (1 ton carbon = 3.7 tons CO_2) exceed removal rates through natural carbon "sinks," **keeping emission rates the same will not lead to stabilization of carbon dioxide. Emission reductions larger than about 80 percent, relative to whatever peak global**

1- Much of the text is taken directly from the research documents but quotation marks and footnotes are omitted for visual clarity. For the most part, Parts I and II are from NAS and Part III is from The Stern Review.

emissions rate may be reached, are required to approximately stabilize carbon dioxide concentrations for a century or so at any chosen target level (Figure 1).

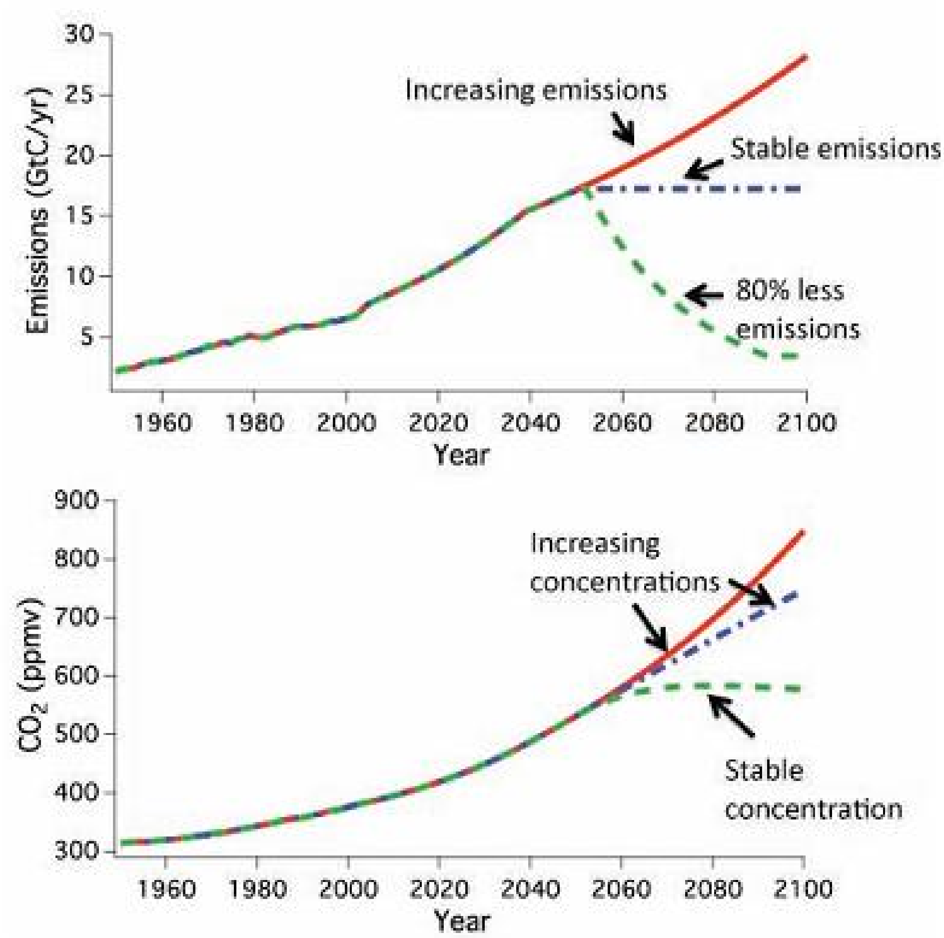

Figure 1 Because emissions of carbon dioxide are greater than the sinks that remove it, emissions reductions larger than about 80% (green line-top graph) are required if concentrations are to be stabilized (green line-bottom graph). The lower graph shows how carbon dioxide concentrations would be expected to evolve depending upon emissions for one illustrative case, but this applies for any chosen target.

Because carbon dioxide in the atmosphere is long lived, and the time lags in the climate system (particularly slow processes in the ocean), it can effectively lock Earth and future generations into a range of impacts, many of them severe. **Emission reduction choices made today matter in determining impacts experienced not just over the next few decades, but in the coming centuries and millennia. Some effects of 21st century human choices will contribute to climate change for more than 100,000 years.** Such extreme persistence is unique to carbon dioxide among major agents that warm the planet.

The higher the total, or cumulative, carbon dioxide emitted and the resulting atmospheric concentration, the higher the peak warming that will be experienced and the longer the duration of that warming. Duration is critical; **longer warming periods allow more time for key, but slow, components of the Earth system to act as amplifiers of impacts**, for example, warming of the deep ocean that releases carbon stored in deep-sea sediments. **Warming sustained over thousands of years could lead to even bigger impacts.**

To date, climate stabilization goals have been most often discussed in terms of stabilizing atmospheric concentrations of CO_2 (e.g., 450 ppmv CO_2e where "e" is CO_2 equivalent – that is-factoring other GHG impacts in terms of equivalent CO_2). NAS asserts it is more effective to assess climate stabilization goals by using global mean temperature change as the primary metric. Global temperature change can in turn be linked both to concentrations of atmospheric carbon dioxide and to accumulated carbon emissions. An important reason for using warming as a reference is that scientific research suggests that many key impacts can be quantified for given temperature increases. The Stern Review, predating this evolution in thinking, refers to this concentration of CO_2e rather than cumulative carbon. Figures 2 and 3 correlate the two methods of reference.

