GREENHOUSE GAS EMISSION REDUCTION SCENARIOS FOR BC

Meeting the Twin Objectives of Temperature Stabilization and Global Equity

By Colin R. Campbell
and Cliff Stainsby

Sierra Club BC

BC Government and Service Employees' Union
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Canadian Centre for Policy Alternatives
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AUGUST 2008

A CLIMATE JUSTICE PROJECT TECHNICAL PAPER

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Summary

Any greenhouse gas emission reduction strategy designed to restrain global average temperature rise to less than 2°C above the pre-industrial value will require a rapid initial reduction in emissions and, depending on the chosen timeline, an extended period ranging from 80 to 400 years during which greenhouse gases (GHGs) will need to be removed from the atmosphere by artificial as well as natural means.

In this report, six greenhouse gas emission scenarios were examined, each not likely to exceed 2°C warming at any time and requiring atmospheric GHGs to stabilize eventually at 400 ppm carbon dioxide equivalents (CO_2e).[1] These parameters were chosen because only at this stabilization level is there a moderately low probability of global average temperature increase exceeding 2°C. These odds, unfortunately, are still significant, i.e. between 0 and 31 per cent (see Table 1).[2] There is growing evidence that even this target is not stringent enough to guarantee "a planet similar to that on which civilization developed and to which life on Earth is adapted…"[3]

Using the University of Victoria Earth System Climate Model (ESC), we find that achieving this goal would require global emission reductions of approximately 83 per cent by 2050. Meeting this target requires an average annual emission reduction of 4.1 per cent between 2008 and 2100 (see Appendix 3).

In all six modeled scenarios, significant artificial withdrawals of GHGs from the atmosphere would also be required in order to meet the stabilization goal.

Stated in the starkest terms, the world can emit a further 223 Gt (i.e. billions of tonnes) of carbon in total by 2100 and have a greater than 70 per cent chance of remaining under the

2°C threshold. If BC were restricted to an equitable per capita contribution to that total, its permissible emissions in total between now and 2100 would be 144 Mt of carbon (i.e. millions of tonnes). This is equal to 7.5 years of emissions at expected 2008 rates (which must then be spread out over the coming 92 years).[4]

Achieving "contraction and convergence"—that is, equal allowable per capita emissions globally—over the 2008 to 2100 period will be very challenging. Because many industrialized jurisdictions, such as British Columbia, are starting with per capita GHG emissions considerably higher than the global average, they must achieve emission reduction rates considerably greater than the global average if global equity is to be achieved. For BC the annual per cent GHG emission reductions required to meet this measure of equity by 2100 would average 12.6 per cent (per year) between 2008 and 2100 with an emission reduction target of 99.7 per cent for 2050. We ref er to this as "2100 carbon budget convergence." It requires that globally and in BC we do not exceed 2008 to 2100 carbon emission budgets of 233 GtC and 144 MtC respectively.

Living within its 2100 carbon budget (144 MtC) will be very difficult for BC. It may be so difficult as to be unrealistic. But, because the global carbon budget (244 GtC) simply cannot be exceeded and because equity ought to be a primary objective, difficult discussions about the meaning of and means of achieving global equity in GHG emissions are likely required. To that end, we consider one possible alternative approach to equity. That approach we call "2050 annual emissions convergence." In this scenario BC converges to equal global per capita emissions by 2050 and remains at that rate into the future. In this scenario, BC will exceed its equity target of 144 MtC over the next 92 years. This highlights the need for, and scale of, transfers to low emitting countries. These transfers of finance or technology will have to be agreed to by the receiving countries and will have to result in emission reductions equal to or greater than the excess emissions from BC.

Failure to ensure that global temperatures remain below 2°C above pre-industrial levels will condemn future generations to massively unreliable and uncertain environments, constrained food supplies, diseases, rising sea levels, and greatly compromised economic and social well being.

Given the civilization-threatening risks expected from global warming, it is clear that we have a profound moral obligation to achieve these global targets, so that Earth's natural life support systems can provide for future generations. Failure to ensure that global temperatures remain below 2°C above pre-industrial levels will condemn future generations to massively unreliable and uncertain environments, constrained food supplies, diseases, rising sea levels, and greatly compromised economic and social well being—in such circumstances even survival will be difficult for millions if not billions of people.[5]

For workers and communities, global warming is likely the most dangerous issue we have faced in a long time—perhaps ever. Global warming is a threat to our way of life, to our jobs, our security, to all those we love and care for, including, most particularly, our children and grandchildren. The battle against global warming will test our resolve and our moral commitment to each other, our children and our world, including those thousands of other species facing imminent extinction.

Introduction

"One of the hardest lessons taught by climate change is that the economic model which drives growth, and the profligate consumption in rich nations that goes with it, is ecologically unsustainable. There could be no greater challenge to our assumptions about progress than that of realigning economic activities and consumption with ecological realities."

"Combating climate change demands that we place ecological imperatives at the heart of economics."

— United Nations Human Development Report[6]

In this paper we review current science, from the most credible sources, to help provide an understanding of the basis for, and the scale of, the global warming problem and the kind of contribution BC might make to its solution. We hope that with this information British Columbians can engage in serious discussions about the tools—both policy and technological—needed to prevent dangerous global warming. We recognize global warming as the present and credible threat of climate change. We do not recommend specific policies, but rather seek here to benchmark what the short, medium and longer term GHG reduction targets must be if BC is to fulfill its fair share of meeting the global challenge.

The underlying logic of this paper is as follows:

- Global average temperature increase due to greenhouse gas emissions should not exceed 2°C above the pre-industrial value;
- To achieve a probability range of 0 to 31 per cent of not exceeding the 2°C threshold, it is necessary to stabilize atmospheric GHGs at 400 ppm CO_2e;
- We used the University of Victoria Earth System Climate Model to calculate emission pathways consistent with these first two assumptions and stabilization at various future dates;
- Based on the emission pathways, we identify global carbon emission budgets (the total amount of permissible GHG emissions that can be released globally between now and 2100);
- We determine a BC carbon emission budget for the period 2008 to 2100 based on BC's population as a proportion of global population;
- We identify average annual emission reduction rates required for the world and BC in order to live within their respective carbon budgets; and
- In conclusion, we highlight the challenge of equity and some of the questions it poses and develop one alternative emission reductions scenario (2050 annual emission convergence) to illustrate the equity issue.

In this paper we review current science, from the most credible sources, to help provide an understanding of the basis for, and the scale of, the global warming problem and the kind of contribution BC might make to its solution.

Context

Global warming is an unequivocal fact.[7] Atmospheric greenhouse gas concentrations are increasing and so are global temperatures.[8] Failure to mitigate global warming will result in widespread and deep economic, social and environmental adjustments.[9]

In February 2007, the Province of British Columbia acknowledged the "critical problem of global warming and climate change." In its Speech from the Throne, the government stated that the science is clear, that global warming is real, and that to preserve the ecological heritage of the province requires reversing our emissions growth, which is presently "increasing at a rate far faster than most of our neighbours." Goals were declared of reducing GHG emissions by 33 per cent below 2007 levels by the year 2020 (the equivalent of 10 per cent below 1990 levels), and of setting a 2050 goal. Interim targets for 2012 and 2016 have also been promised.[10] In a September 2007 speech to the Union of BC Municipalities, the Premier promised to legislate these targets. In this speech he also promised to legislate requirements for municipal and regional actions.[11] On November 27, 2007 the government passed the *Greenhouse Gas Reductions Target Act,* which fixes in law BC's GHG emission reduction targets at 33 per cent by 2020 and 80 per cent by 2050 below 2007 levels.[12] The Act itself imposes no legal obligation to reach these targets. A Climate Action Secretariat has been formed in the Office of the Premier, and a significant program is promised. A 22-member Climate Action Team has been formed, representing many sectors of society (but with the notable omission of labour), to advise on "the most credible, aggressive and economically viable targets possible for 2012 and 2016."[13]

These are important steps by the BC government; they indicate acceptance of the reality of global warming. The strategic direction BC has initiated is to be welcomed, as is the significant shift in perspective it entails. The 2020 emission goal is presently the highest bar set by any North American jurisdiction.

