A 350 ppm Emergency Pathway

A Greenhouse Development Rights brief

Paul Baer and Tom Athanasiou (EcoEquity), Sivan Kartha (Stockholm Environment Institute)
(Revised as of November 23, 2009)

The first phase of the 350 campaign has been a wild success. ”350” is now an international symbol of emergency climate stabilization. More importantly, the 350 target reflects a scientifically-grounded assessment of what global climate protection really means. But what would it actually take to bring the atmospheric carbon-dioxide (CO_2) concentration back to 350 parts per million? This memo provides a quick, up-to-date overview of the issues here, which are significant to any plausible emergency emissions-reduction effort. It focuses on the extremely limited size of the global CO_2 budget that would remain to us in a 350 ppm future, and on the shape of the emissions pathway that's needed if we're to keep within that budget. In particular, it specifies a representative emissions pathway consistent with a 350 ppm *concentration* target. By way of context, it then compares this 350 pathway to an emission pathway consistent with a 2°C *temperature* target, and to other, supposedly 2°C-compliant pathways that have significantly lower odds of actually satisfying their target. Finally, it offers a brief glimpse of the challenges that all true emergency climate-reduction targets raise in this North / South divided world.

The scale of the 350 challenge

The atmospheric CO_2 concentration is now about 389 ppm. Average out seasonal variations, look just a bit ahead, and call it 390 ppm and rising fast. With current concentrations already so high above the 350 target, some observers are inevitably proclaiming 350 to be impossible[1], especially given the political context of fraught and faltering global negotiations. Given these realities, “350” is a call to a new politics – a scientifically well-grounded politics that can draw upon our ever clearer understanding of what it would it actually take to bring concentrations back to 350 ppm.

Jim Hansen and his colleagues have taken important steps toward establishing this understanding, by way of a number of studies[2] designed to motivate a 350 target and explore its emission implications. Here, we've built on their principal 350 emissions pathway, updating it to capture the modest (and no doubt temporary) 2007-2009 downturn in global emissions caused by the recent financial crisis, and adapting it to yield essentially the same outcome in terms of projected atmospheric CO_2 concentrations. The result, shown in Figure 1 below, is our representative 350 emissions pathway – an extremely stringent pathway that has emissions dropping to zero by 2050, and returns atmospheric CO_2 concentrations to 350 ppm by approximately 2100. For comparison, we also show the International Energy Agency's latest (2009) business-as-usual projection, one in which 2030 emissions are eight times higher than they would need to be in the 350 pathway.[3]

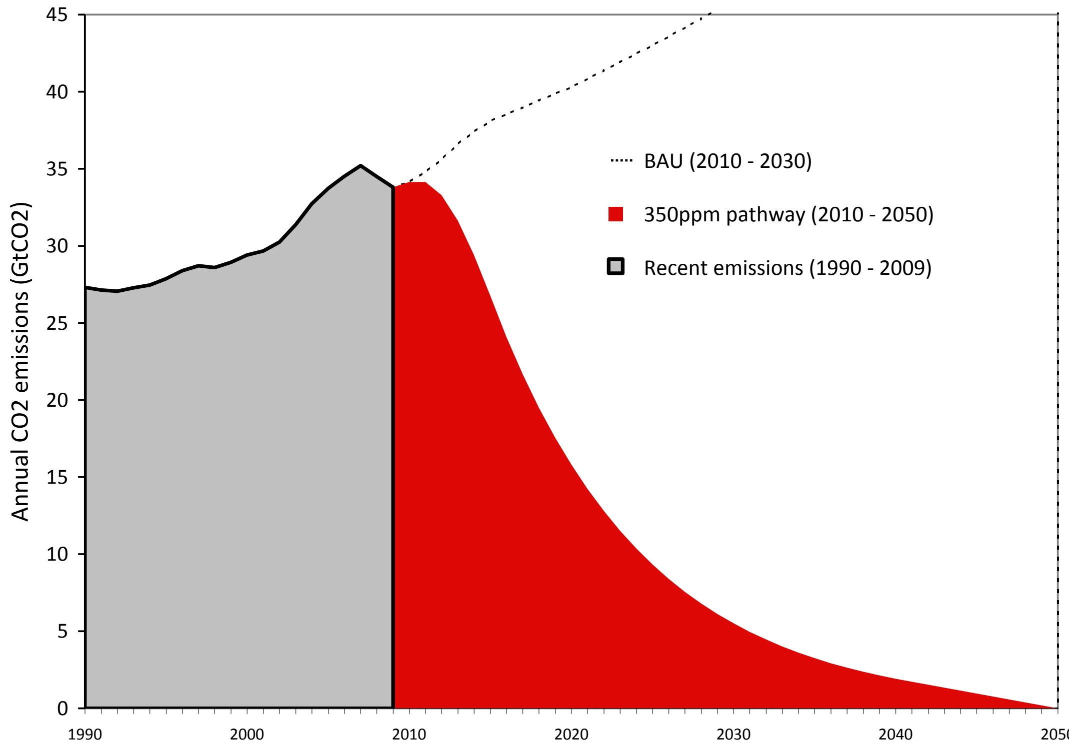


Figure 1 shows recent emissions (the 1990 – 2009 gray area), our representative 350 emissions pathway (the 2010 – 2050 red area) and, for comparison, a business-as-usual pathway (the dotted black line) that's consistent with the International Energy Agency's standard "reference case" (no new climate policy) projections.