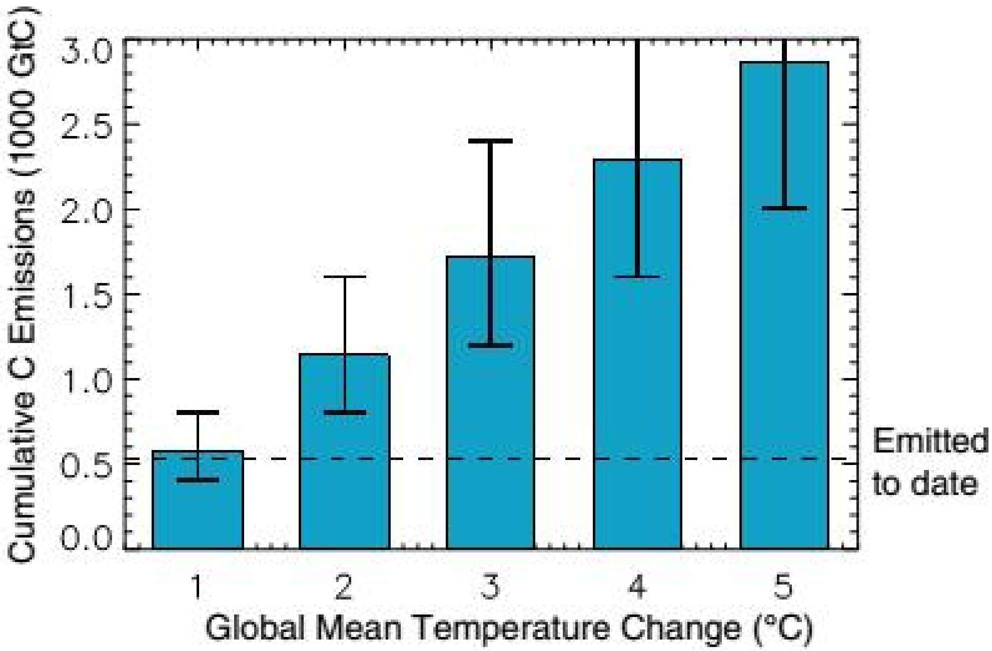

Figure 2 Recent studies show that cumulative carbon dioxide emission is a useful metric for linking emissions to impacts. Error bars reflect uncertainty in carbon cycle and climate responses to carbon dioxide emissions due to observational constraints and the range of model results. Cumulative carbon emissions are in teratonnes of carbon (trillion metric tonnes or 1,000 gigatonnes).

TABLE 1 Relationship of Atmospheric Concentrations of Carbon Dioxide to Temperature

Stabilization CO_2-Equivalent Concentration (ppmv): Range and Best Estimate	Equilibrium Global Average Warming (°C)
320 ⟵ 340 ⟶ 380	1
370 ⟵ 430 ⟶ 540	2
440 ⟵ 540 ⟶ 760	3
530 ⟵ 670 ⟶ 1060	4
620 ⟵ 840 ⟶ 1490	5

Stern Review range (rows for 2 °C and 3 °C: 430–540 and 540–760)

Note: Green and red numbers represent low and high ends of ranges, respectively; **black bolded** numbers represent best estimates.

The report calculates the "likely" range (66% chance) of atmospheric concentrations associated with various degrees of warming, consistent with model results[1] and roughly consistent with paleoclimate evidence. There are large uncertainties in **'climate sensitivity'**—the amount of warming expected from different atmospheric concentrations of greenhouse gas—the range is 30% below and 40% above the best estimates.

[1]The estimated "likely" range presented in this report corresponds to the range of model results in the Climate Modelling Intercomparison Project (CMIP3) global climate model archive.

PPMV = parts per million volume, the ratio of CO2 to air calculated in volumes.

Equilibrium = total warming.

Stabilization = reduction of atmospheric concentrations of carbon dioxide to the level that balances the Earth's natural capacity to remove greenhouse gases from the atmosphere.

Figure 3

As we saw from Figure 1 (upper chart), **emission reductions larger than about 80%** (relative to whatever peak global emission rate may be reached) **are required to approximately stabilize carbon dioxide concentrations (**this was indicated in **ALL** models NAS evaluated**) but this will only be for a few decades or so** at any chosen target level (e.g., 450 ppmv, 550 ppmv, 650 ppmv, 750 ppmv, etc.). Models indicate **longer-term stabilization requires nearly 100% reduction**. It should be emphasized that this finding is not linked to any particular policy choice about time of stabilization or stabilization concentration, but applies broadly, and is due to the fundamental physics of the carbon cycle.

Current representations of the carbon cycle and carbon-climate feedbacks show that ***anthropogenic (human caused) emissions must approach zero eventually if carbon dioxide concentrations are to be stabilized in the long term*** (Matthews and Caldeira, 2008). This is a fundamental physical property of the carbon cycle and is independent of the emission pathway or selected carbon dioxide stabilization target. **Recent studies using more detailed models of key feedbacks in the ocean, biosphere, and cryosphere, have underscored that stabilizing radiative forcing (**the difference between radiant energy received by the earth and energy radiated back to space) **at a given concentration does not lead to a stable climate in the long run.**