Why 2°C?

In developing the parameters for the modeling work itself, we started with the position (commonly accepted worldwide) that global temperatures exceeding 2°C above pre-industrial levels are far too dangerous to be acceptable. While the process of setting these targets is by nature political, the motivation for them is moral and practical, for the consequences of warming above 2°C are unacceptably severe for future human generations and other species.

The earth has already warmed 0.7 degrees Celsius since pre-industrial times, and the effects are apparent in the poleward migration of species' ranges, the increasing intensities of storms and weather extremes, changes in precipitation regimes away from snow toward more rain, melting of mountain glaciers, massive reductions in the seasonal covering of floating Arctic sea ice, thinning and accelerated retreat of glaciers in Greenland and West Antarctica, and rising sea level from these glacial melts as well as thermal expansion of seawater as it warms. All of these climate change indicators highlight the stark realities for human society, for each has significant associated negative effects.[14]

Thermal inertia (the delay between increased atmospheric GHG concentrations and increased atmospheric temperature) in the global climate system promises another 0.50 to 2°C of warming, even were we to stop all greenhouse gas emissions immediately.[15] This implies that a warming of at least 1.2°C and potentially 2.7°C is already inevitable without withdrawals of GHGs from the atmosphere. And, a widespread consensus has developed that 2°C is the maximum warming that should be allowed. The IPCC's Fourth Assessment Report depicts key impacts on major global systems as a function of increasing global average temperature change,[16] and they are highly significant in terms of negative impacts on human well-being at the 2°C warming threshold.

> In February 2007, BC acknowledged the "critical problem of global warming and climate change." The strategic direction BC has initiated is to be welcomed, as is the significant shift in perspective it entails.

A world 2°C warmer than pre-industrial levels is very likely to experience:[17]

- Reduced water availability up to 20 to 30 per cent in some vulnerable regions;
- Sharp declines in crop yield in tropical countries (e.g. 5 to 10 per cent in Africa);
- Exposure of more than 60 million additional people to malaria;
- More than 10 million additional people affected by coastal flooding annually;
- Probable extinction of up to 40 per cent of all species, with polar species at highest risk;
- Potentially irreversible melting of the Greenland ice sheet leading to an eventual six to seven metre sea level rise;
- Abrupt changes to monsoon systems, negatively affecting the agriculture of much of Asia; and
- Collapse of the West Antarctic ice sheet and weakening of the Atlantic thermohaline circulation, with serious sea level and climatic implications for Europe and Asia.

In the last interglacial stage, approximately 130,000 years ago, the global mean temperature was roughly 2°C degrees warmer and sea levels were approximately six to seven metres higher than today.[18] Such conditions would be catastrophic for humanity, as well as for many other species. We have to look very far into the past, approximately 3 million years, to find a warmer stage, 3°C above the present average, when sea levels were around 25 metres higher. Anything beyond 2°C warming, therefore, is considered "dangerous."[19]

Finally, it must be noted that increasing temperature has its own positive feedback effects (highly negative or reinforcing effects despite the "positive" feedback nomenclature) on the global climate system. These include:

- Loss of ice resulting in enhanced absorption of heat by less reflective land, vegetation and water;
- Absorbed heat increases the rate of snow and ice melt, which then accelerates the melt cycle;
- Warmer arctic air melts permafrost which releases organic methane from previously frozen but now decomposing plant remains;
- Methane could also be released from icy lattices, called clathrates, were the oceans to warm sufficiently—because methane is a potent greenhouse gas (approximately 20 times more effective by volume than CO_2 at holding heat in the atmosphere), its release causes additional warming; and
- Higher temperatures will increase microbial metabolism and cause soils at some point to become carbon sources rather than the sinks they are at current and recent temperatures—the same apparently applies to forests.[20]

There is compelling evidence from the past that changes in atmospheric composition, specifically increases in CO_2 and methane have triggered rapid climate change and associated mass extinctions of living organisms.[21] A key moment at which temperature will surely be out of human control would be when the loss of ice became irreversible. A significant body of experts thinks we are very close to this threshold, and that it may in fact lie below 2°C global average warming. There is a growing consensus, also, that once 2°C is breached, 3°C, 4°C, 5°C and even higher temperatures may be inevitable.[22] And those temperatures represent a future so dismal for humanity, it is not to be willingly contemplated.

Achieving Stabilization

To achieve a reasonably low probability range (0 to 31 per cent) of exceeding 2°C a stabilization goal of an atmospheric concentration of 400 ppm CO_2e or lower is required (see Table 1 on page 12).[23] Given that the present GHG level is already 430 ppm CO_2e, achieving 400 ppm CO_2e will require a concerted global effort. It is important to distinguish peak concentration, which is the maximum concentration of greenhouse gases we allow to accumulate, and stabilization, which is the concentration we reach after reducing the GHG concentrations in the atmosphere. Think of it as the difference between keeping water flowing into a closed tub, and then allowing it to drain at a rate greater than it accumulates. The atmosphere is already "too full" of greenhouse gases, and more are being added. CO_2 levels are rising 2 ppm to 3 ppm each year, so even a 450 ppm level could be realized in less than 10 years.

Not only do we need to turn the GHG faucet down and then off to stop the addition of GHGs, we need also to pull the plug and drain some—a lot in fact—from the atmosphere in the near future. Some of this will occur naturally (thanks to the normal functioning of oceans and forests), but not enough. Ultimately, our GHG reduction efforts will need to be reinforced by some form of human-initiated means of pulling GHGs out of the atmosphere. But that latter task will be that of the next generation; the obligation of our current generation is to meet the task of reducing and ultimately eliminating further GHG emissions—of turning off the faucet – and that alone will be challenging to achieve.

Table 1: Risk of Overshooting Pre-industrial Temperature Levels for Different CO_2e Levels				
	Probability of Exceeding Pre-industrial Levels by (x)°C			
ppm CO_2e (K) at stabilization	2°C	3°C	4°C	5°C
(350)	0%	0%	0%	0%
(400)	0-31%	0-5%	0%	0%
(450)	8-57%	1-34%	0-17%	0-3%
(500)	26-78%	4-50%	0-34%	0-21%
(550)	48-96%	11-61%	2-45%	0-32%
(600)	68-99%	21-69%	6-53%	1-41%

Source: Meinshausen (2006)[24]

Questions for BC

In light of the above discussion, we assess British Columbia's commitments to the necessary targets by asking:

- How well does BC's goal of a 33 per cent reduction in GHG emissions by 2020 reflect what is necessary for achieving a reasonably low probability of exceeding 2°C, namely an atmospheric concentration of GHGs stabilizing at a maximum of 400 ppm CO_2e?
- What should the 2012, 2016, 2020 and 2050 provincial targets be to meet scenarios modeled to stabilize the atmosphere at 400 ppm CO_2e?

With the cooperation of the Climate Modelling Lab of the University of Victoria, we have at hand the results of six runs from the University of Victoria ESC model.[25] We asked the model to determine CO_2e emission pathways through time and to calculate the accompanying levels of atmospheric CO_2e concentrations and average surface temperatures for the six scenarios. The stabilization dates were extended outward in successive runs in order to determine which emission reduction pathways might be most practical to achieve.

The model runs are at a global level. Based on BC's share of the global population and the assumption of equity, i.e. that each person on earth has "rights" to the same amount of emitted carbon, we then calculate the actual emissions "permitted" for BC, and the average rates of reduction per annum to meet those targets. Results are graphically displayed in Figures 1 to 3 and numerically in Appendices 5 to 8.

Scenario 1 (2050/2100)

Stabilizing at 400 ppm CO_2e *in 2100 and peaking at 450 ppm* CO_2e *in 2050*

This scenario requires a rapid reduction in CO_2e emissions, and starting in 2056 large withdrawals of atmospheric carbon are required, which increase to a peak annual extraction of approximately 5GtC in 2082, then decrease annually until 2138 at which point stabilization is achieved at 400 ppm CO_2e with global annual emissions at approximately 0.01 GtC. Maximum surface air temperature predicted is +1.37°C above pre-industrial, inside the +2.0°C envelope. Note that 5 Gt of carbon is approximately 60 per cent of present annual emissions.[26]

Scenario 2 (2050/2150)

Stabilizing at 400 ppm CO_2e *in 2150 and peaking at 450 ppm* CO_2e *in 2050*

In this case peak concentration again occurs in 2050, but the time designated to reach the same stabilization level is moved out by 50 years to 2150. Initial emission reductions are more severe. Again there is a need to withdraw atmospheric CO_2e, beginning somewhat later by 2067, increasing to a peak annual extraction of approximately 2.65 GtC/year in 2100, then decreasing annually until 2172 when stabilization is achieved at 400 ppm CO_2e, and maintained by limiting global annual emissions to 0.2 GtC or less. While still challenging, the sequestration phase is significantly less strenuous than in Scenario 1. Maximum surface temperature reached is +1.39°C, marginally higher than in Scenario 1.

Scenario 3 (2100/2300)

Stabilizing at 400 ppm CO_2e *in 2300 and peaking at 450 ppm* CO_2e *in 2100*

By pushing the peak out to 2100 and the stabilization target out to 2300, initial emission reductions must be more strenuous. Sequestration would need to begin in 2130 and would last 191 years until 2321, reaching a maximum annual value of approximately 1.41 GtC/year. The maximum surface air temperature reached would be 1.54°C above pre-industrial, which is higher than the above scenarios due to the increased delay in the onset of CO_2 withdrawal.

Scenario 4, 5 and 6

Stabilizing at 400 ppm CO_2e *in 2400, 2500 and 2600 respectively and peaking at 450 ppm* CO_2e *in 2050*

Extraction and sequestration of CO_2 from the atmosphere in the multi-gigatonne per year range is potentially an insuperable challenge in any time. Therefore, three scenarios (4 to 6) were run that have the same initial demands as Scenarios 1 and 2, i.e. peaking at 450 ppm CO_2e in 2050 but stabilizing at 400 ppm CO_2e, in 2400, 2500, and 2600 respectively.

As expected, the year in which the extraction of CO_2 must begin is progressively further out; 2128, 2170 and 2206. The CO_2 withdrawal phases last correspondingly longer—275, 331 and 394 years respectively—and require smaller maximum annual extractions—0.74, 0.61 and 0.53 Gt—while temperatures reach +1.51, 1.55 and 1.58 degrees respectively. These pathways offer more time in which to achieve the technical challenge of effective carbon sequestration from the atmosphere. While apparently small, the higher temperatures incurred by the longer pathways mean greater risk of damage to Earth's biophysical systems.

Recent work done at the University of Victoria and described publicly at a conference in Vancouver on November 14, 2007 by Dr. Andrew Weaver, indicates that global temperature increase depends more on the total mass of carbon released than the emissions pathway or the peak level of atmospheric GHG concentrations. Simply put, in order to restrict global warming to particular limits there is a total budget of carbon emissions that must not be exceeded.

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Figure 1 (on page 15) shows us that Scenarios 1 to 3 (with stabilization dates earlier than the year 2300) all require massive negative emissions, i.e. removal of atmospheric CO_2 in the gigatonne range annually when the sequestration phase begins. Scenarios 4, 5 and 6 (with stabilization in 2400, 2500 and 2600 respectively) have maximum atmospheric GHG withdrawal rates less than 1 Gt/year and are therefore technically more feasible. Therefore, carbon emission budgets in GtC were developed for the period 2005 to 2100 for Scenarios 4, 5 and 6. These are 218 GtC for Scenario 4, 221 GtC for Scenario 5, and 223 GtC for Scenario 6 (see Appendix 2: Carbon Budgets).

As Scenario 6 seems the "easiest" to achieve, and as we at present know of no technology that extracts large amounts of CO_2 from the atmosphere, it was considered prudent to use Scenario 6 as the preferred option. Using the carbon budget for Scenario 6, a constant, annual per cent emission reduction path was calculated to provide illustrative emission targets for 2012, 2016, 2020 and 2050 (Table 2) that stay within the carbon budget for 2100.

Figures 1, 2 and 3 track these modeled scenarios by annual emissions required (Figure 1), accompanying change in atmospheric concentration of GHGs (Figure 2) and the change in global average temperature on the way to stabilization (Figure 3).

Figure 1: Emissions in GtC/yr (=PgC/yr)

Note: In all cases emissions become negative, i.e. to reach the chosen stabilization point, CO_2 will need to be extracted from the atmosphere.

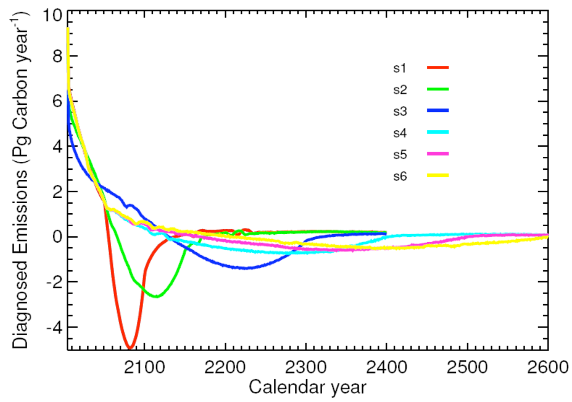


Figure 2: Atmospheric concentration of GHGs in ppm CO_2e

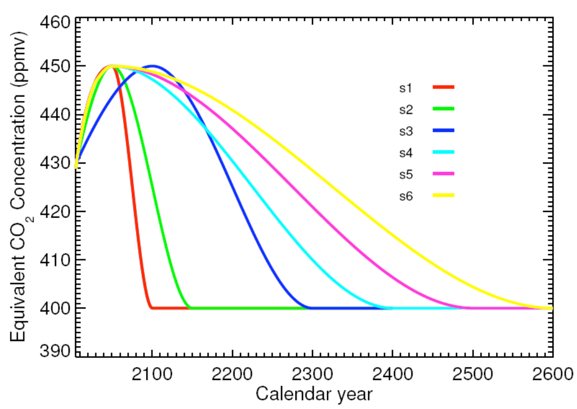
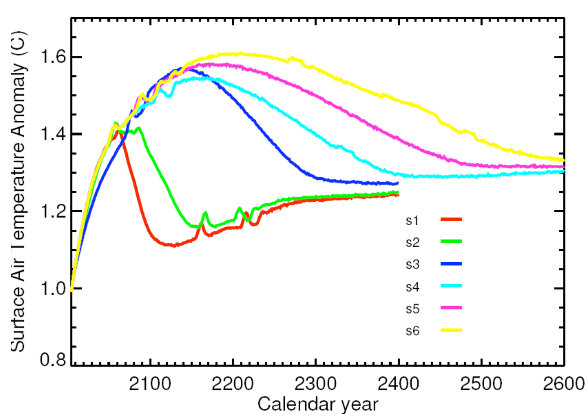


Figure 3: Increase in global average surface temperature, where the pre-industrial value of 13.1°C is set as 0.0, and stabilization occurs at 14.4°C, i.e. +1.3°C above pre-industrial

Note: Highest temperature reached is 1.58°C, in pursuit of Scenario 6.