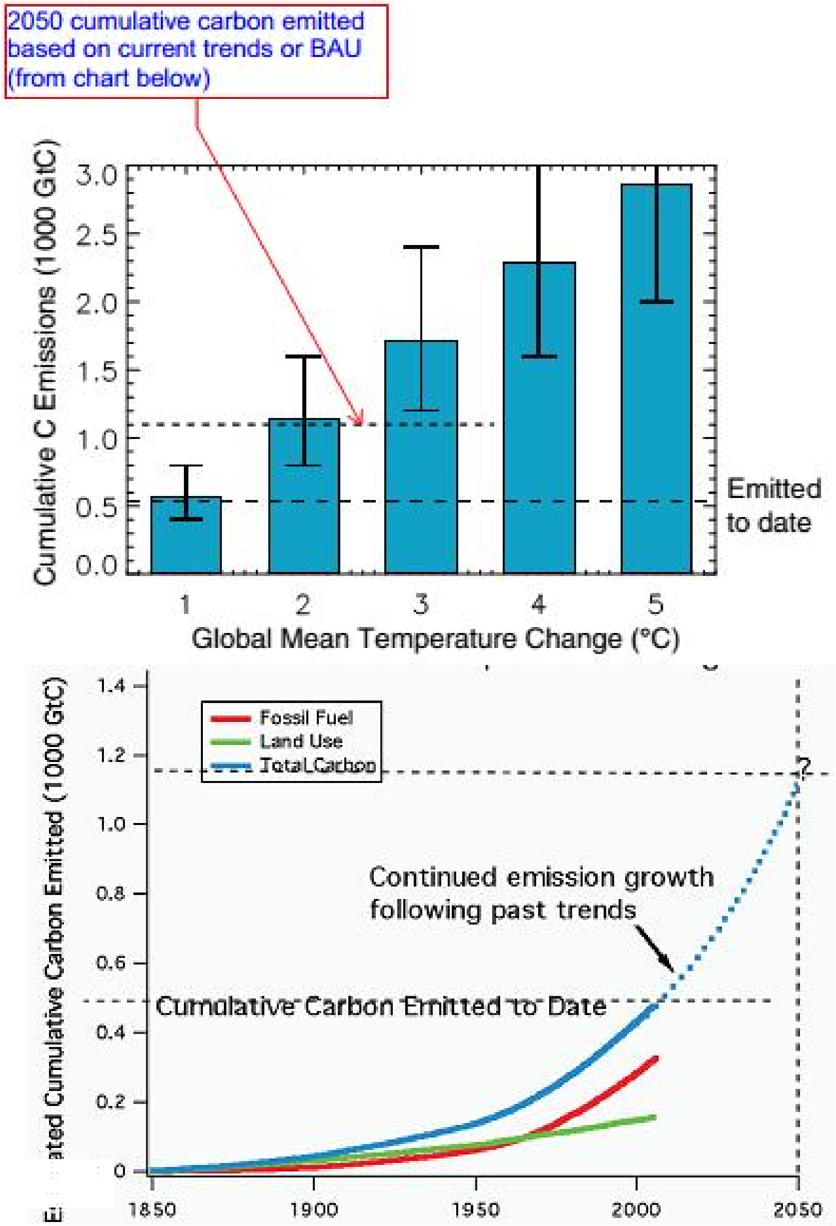

Figure 4 (top) Best estimates and likely range of cumulative carbon emissions that would result in global warming of 1°C, 2°C, 3°C, 4°C, or 5°C (see Figure S.1), based on recent studies that have demonstrated a near linearity in the temperature response to cumulative emissions (see Section 3.4). Error bars reflect uncertainty in carbon cycle and climate responses to CO_2 emissions, based on both observational constraints and the range of climate-carbon cycle model results (see Section 3.4). (bottom) Estimated global cumulative carbon emissions to date from fossil fuel burning and cement production, land use, and total. The figure also shows how much cumulative carbon would be emitted by 2050 if past trends in emission growth rates were to continue in the future, based upon a best fit to the past emission growth curve. {3.4}

The **instantaneous response** of Earth's atmosphere and oceans to increases in greenhouse gases and net radiative forcing **represents a transient climate change.** Stabilizing atmospheric concentrations does not mean that temperatures will stabilize immediately. Because of time lags inherent in the Earth's climate, warming that occurs in response to a given increase in the concentration of carbon dioxide ("transient climate change") reflects only about half the eventual total warming ("equilibrium climate change”) that would occur for stabilization at the same concentration (Figure 1 and 5). For example, if concentrations reached 550 ppmv, transient warming would be about 1.6°C, but holding concentrations at 550 ppmv would mean that warming would continue over the next several centuries, reaching a best estimate of an equilibrium warming of about 3°C.

Estimated Likely Ranges and Best Estimate Values for Transient and Equilibrium Global Averaged Warming Versus Carbon Dioxide Equivalent Concentrations.

CO_2-Equivalent Concentration (ppmv)	Best Estimate Transient Warming (°C)	Estimated Likely Range of Transient Warming (°C)	Best Estimate Equilibrium Warming (°C)	Estimated Likely Range of Equilibrium Warming (°C)
350	0.5	0.4-0.7	1	0.7-1.4
450	1.1	0.9-1.5	2.2	1.4-3.0
550	1.6	1.3-2.1	3.1	2.1-4.3
650	2	1.6-2.7	3.9	2.6-5.4
1000	3	2.4-4.0	5.9	3.9-8.1
2000	4.7	3.7-6.2	9.1	6.0-12.5

Stern Review range

Figure 5

Theoretical arguments and numerical models suggest that the efficiency of both the land and ocean carbon sinks may decline in the future under warmer climate conditions, which would act to amplify climate warming

Subconclusion

A given level of cumulative CO2 emissions does not result in stable CO2 concentrations, but rather in CO2 concentrations that peak at some value and then decrease slowly when emissions fall below the level of persistent natural carbon sinks. **Even if CO2 emissions become close to zero, the decrease in atmospheric concentrations may occur very slowly over centuries**. In a framework of cumulative carbon emissions, CO2 concentrations do not necessarily “stabilize” but rather change over time in response to given CO2 emissions scenarios. It is the total cumulative carbon emitted over time, rather than the atmospheric CO2 concentration itself, that indicates the level of expected climate warming. Enough carbon has accumulated to date to cause 1°C global temperature rise, emissions are on track to cause 2°C rise by 2050 and possibly double that by the end of the century.

Part II: Physical Impacts

If the above review of the NAS *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia* paper is compelling enough to accept that our actions or inactions now, will have consequences for thousands of years, and that current BAU trends do not portend well for our future - suggesting a level of urgency to begin reducing our emissions - then the next step is to explore the outcomes from possible temperature rise scenarios.