Observations and Comments

To avoid a 2°C temperature increase, the following must occur.

Globally reduce greenhouse gas emissions by 83 per cent by 2050

All six scenarios have two things in common: first, they call for a very rapid and challenging reduction in the emissions of GHGs from fossil hydrocarbons and from other activities, like forestry, that currently release massive volumes of greenhouse gases into the atmosphere. This step is the one that "stops things from getting worse"—that is, stops the growth in concentration of atmospheric GHGs. Successful action on climate change therefore requires us—the present generation—to embark on a massive GHG emissions reduction effort beginning immediately and extending over the next 90 years. This we must do to give the post-2050 generations any chance of living on an Earth resembling the one we have known. To not make the maximum effort is in all ways inexcusable.

Globally, we must reduce GHG emissions by 83 per cent by 2050 (Table 2), which will require average annual reductions of at least 4.1 per cent over the period. Simply put, we need huge reductions in our use of hydrocarbon fuels, massive efficiency increases in the use of hydrocarbons we continue to consume, the removal and sequestration of the carbon in these fuels and their combustion products, minimization of GHG emissions from forests and soils, a transition to generating power from renewable sources, a significant reduction in the consumption of manufactured products that require hydrocarbon generated energy in their production, and an agriculture decoupled from dependence on fossil hydrocarbons. Even following a path of constant annual percentage reduction in emissions, the levels required for all four interim target years will be tough to achieve (Table 2).

Remove CO_2 from the atmosphere by artificial means

To "make things safe again" we need to reduce the concentration of GHGs in the atmosphere below present levels. The University of Victoria ESC model factors in the capacities of the natural sinks (the oceans and the biosphere), and yet we see in Figure 1 that the emissions pathways required to stabilize the atmosphere at 400 ppm all fall below zero GHG emissions, i.e. they become negative. We refer to "withdrawal" or "extraction" of CO_2 by sequestration rather than to "negative emissions," but they are the same concept. These withdrawal phases are very long, realistically ending at the earliest by 2300, and with 2600 a strong possibility. And this may be optimistic—at present we know of no extraction technology that removes GHGs from the atmosphere at the scale required. And this is quite apart from the unprecedented and centuries-long cooperation that will be required of all humanity.

However, the modeling indicates we can delay the onset of removal of atmospheric carbon until at least 2128 if we reduce global emissions by 83 per cent by 2050. At that time we would have the option of assessing our capacity to extract CO_2 from the atmosphere and deciding on a timeline matching that projected capacity. The concern is that the longer we take to begin significant emissions reductions, the higher the maximum surface air temperature that will be reached. All maximum temperatures modeled are below +2.0°C above pre-industrial temperatures, but the lower the maximum temperature, the lower the risk of triggering positive feedbacks and the less the damage to global and human systems.

To "make things safe again" we need to reduce the concentration of GHGs in the atmosphere below present levels. At present we know of no extraction technology that removes GHGs from the atmosphere at the scale required.

This difficult situation poses a "known possible"—namely big upfront emission reductions over the next half century—against an "unknown possible"—the technology of extraction and sequestration. The easier we make the first step the more difficult we make the second, and, also, the sooner it needs to come online. Technological caution and the need to minimize the risk of planetary disaster morally compel us to expend greater immediate effort in emissions reduction.

Each of the six scenarios stabilizes global average temperature at +1.25°C above the pre-industrial value, and the highest temperature predicted is +1.58°C.

It might be considered tempting to run the model so that the temperature increases approach 2°C warming more closely, in the anticipation that the requirements for emission reduction and subsequent extraction might be less onerous. However, Table 1 reveals a very significant risk of exceeding 2°C warming even with stabilization at 400 ppm CO_2e. We have a lot to do soon, and a lot more thereafter. Future research could easily determine that +1.58°C is itself dangerous, and so recommend an even greater drawdown in atmospheric CO_2. In fact, this discussion has already begun.[27]

A cautionary note on the oceans as carbon sinks

Ultimately, the great regulator of planetary climatic conditions is the world ocean. Its capacity to store heat and CO_2 greatly exceeds that of the atmosphere. But we must not assume that these properties will be our salvation. If we were to continue to produce emissions at the rate the ocean can absorb them, the ensuing changes would put all species with carbonate skeletons, and the food chains they occupy, at great risk of collapse. We ignore at our peril the fact that humanity is now at the top of, and highly dependent on, marine food chains.

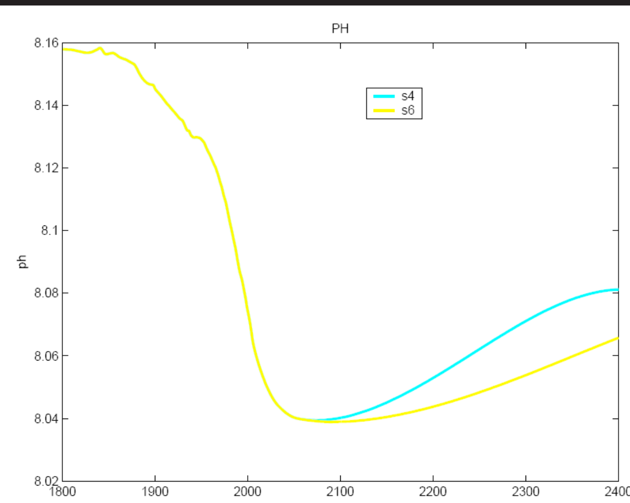
The oceans have not yet absorbed the quantity of CO_2 or heat they are capable of absorbing, and were they to do so there would be a severe risk of losses in both biodiversity and productivity, the former for chemical reasons — loss of access to carbonate for skeleton building, and the latter for physical reasons — thermal stratification preventing water and nutrient turnover. For both reasons the amount of free CO_2 in the atmosphere needs to be rapidly reduced.

When CO_2 dissolves in sea water it increases acidity and competes for the same carbonate ions (CO_3^{2-}) that many organisms require for the construction of their skeletons — including corals, tiny photosynthetic forms at the base of food chains, and other small but vastly abundant "food species" like foraminifera and swimming pteropod molluscs. When carbonate is low (under-saturated), these organisms cannot access it — indeed they begin to lose what they have — their skeletons dissolve back into the sea water.

The German Advisory Council on Global Change (WBGU) has proposed an ocean acidification "guard rail" — a quantitative boundary that precaution determines we should not overstep. This value is defined as a drop of less than 0.2 pH units below the pre-industrial average value of 8.18, twice that already observed since 1800 (present average is 8.07), and twice the known natural range for the past 23 million years. It is designed to prevent the under-saturation of the most soluble form of calcium carbonate (called aragonite) in the ocean's surface layer.[36]

Figure 4: Average surface ocean pH for scenarios 4 and 6

Atmospheric GHGs peaking at 450 ppm CO_2e and stabilizing at 400 ppm CO_2e in 2400 and 2600 respectively



A cautionary note on the oceans as carbon sinks continued

Business as usual scenarios predict under-saturation of highly soluble aragonite in the sub-Arctic, sub-Antarctic and polar surface seas beginning as early as 2050, and becoming extensive by 2100, at which time pH would have dropped 0.23 units if atmospheric CO_2 reached 540 ppm (note *not* equivalent).[37] The University of Victoria ESC model, when run to determine ocean average surface pH for Scenarios 4 and 6 (Figure 4) as defined above, shows both with pH lows at approximately 8.04, i.e. a drop of 0.12 units overall, and within the WGBU threshold of safety.