There is now increased confidence in how global warming levels relate to certain future impacts. Some of these effects per degree (°C) of global warming (Figure 6), include:

- 5-10 percent changes in precipitation in a number of regions
- 3-10 percent increases in heavy rainfall
- 5-15 percent yield reductions of a number of crops
- 5-10 percent changes in stream flow in many river basins

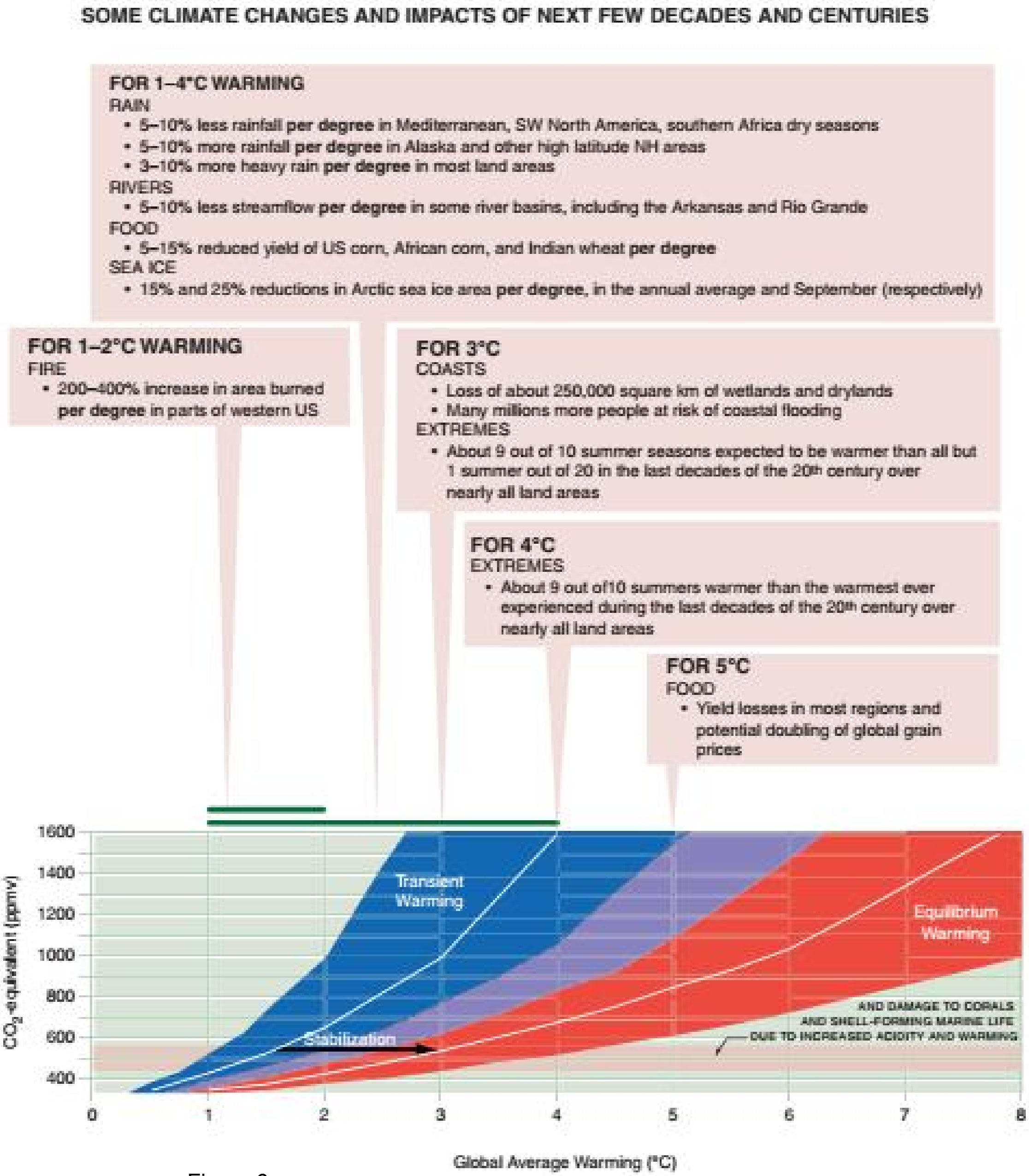
SOME CLIMATE CHANGES AND IMPACTS OF NEXT FEW DECADES AND CENTURIES
FOR 1–4°C WARMING
RAIN
• 5–10% less rainfall per degree in Mediterranean, SW North America, southern Africa dry seasons
• 5–10% more rainfall per degree in Alaska and other high latitude NH areas
• 3–10% more heavy rain per degree in most land areas
RIVERS
• 5–10% less streamflow per degree in some river basins, including the Arkansas and Rio Grande
FOOD
• 5–15% reduced yield of US corn, African corn, and Indian wheat per degree
SEA ICE
• 15% and 25% reductions in Arctic sea ice area per degree, in the annual average and September (respectively)
FOR 1–2°C WARMING
FIRE
• 200–400% increase in area burned per degree in parts of western US
FOR 3°C
COASTS
• Loss of about 250,000 square km of wetlands and drylands
• Many millions more people at risk of coastal flooding
EXTREMES
• About 9 out of 10 summer seasons expected to be warmer than all but 1 summer out of 20 in the last decades of the 20th century over nearly all land areas
FOR 4°C
EXTREMES
• About 9 out of10 summers warmer than the warmest ever experienced during the last decades of the 20th century over nearly all land areas
FOR 5°C
FOOD
• Yield losses in most regions and potential doubling of global grain prices
1600
1400
1200
1000
800
600
400
CO2-equivalent (ppmv)
Transient Warming
Equilibrium Warming
Stabilization
AND DAMAGE TO CORALS AND SHELL-FORMING MARINE LIFE DUE TO INCREASED ACIDITY AND WARMING
0
1
2
3
4
5
6
7
8
Global Average Warming (°C)

Figure 6

For warming levels of 1 to 2°C, the area burned by wildfire in parts of western North America is expected to increase by 2 to 4 times for each degree (°C) of global warming (Figure 7)**.**