Any decrease in ocean pH can only be reversed by re-supplying carbonate from seafloor sediments, but this process takes thousands to tens of thousands of years due to the slow rate of circulation of oceanic waters. Because of this limitation, the oceans to date have absorbed only about 30 per cent of the anthropogenic carbon they could absorb over longer time periods at present atmospheric concentrations.[38] Only the reduction of atmospheric CO_2 emissions can slow further acidification of the oceans — and that which has already occurred will, as noted, be present for a very long time. If the emissions constraints of the proposed scenarios (4, 5 or 6) are met, the pH "guardrail" value will not be crossed.

Choose the better option from Scenarios 4 to 6

The upfront reduction in emissions called for is a rugged challenge, and is essentially identical for each scenario. But by achieving the 83 per cent global reduction by 2050, we can set up a possible future where ongoing emissions, at a greatly reduced level, can be sustained until effective sequestration technology is in place. While sooner will always be better, it becomes feasible to allow a century or more to begin the extraction of CO_2 from the atmosphere — but this model tells us this eventually will be necessary.

Constraining ourselves to the allowed total of 223 GtC emissions by the year 2100 requires an average global annual reduction rate of at least 4.1 per cent. If this path were followed, the interim targets for global emission reductions required to achieve stabilization without exceeding a 2°C rise above pre-industrial temperature are as shown in Table 2 (see Appendix 3).

Table 2: Global reduction targets at 4.1% annual emission reduction

2012	15%
2016	28%
2020	39%
2050	83%

The Question of Equity

BC Reductions to Achieve Emissions Equity by 2100 and Avoid Catastrophic Climate Change

Even though BC's emissions per capita are about one third less than Canada as a whole, we are still among the highest per capita emitters of GHGs in the world, and thus share the greatest moral obligation to reduce our emissions. Assuming equal per capita global rights to emit GHGs, British Columbians will have to achieve emission reductions significantly faster than the global average. The designation "contraction and convergence" has been used to describe the strategy that requires high per capita emitters to reduce emissions most quickly so as to achieve convergence of global emissions rates within a reasonable time. This will not be easy for BC, as the following analysis demonstrates.

In 2004, the global average per capita emission of carbon was 1.4 metric tonnes (tC). The average for BC was 4.3 tC, more than three times the global value (Appendix 1). To meet the 83 per cent global reduction target required in 2050, annual global carbon emissions that year must total no more than 1.57 GtC, and with a population estimate of 9.2 billion in 2050,[28] this allows a mere 0.17 tC per person (i.e. 170 kg) per year. For reference, a round-trip jet flight from Vancouver to Toronto releases 200 kg of carbon into the atmosphere for each passenger, which not only exceeds the individual 2050 quota, but because of the high altitude of release causes warming equivalent to 540 kg of carbon.[29] At present BC emits roughly 18.2 million tonnes (MtC) annually.

Assuming BC's population remains at 0.065 per cent of world population, as it was in 2004 (Appendix 1), BC's share of allowable global carbon emissions between now and 2100 would be in that same proportion, which is 144 Mt of the 223 Gt total. The rate of emissions can be varied over time, so long as the total is not exceeded. The constant annual average percentage reduction in GHG emissions required if BC is to stay within its "equitable" carbon budget is 12.6 per cent between 2008 and 2100. If this constant reduction path is followed the interim targets would be as shown in Table 3 (Appendix 3).

Such targets, based on global equity over the next 92 years, are likely unrealistic. It is not our purpose to recommend any particular path, but rather to show what must be accomplished by whatever path is decided upon. These numbers reveal very clearly two essential points: our emissions must be greatly reduced by 2100, and they must average at least 12.6 per cent per year over that period.

It should be noted that it is not necessary to assume a constant rate of reduction as we have done here—the drawdown can be staged in other ways—but the absolute reductions will continue to be high percentages of the remaining stock.

If, for instance, there exists a large amount of low hanging fruit—easily realizable reductions with existing easy-to-implement technology—short term emission reductions might be significantly higher than in the simple mathematical path we have identified. If this were the case and high short term reductions are achieved, the path for the remainder of the period would become easier.

If, like global warming itself, GHG reductions have positive feedback loops, such that some key actions facilitate a range of other actions resulting in emission reductions, those reductions may grow considerably larger over time. Some areas to consider in this regard would be early commitments to urban redesign that facilitate much greater transportation efficiency, building efficiency and such things as neighbourhood heating.

Even though BC's emissions per capita are about one third less than Canada as a whole, we are still among the highest per capita emitters of GHGs in the world, and thus share the greatest moral obligation to reduce our emissions. Assuming equal per capita global rights to emit GHGs, British Columbians will have to achieve emission reductions significantly faster than the global average.

Table 3: BC reduction targets at 12.6% annual emission reduction

Year	Target
2012	41.8%
2016	66.1%
2020	80.3%
2050	99.7%

Other fields that hold promise of beneficial positive feedbacks are transportation and food system redesigns. The UN Food and Agriculture Organization published a report in 2007 that concluded that red meat and poultry production alone was responsible for 18 per cent of our global GHG emissions.[30] The food system is clearly capable of enormous increases in efficiency.

> The respective paths we identify—4.1 per cent globally and 12.6 per cent in BC—are simply illustrative of the scale, difficulty and urgency of what must be done. Many paths are possible; successful ones must begin immediately.

Also, the task could be made considerably easier if a viable technology were developed that enables the large-scale removal of GHGs from the atmosphere.

The point is that the respective paths we identify—4.1 per cent globally and 12.6 per cent in BC—are simply illustrative of the scale, difficulty and urgency of what must be done. Many paths are possible; successful ones must begin immediately.

It should also be noted that the difficulty of meeting such targets may prompt us to think again about what equity might mean. It could have less to do with numerical equality in emissions and more to do with what services we provide the world in meeting its global goals. It is important to note the United Nations has begun this discussion.[31]

Table 4: Interim emission targets

Based on Scenario 6 carbon budget convergence to 2100 for the global community and BC, and for the 2050 annual emission convergence strategy

	Annual carbon emissions		% reduction below 2008 carbon budget convergence		% reduction below 2008 emission convergence and BC policy	
Year	Global (GtC)	BC (MtC)	Global	BC	BC 2050 convergence	BC policy
2008	9.2600	18.2				
2012	7.8	10.6	15.3	41.8	23.9	
2016	6.6	6.17	28.3	66.1	42.1	
2020	5.6	3.59	39.3	80.3	55.9	33.0
2050	1.6	.062	82.6	99.7	94.3	80.0
2008–2100 (%/yr)			4.1%	12.6%		

One alternative approach to equity[32]

Our analysis, so far, has focused on reaching equity in 2100 based on identifying a 92 year global carbon budget and then calculating a BC budget for the same period based on BC's population as a proportion of the projected 2100 global population. We refer to this as the 2100 carbon budget convergence, the fairest form of global equity with regards to emissions reductions. However, as shown above, the BC targets are very stringent and possibly unrealistic.

One alternative, out of many, would be to achieve per capita equity of emissions at some point during the 92 year period to 2100. We have chosen to look at BC's *annual* per capita emissions reaching parity with the global average in the year 2050 based on the global path we have identified above. We refer to this as the 2050 annual emissions convergence (see Table 4).

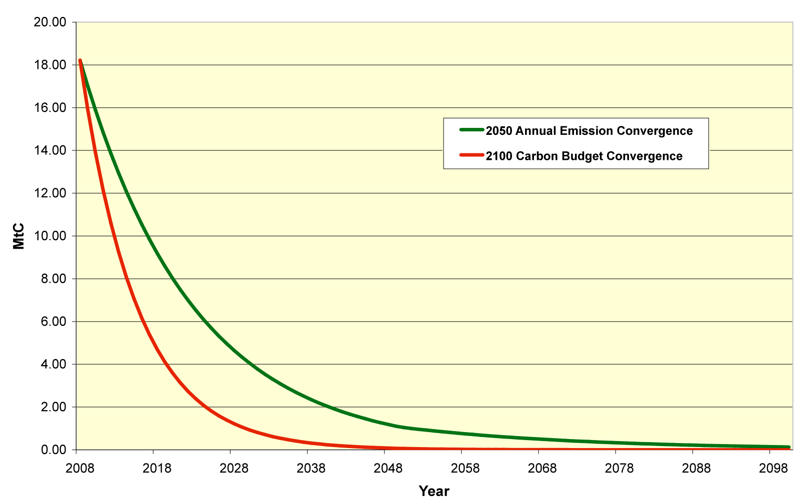
In 2050 the global emissions target is 1.61 GtC, and BC's share of that, at .065 per cent based on BC's share of global population, is about 1.04 MtC (Appendix 5). This can be achieved with annual emission reductions of 6.6 per cent. From 2050 to 2100 emissions reductions are a constant 4.1 per cent per year, having converged on the global reduction rate.

As both the 6.6 per cent and 4.1 per cent reductions rates are significantly lower than the 12.6 per cent required to achieve a 92 year carbon budget equity, there is an emissions price to pay. BC's total emissions over the 92 years would jump from the strict equity requirement of 144 MtC to 264.5 MtC, an increase of 120.5 MtC or 84 per cent.

If BC were to exceed its carbon budget by such a large amount, others would have to reduce their budgets to make up the difference, because, as we have indicated, exceeding the global carbon budget is far too risky. And if BC were to find its carbon budget equity targets too tough, so too would much of the industrialized world, particularly the excessively high per capita emitters like the rest of Canada, the US and Australia.

The annual emissions of the two BC scenarios are shown in Figure 5 (Appendix 11).

Figure 5: Two approaches to equity—carbon budget convergence in 2100 and annual emissions convergence in 2050



As Table 5 indicates, the 2050 annual emissions scenario targets, particularly through 2020, are considerably less difficult than those in the 2100 carbon budget equity scenario. However, we note that they also mean BC's current legislated targets for 2020 and 2050 are too low, by a significant margin, compared with either of the above scenarios.

Of course, the annual emissions convergence scenario is not equitable at all, unless some acceptable transfer is identified from BC to poor nations that currently produce less than their fair share of global emissions. If BC follows our 2050 annual emissions convergence scenario, low emitting countries would have to reduce or preserve their emissions to compensate for our increase. This transfer might, for example, be in the form of technology that reduces emissions elsewhere by 121 MtC by 2100.

If BC were to find its carbon budget equity targets too tough, so too would much of the industrialized world, particularly the excessively high per capita emitters like the rest of Canada, the US and Australia.

If the cost of the transfer were to take the form of carbon offsets the costs can be calculated. At $100 per tonne of CO_2 the average cost (to 2050) to the BC Treasury would be $1.5 billion per year, an amount equivalent to one half of one per cent of BC's 2008 GDP (Appendix 5).

This scenario is only equitable if a global framework of offsets, agreed to by the low emitting countries, was implemented—allowing us to exceed our fair share of emissions—and if the transfer actually results in a reduction in global emissions of 121 MtC by 2100.

Table 5: BC targets

Year	2100 carbon budget convergence	2050 annual emissions convergence
	(per cent)	
2012	41.8	23.9
2016	66.1	42.1
2020	80.3	55.9
2050	99.7	94.3

The Challenge of Growth

In attempting to meet the emission targets we know to be necessary the additional difficulties imposed by ongoing economic and population growth need to be faced. At present (2005 figures), one gram of GHG (CO_2e) "generates" $0.005 of global GDP. If we are to achieve an 83 per cent global reduction in GHG emissions by 2050, each gram of GHG will have to generate $0.028 of GDP, an improvement factor of almost six—assuming no economic growth. However, if we were to assume 3 per cent per year growth in GDP until 2050, each gram of GHG would be required to generate $0.108—almost 11 cents—which is 22 times (2,200 per cent) more than it does currently.

The same calculation based on data for BC, where global convergence calls for a 99.7 per cent reduction in emissions, would see one gram of GHG generating $0.002 (2004 figure) being required to generate $0.263 of GDP under the 3 per cent growth scenario. This is an improvement factor of 126 times.

Clearly, the size of the global population is a crucial factor. A large global population requires larger economies than smaller populations to provide the same per capita level of goods and services. If global population were to exceed the 9.2 billion projected for 2050, the emissions reduction task becomes tougher than we have suggested because the biophysical reality of what constitutes dangerous concentrations of greenhouse gases does not change, so as population increases the per capita allowance for "safe" GHG emissions becomes smaller.

Conversely, of course, if global population decreases, the per capita GHG emission allowance increases. It is non controversial to state that a reduction in global population will ease the problem of emission reductions so long as GHG emissions from economic growth do not overwhelm them. Simply put, a global population of 4.6 billion would have a per capita emissions allowance twice that of the projected 9.2 billion.

These numbers further highlight the need to:

- Implement massive improvements in energy efficiency;
- Move very quickly to non-GHG-emitting sources of energy;
- Consider stable state economic models;
- Carefully consider global population control;
- Carefully evaluate the distribution of the costs and benefits of emission reduction initiatives;
- Carefully evaluate the social justice implications of the path to a carbon free economy; and
- Ensure that the path taken does not create ecological unsustainability in other areas, such as the use of water, or ecosystem or soil health.

While BC's stated intention to reduce GHG emissions 33 per cent below 2007 levels by 2020 is a very good start, it is considerably less than required in either of our scenarios. Limiting reductions to 33 per cent by 2020 will require increasing the rate of reductions very considerably thereafter. The interim targets are high and very challenging, but are constrained by world population and the year 2100 global carbon budget, which is in turn constrained by the overall goal—the possibility of returning the atmosphere to a composition where the probability of global average temperature exceeding 2°C is kept within "acceptable" limits. The latter step, as noted above, will require artificial removal of greenhouse gases from the atmosphere (above and beyond the reductions in emissions) beginning early next century or sooner.

> The scale of emission reductions will require us to quickly redesign our urban centres, transportation systems, food systems and environmental and resource policies. For workers, despite the immense shifts implied, the good news, aside from leaving a livable planet for our next generations, is that the first three measures mean abundant jobs.

In BC, as in other industrialized nations, the scale of emission reductions will require us to quickly redesign our urban centres, transportation systems, food systems and environmental and resource policies. For workers, despite the immense shifts implied, the good news, aside from leaving a livable planet for our next generations, is that the first three measures mean abundant jobs. So abundant, in fact, the challenge is likely to be finding workers to fill the jobs. For example, retrofitting the building stock and sewage and water systems, developing new energy systems, building new transportation systems, and the development of local/regional food systems will require large numbers of workers for several decades.