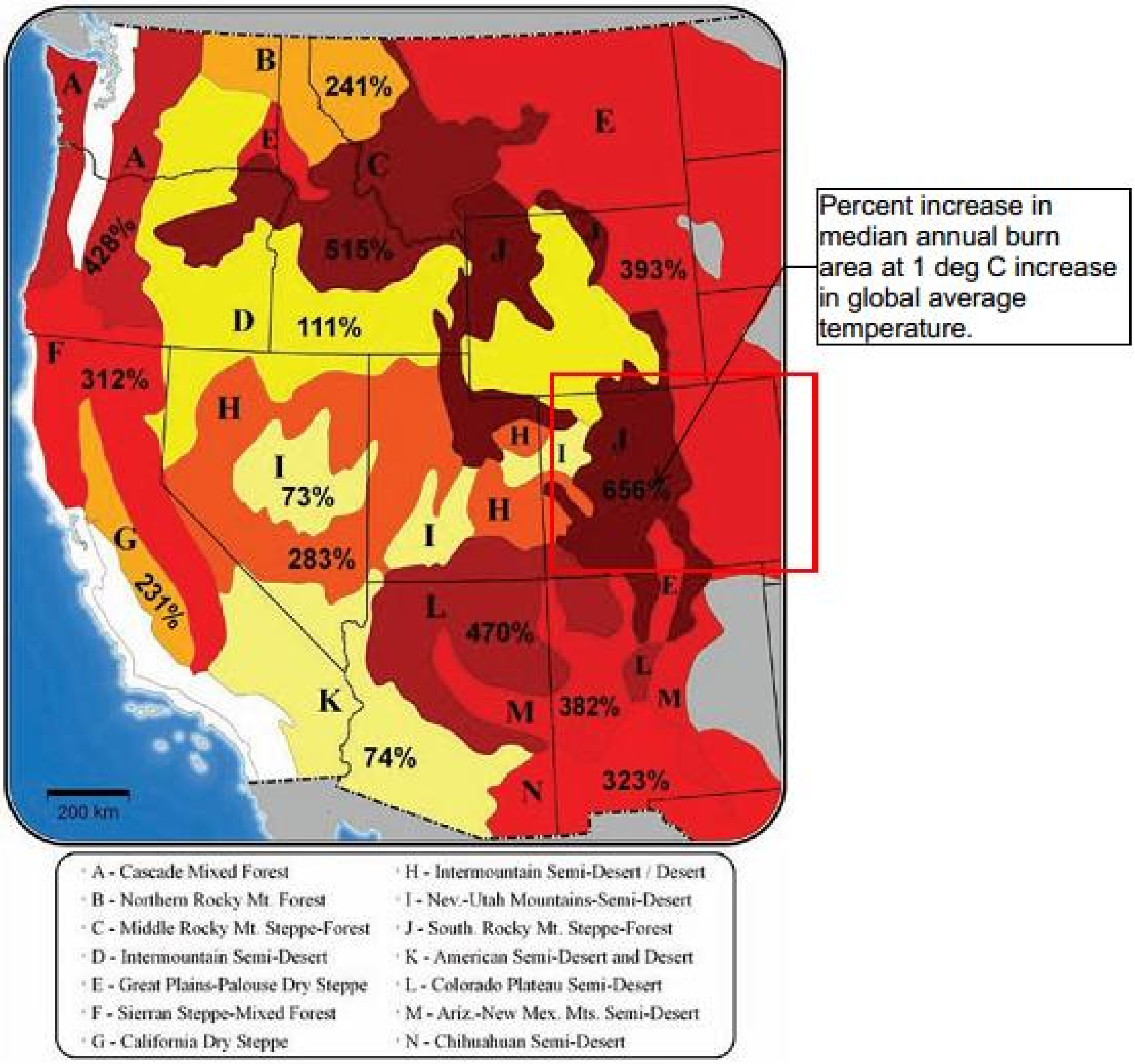

Figure 7 Percent increase (relative to 1950-2003) in median annual area burned for ecoprovinces of the West with a 1°C increase in global average temperature. Changes in temperature and precipitation were aggregated to the ecoprovince level using the suite of models in the CMIP3 archive. Climate-fire models were derived from National Clmatic Data Center (NCDC) climate division records and observed area burned data following methods discussed in Littell et al. (2009). {5.4}

About 15 percent and 25 percent decreases in the extent of annually averaged and September Arctic sea ice, respectively worldwide Increased tropical fire associated with El Niño droughts may contribute to increases in the growth rate of atmospheric carbon dioxide concentrations during recent El Niño years.

Warming of a few degrees can be expected to lead to large impacts to water resources, especially in the southwestern and southern parts of the United States. About 12% per degree decreases are projected for the Rio Grande Basin.

Models suggest that the average intensity of tropical cyclones is likely to increase roughly by 3-12% per degree C for the cube of this wind speed (often taken as a rough measure of the destructive potential of storm winds).

A 2°C global temperature rise would be sustained for millennia. This could lead to eventual sea level rise on the order of 1 to 4m due to thermal expansion of the oceans and to glacier and small ice cap loss alone. Melting of the Greenland ice sheet could contribute an additional 4 to 7.5m over many thousands of years. Adaptations to sea level rise will be ongoing and expensive – ports and infrastructure will repeatedly have to be altered over time.

It has been projected that 0.5m of sea level rise would increase the number of people at risk from coastal flooding each year by between 5 and 200 million; as many as 4 million of these people could be permanently displaced as a result. More than 300 million people currently live in coastal mega-deltas and mega-cities located in coastal zones. The corresponding projections for 1.0m of sea level rise suggest that the number of people at risk of flooding each year would increase by 10 to 300 million.

Global climate change is expected to reduce yields of key food crops in some tropical regions by about 7-15% over about the next 20 years, about 7-15% per °C of global warming while global demand for cereal crops can be expected to rise by about 25%. Global warming of 2°C would be expected to lead to average yield losses of U.S. corn of roughly 25%. Nearly 40% of global corn production occurs in the United States.