It will be a major task to ensure just transitions so that workers and their communities do not bear an unfair share of the costs of these changes and to ensure that everybody gets a fair share of the benefits—of which, if the change is properly managed, there will be many. A just effort for BC in the global context is likely to engage our industrial and organizational capacities in the service of the larger global challenge.

Conclusion

It is sobering to discover that the work of this generation is to provide future generations a situation from which recovery to a stable climate regime is still possible. The pathway to an atmosphere that is both stable in composition and unlikely to foster an unsustainable temperature increase requires a retreat from the present situation—for we have already overshot, by a considerable margin, the safe limits of atmospheric greenhouse gas concentrations.

Because of this overshoot, the analysis indicates that dramatically reduced emissions alone will be insufficient to achieve an equilibrium temperature less than 2°C above pre-industrial levels. Even in the unlikely event that natural sinks were capable of reducing GHG concentrations to 400 ppm or less, it would take so long that unacceptable levels of ocean acidification would occur.

Other recent studies[33] present conclusions comparable to those reached here. Namely, that global reductions of 80+ per cent, and western country reductions of 90+ per cent in carbon emission are needed by 2050. However, and of high importance, in each case they have assumed that reducing emissions to well below the capacity of natural sinks, primarily the ocean sinks, will allow an eventual drawdown of atmospheric CO_2 to safe levels. The model used here accounts for the capacity of carbon sinks, and predicts that GHGs, primarily CO_2, will have to be removed from the atmosphere by artificial means. Thus, a major sequestration challenge lies in humanity's near-term future.[34] Sequestration has come to be associated with the capture of CO_2 before it is emitted to the atmosphere, and diverting it to subterranean repositories. We employ it in its plain English meaning of removing or withdrawing; in this case withdrawing GHGs already in the atmosphere.

The model runs described here indicate that removing sufficient CO_2 from the atmosphere will likely require between two and six centuries. Achieving this will be daunting. We first must dramatically reduce GHG emissions such that global concentrations stabilize at 400 ppm CO_2e. As we are currently at more than 430 ppm CO_2e and increasing that number by 2 to 3 ppm per year, we clearly have not yet begun the process of actual GHG emission reductions, and this is as true locally as it is globally.[35] While the ongoing emission growth figures tell a grim enough story, an even grimmer future awaits if governments follow through on policy decisions to continue the extraction and use of fossil carbon resources and to build new freeways and bridges and airports to encourage their use.

We believe this analysis raises very important questions for British Columbians to consider as we design our response to climate change:

- First, we must decide—are we concerned about global equity in access to energy?
- If so, what is the appropriate time frame for achieving such equity?
- What is the best way in which to achieve equity? Is it equal emissions for every individual, or is it a contribution to the strategy of global success?
- How do we reduce our emissions in a way that is equitable among British Columbians?

Notes and References

1 This paper follows the protocols of the Stern Review (2007, Figure 1.1) where the total warming effect (positive radiative forcings) of greenhouse gases is quoted in CO_2 equivalents of the six Kyoto "long-lived" greenhouse gases: carbon dioxide (CO_2), methane (CH4), nitrous oxide (N20), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF6). This value is approximately 50 ppm higher than CO_2 alone, so working with 2005 figures, when CO_2 was 379 ppm, CO_2e is thus approximately 430 ppm. Other models and researchers use the sum of all forcings, positive and negative, therefore including the large cooling effects of sulfate aerosols and tropospheric ozone. In this case CO_2e (total) = ~375 ppm, the latter being coincidentally close to the forcing of CO_2 considered alone (IPCC WG1, 2007, Figure 22.1 and Table 2.12). Note that this value is used in projecting the probability of future temperatures, and the necessary adjustments are noted in the text. The logic of using CO_2e (Kyoto) is that all the other radiative forcing agents have much shorter timescales of residence in the atmosphere and will substantially decrease over the timescale of stabilization—particularly the aerosol cooling agents, some of which would be cleared from the atmosphere in days or weeks if their production ceased.

2 Meinshausen, M., 2005, *On the risk of overshooting 2 degrees Celsius*, accessed at www.stabilisation2005.com/14_Malte_Meinshausen.pdf.

3 Hansen, J. et al., 2008, *Target Atmospheric* CO_2*: Where should Humanity Aim?,* accessed at http://arxiv.org/ftp/arxiv/papers/0804/0804.1126.pdf.

4 Bailie, A. et al., 2007, *Mind the Gap: A Blueprint for Climate Action in British Columbia*, full report, Pembina Institute, p. 2, accessed at http://pubs.pembina.org/reports/mindthegap-full.pdf. Note that in this paper we measure emissions as tonnes of carbon, whereas other publications refer to tonnes of carbon dioxide. One tonne of carbon is equivalent to 3.67 tonnes of carbon dioxide.

5 Stern, N., 2007, *The Economics of Climate Change—The Stern Review*, Cambridge University Press, Chapter 3 and Table 2.1.

6 United Nations Development Programme, 2007, *Human Development Report 2007-2008: Fighting Climate Change: Human Solidarity in a Divided World*, accessed at http://hdr.undp.org/en/reports/global/hdr2007-2008/.

7 Intergovernmental Panel on Climate Change, 2007, *Summary for Policymakers of the Synthesis Report of the IPCC Fourth Assessment Report*, p. 1.

8 Ibid., Figures SPM 3 and Figure SPM 1.

9 Stern, supra note 6, Chapter 4.

10 British Columbia Speech from the Throne, February 13, 2007, accessed at www.leg.bc.ca/38th3rd/4-8-38-3.htm.

11 Premier's speech to the Union of BC Municipalities, September 28, 2007, accessed at http://ubcm.ihostez.com/content/pdfstorage/B212E07021A74D67A44174416A370F0C-Premier_Campbell.pdf.

12 *Greenhouse Gas Reduction Targets Act*, accessed at http://leg.bc.ca/38th3rd/1st_read/gov44-1.htm.

13 BC Premier's Office news release, November 20, 2007, *Province Announces Climate Action Team*, accessed at www2.news.gov.bc.ca/news_releases_2005-2009/2007OTP0180-001488.htm.

14 Flannery, T., 2005, *The Weather Makers: The history and future impact of climate change*, Text Publishing, Melbourne.

15 Hansen, supra note 4.

16 Intergovernmental Panel on Climate Change, 2007, *Climate Change 2007: Climate Change Impacts, Adaptation and Vulnerability. Working Group II Contribution to the IPCC Fourth Assessment Report, Summary for Policymakers*, p. 15.

17 Stern, supra note 6, Table 2.1, p. 57.

18 Overpeck, J. et al., 2006, "Paleoclimatic evidence for future ice-sheet instability and rapid sea level rise" *Science* 311: 1747-1750.

19 Baer, P. and M. Mastrandrea, November 2006, *High Stakes—Designing emissions pathways to reduce the risk of dangerous climate change*, Institute for Public Policy Research.

20 Steffen, W., 2006, *Stronger Evidence but New Challenges: Climate Change Science 2001–2005*, Australian Greenhouse Office.

21 Ward, Peter D., 2007, *Under a Green Sky: Global Warming, the Mass Extinctions of the Past, and What They Can Tell Us About Our Future*, Harper Collins/Smithsonian Books.