Part III Economic Impacts

Part II above outlined projected physical impacts. Of course those physical impacts will have economic implications. The UK government commissioned a review (*The Stern Review - The Economics of Climate Change*) of those implications which was published in 2006. The Review focused on the feasibility and costs of stabilization of greenhouse gas concentrations in the atmosphere in the range of 450-550ppm CO_2e. Since that time, its conclusions about likely climate change manifestations have been borne out by better modeling and understanding of the Earth's climate system. In fact, this enhanced understanding indicates that the trends in the Stern Review are accelerating and the implications more severe than initially understood.

Like the NAS study, the Stern Review evaluation of climate research indicated that temperature changes resulting from business as usual (BAU) trends in emissions may exceed 2-3°C within the next 50 years. At 4°C and above, global food production is likely to be seriously affected and that according to one estimate, by the middle of the century, 200 million people may become permanently displaced due to rising sea levels, heavier floods, and more intense droughts. Around 15 - 40% of species potentially face extinction after only 2°C of warming.

The impacts of climate change are not evenly distributed - the poorest countries and people will suffer earliest and most. With 5-6°C warming - which is a real possibility for the next century – models at that time (2006) that included the risk of abrupt and large-scale climate change estimated an average 5-10% loss in global GDP, with poor countries suffering costs in excess of 10% of GDP.

Stern estimates the total cost over the next two centuries of climate change associated under BAU emissions involves impacts and risks that are equivalent to an average reduction in global per-capita consumption (GDP is calculated using several measures, consumption is the single most important component) of at least 5%, now and forever. While this cost estimate is already strikingly high, it also leaves out much that is important.

- First, including direct impacts on the environment and human health (sometimes called 'non-market' impacts) increases the estimate of the total cost of climate change on this path from 5% to 11% of global per-capita consumption.
- Second, some recent scientific evidence at the time indicated that the climate system may be more responsive to greenhouse-gas emissions than previously thought. Modeling a limited increase in this responsiveness indicates the potential scale of the climate response could increase the cost of climate change on the BAU path from 5% to 7% of global consumption, or from 11% to 14% if the non-market impacts described above are included.
- Third, a disproportionate share of the climate-change burden falls on poor regions of the world. If this unequal burden is weighted appropriately, the estimated global cost of climate change at 5-6°C warming could be more than one-quarter higher than without such weights.

Putting these additional factors together would increase the total cost of BAU climate change to the equivalent of around a 20% reduction in consumption per head, now and into the future.

Analyses that employ the basic economics of risk, suggest that BAU climate change will reduce welfare by an amount equivalent to a reduction in consumption per head of between 5 and 20%. Taking account of the increasing scientific evidence of greater risks, of aversion to the possibilities of catastrophe, and of a broader approach to the consequences than implied by narrow output measures, the appropriate estimate is likely to be in the upper part of this range.

Stabilization - at whatever level - requires that annual emissions be brought down to the level that balances the Earth's natural capacity to remove greenhouse gases from the atmosphere. The longer emissions remain above this level, the higher the final stabilization level. In the long term**, annual global emissions will need to be reduced to below 5 GtCO2e (1.35 GtC), the level that the earth can absorb without adding to the concentration of GHGs in the atmosphere. This is more than 80% below the absolute level of current annual emissions (the same conclusion as NAS).**

Stabilizing at 450ppm CO2e (correlates to 2°C temperature rise per Figure 3 and 1200GtC emitted per figure 2)**, without overshooting the stabilization level, global emissions would need to peak in the next 10 years (bear in mind that we are now 7 years after the Stern Review) and then fall at more than 5% per year, reaching 70% below current levels by 2050.**

Estimating the costs of achieving the necessary reductions was done in two ways:

- by looking at the **resource costs** of measures, including the introduction of low-carbon technologies and changes in land use, compared with the costs of the BAU alternative. This provides an upper bound on costs, as it does not take account of opportunities to respond involving reductions in demand for high-carbon goods and services.
- using **macroeconomic models** to explore the system-wide effects of the transition to a low-carbon energy economy.

Resource estimates suggest that an upper bound for the expected annual cost of emissions reductions consistent with a trajectory leading to stabilization at 550ppm CO2e is likely to be around 1% of GDP by 2050.

Macroeconomic models confirm these estimates. The average expected cost is likely to remain around 1% of GDP from mid-century, but the range of estimates around the 1% diverges strongly thereafter, with some falling and others rising sharply by 2100, reflecting the greater uncertainty about the costs of seeking out ever more innovative methods of mitigation.

There is a high price to delay. Delay in taking action on climate change would make it necessary to accept both more climate change and, eventually, higher mitigation costs. Weak action in the next 10-20 years would put stabilization even at 550ppm CO_2e (1800 GtC emitted) beyond reach – and this level is already associated with significant risks. **Costs of mitigation of around 1% of GDP are small relative to the costs and risks of climate change that will be avoided.**

The evidence suggests aiming for stabilization somewhere within the range 450 - 550ppm CO_2e, or 2°C to 3°C temperature rise (again, this is consistent with the NAS findings)**.** Anything higher would substantially increase the risks of very harmful impacts while reducing the expected costs of mitigation by comparatively little. Aiming for the lower end of this range would mean that the costs of mitigation would be likely to rise rapidly. Anything lower would certainly impose very high adjustment costs in the near term for small gains and might not even be feasible, not least because of past delays in taking strong action.

Preliminary calculations suggest that the social cost (estimates of the changes in the expected benefits and costs over time from a little extra reduction in emissions) of carbon, if we remain on a BAU trajectory, is of the order of $85 per tonne of CO_2. Preliminary work suggests that, if the target were between 450-550ppm CO_2e, then the **social cost of carbon** would start in the region of $25-30 per tonne of CO_2 – **around one third of the level if the world stays with BAU**. The social cost of carbon is likely to increase steadily over time because marginal damages increase with the stock of GHGs in the atmosphere, and that stock rises over time.

The investments made in the next 10-20 years could lock in very high emissions for the next half-century, or present an opportunity to move the world onto a more sustainable path

Subconclusion

Most people understand that that we have a problem that is getting worse and the more we delay taking serious action, the more difficult it will be to counter the consequences. The Stern Review provides an understanding that within the range of the 450-550ppm CO_2e (the same scenario as NAS though NAS is expressed in cumulative carbon) resulting in about a 2°C temperature rise, the cost of mitigation is likely to be 1% of global GDP by 2050 but that BAU estimated in the 5°C-6°C range over the next century to may cause an average 5-10% loss in global GDP, with poor countries suffering costs in excess of 10%. Further BAU may reduce per capita consumption by as much as 20%.

The Stern Review makes the case that it is economic to reduce GHG emissions and more economic to do it now rather than later.

Part IV: Conclusion

If the previous chapters (Parts II-III) make the case that we need to and can economically address climate change by reducing GHG emissions to the equivalency of a 2°C then that should be our general target and the next step is to derive a specific target including a timeline for achieving the target.

Sam and I have made a stab at that, utilizing the findings in the NAS and Stern Review documents. The basic goal we suggest is to limit cumulative GtC to a 2°C temperature rise and establish an emissions reduction rate to achieve 80% annual emissions reduction between now and 2050.

Attached is a spreadsheet with two tabs, for World reductions and Boulder reductions. The World tab, column C indicates annual GtC emissions with a 3% (average increase for the past decade) annual emissions increase rate starting in 2010 and reaching peak emissions in 2016 red row (11), within 10 years of 2006 per the Stern Review) and subsequent reductions thereafter. Annual emissions for 2010 were 10 GTC and cumulative were 600 GTC.

With the annual emissions reduction rate at 4.6%, the aqua row (45) indicates an 80% reduction in annual emissions by 2050. 80% is indicated by both the Stern Review and NAS. 2050 is a time frame referenced by Stern for achieving 70% annual emissions reductions. A lower rate of emissions reduction will push the 80% reduction and the cumulative stabilization point further into the future.

The green row (274) indicates annual emissions reduced to zero in 2279, 266 years from now.

Were the annual emissions reduction rate reduced to 2%, the 80% reduction will not occur until 2210 and annual emissions will not be reduced to zero until 2629, 616 years from now and 2.3 times longer than a 4.6% rate. Cumulative emissions will also exceed 1200GtC, crossing the 2°C threshold.

Figure 8 below illustrates this emissions reduction profile for Boulder and includes expected population increase over that time span.

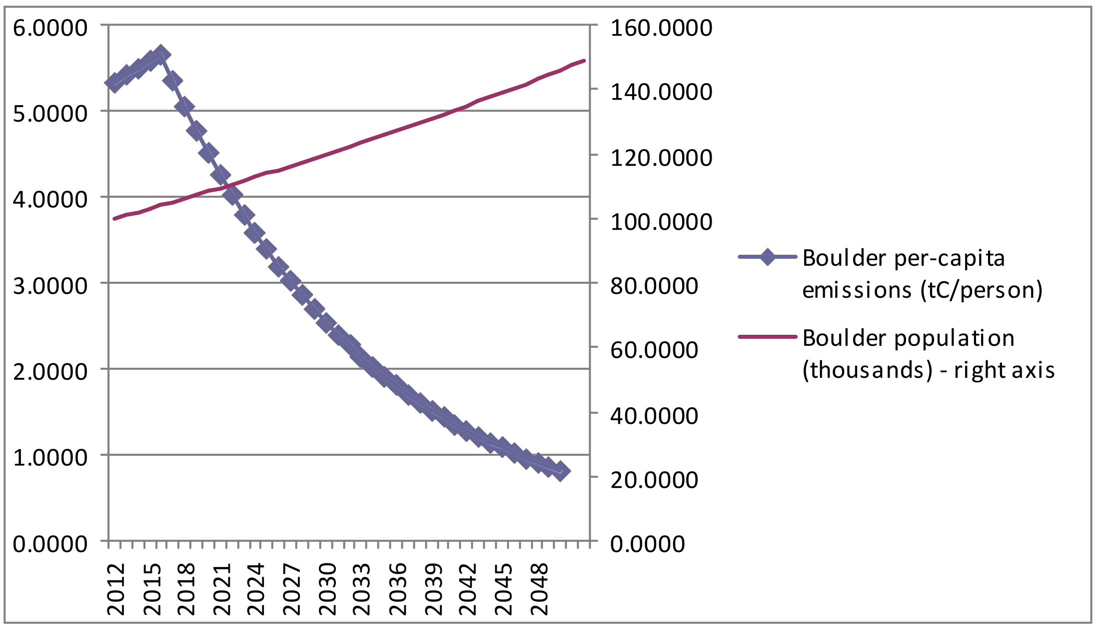

Figure 8 – Boulder GHG emissions and population changes to 2050 under 4.6% annual emissions reduction program with a 1% Boulder population growth rate.

This establishes a target reduction rate discussion – 4.6% annual decrease in all Boulder GHG emissions to contribute its share toward getting to a 2°C locked-in planetary temperature rise.

Currently, **global per capita annual emissions are 1.53 tons of carbon vs. 5.33 in Boulder**. **Under the 4.6% annual emissions reduction scenario, by 2050 Boulder's annual emissions will be reduced 80% below the current level but per capita emissions will still be 2.8 times greater than global**. It should be noted that Boulder emissions in the spreadsheet which come from the CAP, do not include certain externalities such as Boulderite air travel emissions, whereas the global values include all emissions. Thus the Boulder emissions are actually higher than portrayed in the CAP and in the spreadsheet. Nonetheless, a 4.6% annual reduction in emissions might be an appropriate global target to set as a basis for deriving a Boulder building emissions target. These reference levels are illustrated in Figure 9.