22 Lynas, M., 2007, *Six Degrees: Our Future on a Hotter Planet*, Fourth Estate, London.

23 Meinshausen, supra note 3.

24 Meinshausen, M., 2006, "What does a 2°C target mean for greenhouse gas concentrations?" pp. 265–280 in *Avoiding Dangerous Climate Change*, Schellnhuber et al. (eds.) Cambridge University Press. In the source data, ppm CO_2e is quoted as ppm CO_2e (Total), i.e. including all positive and negative forcings. The value in the left column has been raised by 50 ppm from the source to be consistent with ppm CO_2e (Kyoto) as used in this paper. Only for stabilization levels well below 400 ppm CO_2e are the probabilities of exceeding 2°C low enough to be even marginally reassuring.

25 This model works with a horizontal resolution (cell size) of 1.8° x 3.6° (approximately 110 x 396 km at the equator). The model integrates atmospheric energy and moisture and is coupled to a comprehensive ocean circulation model with 19 vertical levels and a sea-ice component. The terrestrial carbon model includes both land surface and vegetation components. Ocean inorganic carbon is accounted for, and ocean biology is simulated by an ecosystem model of nitrogen cycling. The model has participated in a number of model inter-comparison projects and was used as an assessment tool in the Intergovernmental Panel on Climate Change 4th assessment report. Its computational efficiency allows sensitivity experiments that would be more difficult to perform in coupled atmosphere-ocean general

circulation models. The climate sensitivity of the University of Victoria model is 3.5°C and it does not include carbon cycle feedbacks.

26 To convert gigatonnes of carbon (GtC) to gigatonnes of CO_2, multiply by 3.67 (Appendix 1).

27 Spratt, D. and P. Sutton, February 2008, *Climate Code Red: The case for a sustainability emergency*, Friends of the Earth (Australia).

28 United Nations Population Division, accessed in 2008, *World Population Prospects: The 2006 Revision Population Database*, accessed at http://esa.un.org/unpp/. However, it should be noted that these projections do not consider the implications of climate change on world population. As recent concerns about food prices indicate, plus the likelihood of increased drought, flooding and extreme weather events, climate change itself may put limits on population growth.

29 Emissions data from climatefriendly.com, accessed in 2008 at www.climatefriendly.com/offset-air.php.

30 Livestock, Environment and Development Initiative, 2006, *Livestock's long shadow: Environmental issues and options*, accessed at www.virtualcentre.org/en/library/key_pub/longshad/A0701E00.htm.

31 United Nations Development Programme, supra note 1.

32 The authors thank Marc Lee of the CCPA–BC Office for suggesting this scenario.

33 Bramley, M., 2005, *The Case for Deep Reductions: Canada's Role in Preventing Dangerous Climate Change*, David Suzuki Foundation and the Pembina Institute; Friends of the Earth Australia, January 2007, *Avoiding Catastrophe: Recent science and new data on global warming Emissions scenarios to avoid catastrophic climate change*, Carbon Equity Project.

34 Weaver, A. J. et al., October 2007, "Long term climate implications of 2050 emission reduction targets" in *Geophysical Research Letters*, Vol. 34.

35 Intergovernmental Panel on Climate Change, 2007, *Climate Change 2007: The Physical Science Basis*, Working Group I, pp. 2–3.

36 German Advisory Council on Global Change (WBGU), 2006, *The Future Oceans—Warming Up, Rising High, Turning Sour*, accessed at www.wbgu.de/wbgu_sn2006_en.pdf.

37 Caldeira, K. and M. E. Wickett, 2005, "Ocean model predictions of chemistry changes from carbon dioxide emissions to the atmosphere and ocean" in *J. Geophys. Res., 110*, C09S04, doi:10.1029/2004JC002671.

38 German Advisory Council on Global Change, supra note 36, p. 67.

Appendices: Base Data and Targets

The following data and figures can be accessed in an Excel file at www.policyalternatives.ca/documents/BC_Office_Pubs/bc_2008/ccpa_ghg_emissions_appendices.xls.

Appendix 1: Base Data—Emissions and Population

- Global, BC and Canadian emissions for 1990 and 2004 in megatonne and gigatonne CO_2 equivalents, and gigatonne carbon equivalents
- Canada and BC 2004 emissions as a percentage of global emissions
- Global, Canadian and BC populations in 1990 and 2004
- Emissions per capita, global, Canada and BC for 1990 and 2004

Appendix 2: Carbon Budgets

- Carbon budgets from Scenarios 4, 5 and 6
- Global in GtC; BC in MtC

Appendix 3: Emission Reduction Targets

- Percent reduction targets below 2004 levels for the years 2012, 2016, 2020 and 2050 for world and BC
- Constant rate emission reduction from 2004 levels expressed as constant per cent per year

Appendix 4: Scenario Comparisons

- For scenarios 1 to 6, the maximum and minimum:
- Temperatures in degrees Celsius above the pre-industrial average (13.1°C)
- Parts per million by volume of CO_2 equivalent greenhouse gases
- Emissions of CO_2e in gigatonnes of carbon per year (GtC per year)

Appendix 5: 2100 Carbon Budgets and Annual Emission Reductions

- For the world and BC for Scenarios 4, 5 and 6
- Total annual emissions in gigatonnes carbon equivalent (GtCe)
- BC emissions each year in megatonnes of carbon (MtC per year)
- The annual change, as a percentage, from 2008 (assume reductions begin in 2008; use data from 2004 levels)

Appendix 6: Model data—Annual Emissions in GtC

Appendix 7: Model data—Annual ppm CO_2 and CO_2e

Appendix 8: Model data—Annual Temperature in Degrees C

Appendix 9: Model Results Summary

- Tabulated model run results for Scenarios 1 to 6

Appendix 10: Emissions Pathways

- Graph of global and BC constant annual per cent emissions reductions pathways to 2050 for 2100 carbon budget

Appendix 11: Annual Emission Paths

- Graph of annual emission paths of BC 2100 carbon budget equity versus BC 2050 annual emissions equity scenarios

Appendix 12: Calculation Tables

- Table 1: Summary of calculations for the change in $GDP per gram of GHG emissions with no GDP growth and with 3 per cent GDP growth to 2050

- Table 2: Detailed calculations summarized in Table 1

Canadian Centre for Policy Alternatives

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CCPA
CANADIAN CENTRE
for POLICY ALTERNATIVES
BC Office

Established in 1997, the CCPA's BC Office offers policy research and commentary on a wide range of provincial issues, such as: BC finances, taxation and spending; poverty and welfare policy; BC's resource economy; privatization and P3s; public education financing; health care; and more.

Climate Justice Project

The Climate Justice Project is a multi-year initiative led by the CCPA and the University of British Columbia in collaboration with a large team of academics and community groups from across BC. The project connects the two great "inconvenient truths" of our time: climate change and rising inequality. Its overarching aim is to develop a concrete policy strategy that would see BC meet its targets for reducing greenhouse gas emissions, while simultaneously ensuring that inequality is reduced, and that societal and industrial transitions are just and equitable.

Sierra Club of BC

www.sierraclub.bc.ca

The Sierra Club BC has worked since 1969 to protect and promote the responsible use of the forest, land and marine resources of BC. As one of BC's best known and effective voices for the environment, the Sierra Club has found success by advocating for science-based policy, supporting grassroots initiatives and inspiring passionate commitment to the values of environmental stewardship. Since 2004 the Sierra Club has recognized climate change and ecosystem resilience as its key conservation priorities.

BC Government and Service Employees' Union

www.bcgeu.ca

BCGEU represents almost 70,000 workers in the public service, broader public service, and the private sector, including scientific and technical staffin the B.C. environment ministry who monitor greenhouse gas emissions.

BCGEU is taking action to reduce our union's carbon footprint. And through our Cool Communities Campaign, we are working to create opportunities for our members to be part of the solution to the threat posed by global warming.

CAW TCA CANADA