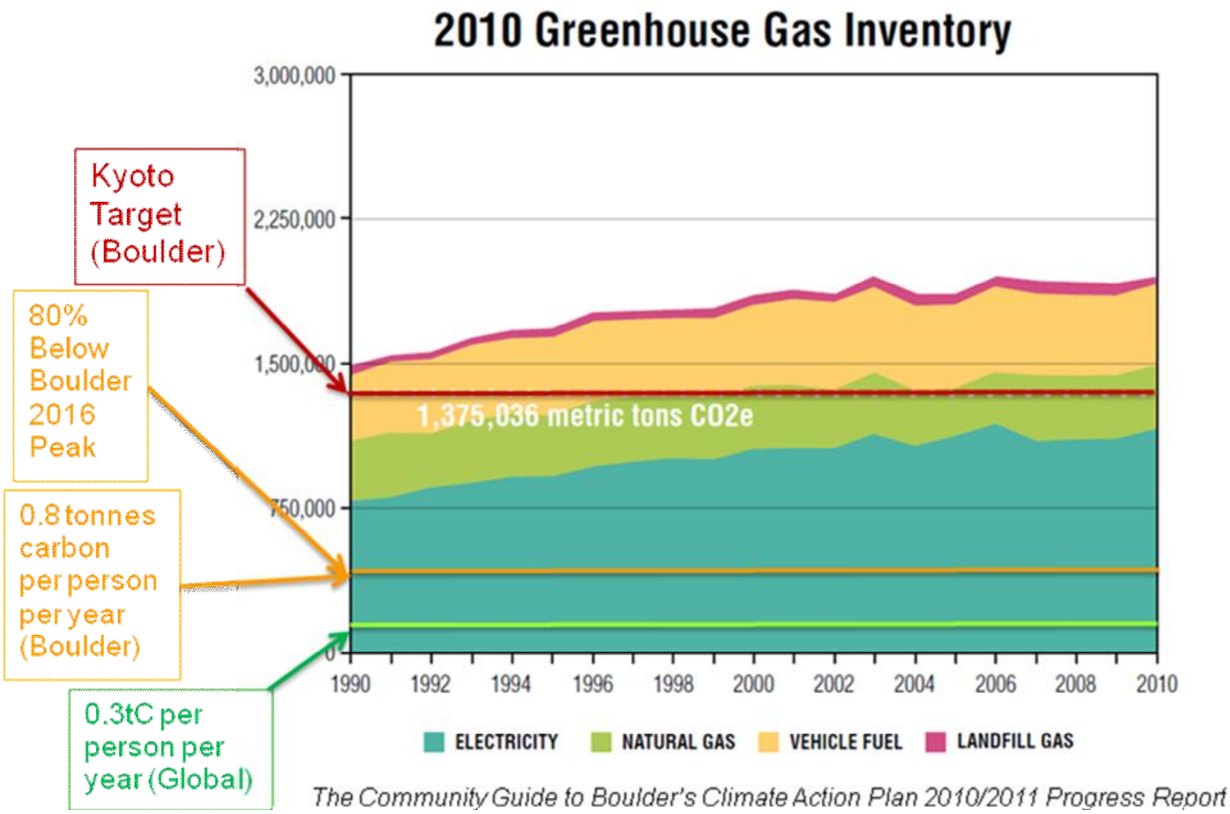

Figure 9 – Boulder 1990 - 2010 GHG emissions levels, and reference levels required for the Boulder Kyoto protocol targets (red line), as well as 80% emissions reductions from a nominal 2016 Boulder emissions peak (orange line). The green line illustrates the required reduction if Boulder citizens were to match the world per capita annual emissions in 2050 resulting from a global 80% GHG emissions reduction from a nominal 2016 peak.

Hopefully, what readers will conclude from this brief is that:

- it is economic to reduce GHG emissions and more economic to start doing it now rather than later, even at a 4.6% annual reduction rate;
- actions taken or not taken in the next decade could lock in very high emissions for the next half-century, or present an opportunity to move the world onto a more sustainable path;
- there is a high price to delay; delay in taking action on climate change will make it necessary to accept both more climate change and, eventually, higher mitigation costs
- the longer annual emissions remain high, the higher the final stabilization level
- the higher the cumulative carbon dioxide emitted, the higher the peak warming and the longer the duration of that warming
- duration of warming is critical; longer warming periods allow more time for key components of the Earth system to act as amplifiers of impacts. Warming sustained over thousands of years could lead to even bigger impacts
- emissions must approach zero eventually if carbon dioxide concentrations are to be stabilized in the long term

As Boulder updates its climate change mitigation policies, consideration should be given to whether each emitting facet of the City should be required to reduce by whatever overall annual emission reduction goal Boulder adopts. Where they are not, all other components of Boulder's emissions profile, existing buildings, new buildings, transportation, power generation, etc. will have to make up the shortfall.

If the electricity municipalization effort is successful, it will make a huge contribution to the necessary GtC reductions from the supply side. In the very near future there will be two additional and equally significant opportunities for reduction on the demand side; the existing commercial building energy conservation ordinance (CECO) and a building code update will be under consideration by City Council. Buildings and their processes account for nearly 50% of North American GHG emissions and about 76% of Boulder emissions. Thus, no less effort than with municipalization should be expended, or importance ascribed, toward ensuring building emissions achieve the necessary reductions to cap global temperature rise at 2°C.

The core data sources can be found online at as follows:

NAS paper - http://www.nap.edu/catalog.php?record_id=12877

Stern Review - http://webarchive.nationalarchives.gov.uk/+/http:/www.hm-treasury.gov.uk/sternreview_index.htm

Boulder Climate Action Plan, 20190-11 Update (CAP) - http://www.bouldercolorado.gov/files/LEAD/climate%20and%20energy/cap_final_25sept06.pdf

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