Separately, in *Nature* in April of 2009, a team led by Malte Meinshausen published an extremely relevant milestone analysis on various global pathways and their temperature implications.[4] This analysis focused on the relationship between cumulative CO_2 emissions budgets and the odds of staying below 2°C of warming, and thus had the important side effect of establishing cumulative budgets (in this case over the 2000-2050 period) as the best predictors of success for any given global emissions pathway. With it, we finally had an internationally recognized method for assessing the likelihood that a given pathway could meet a given target, whether a temperature target like 2°C, or (though this wasn't done in the *Nature* paper) a concentration target like 350 ppm.

The most salient outcomes of such assessments are, briefly, that a 2°C target would be extremely difficult to meet, a 350 ppm target would be even more challenging, and that, despite all difficulty, neither is physically out of reach. More particularly, Meinshausen and his colleagues conclude that we can preserve a reasonable probability (about 75%) of keeping warming below 2°C, provided that cumulative CO_2 emissions between 2000 and 2050 are kept below 1000 gigatonnes of CO_2 and comparable reductions are made in non-CO_2 greenhouse gases. By comparison, they also report that Hansen's central case for a 350 ppm CO_2 budget (which we used as the basis of our 350 pathway) provides for cumulative emissions of about 750 gigatonnes between 2000 and 2050.

The difference between these two budgets, 250 gigatonnes CO_2, might easily appear less important than it actually is. Obviously, it makes up a significant portion of the cumulative (2000 - 2050) 1000 gigatonne budget for the 2°C pathway. But even more to the point, 250 gigatonnes CO_2 is an *extremely* significant fraction of the *total remaining* 2°C emissions budget, which (since about 330 gigatonnes of this 1000 gigatonne budget was already consumed between 2000 and 2009) is only 670 gigatonnes. In other words, during this past decade, we've consumed nearly one-third of the 2°C budget (330 out of 1000 gigatonnes CO_2) that was available at the turn of the century. And if we think instead of 350 ppm, we've consumed nearly *half* of the budget (330 out of 750 gigatonnes CO_2) that we had left in 2000.

Figure 2 shows the portion of the global carbon budget consumed between 2000-2009 (the grey area), the portion that remains to be emitted during the 2010-2050 period, relative to a 350 target (the red area), and the additional budget that would be available during this same 2010-2050 period if we accept the more risky goal of 2°C (the white area beneath the thin red line). And, for comparison, it also shows a representative "G8 style" emissions pathway, which returns to 50% below 1990 levels in 2050. This pathway, based on the proposal put forward by the G8 governments, and since repeated by numerous heads of state, is often presented as being consistent with a 2°C target[5], though it is not. It is (unsurprisingly) much less stringent than either the 350 ppm pathway or the actual 2°C pathway. It peaks after 2020, sees emissions halving (relative to 1990 levels) by mid-century, and consumes, during the 2010-2050 period, a total of 1170 gigatonnes CO_2 – nearly three times the emissions that are permissible under the 350 pathway.

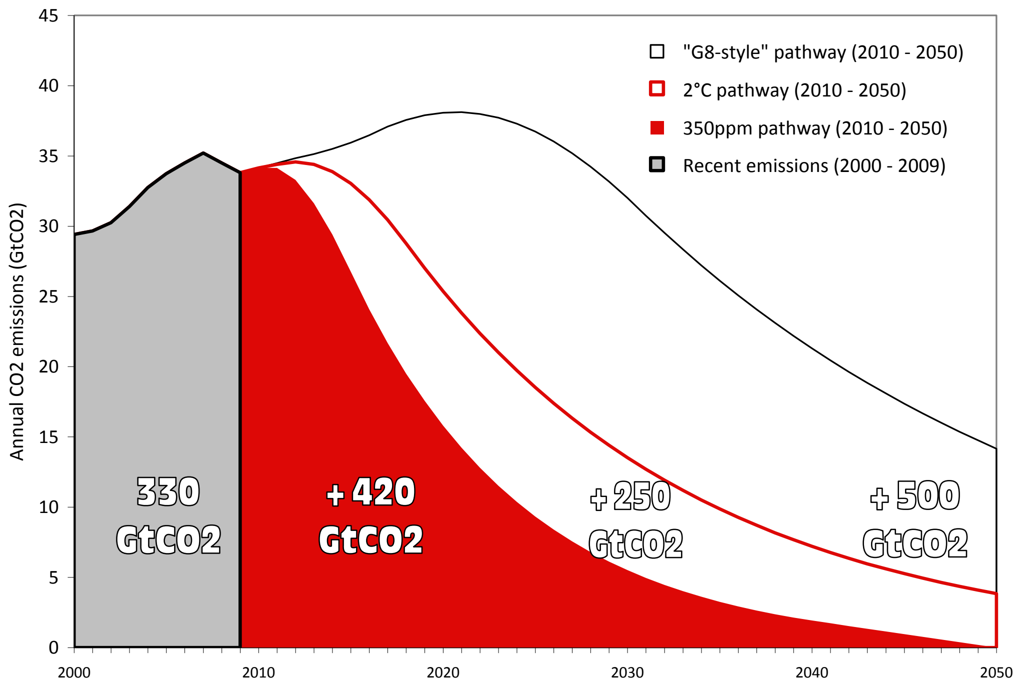


Figure 2 shows the century's emissions to date (the grey area), the 350 pathway (the top of the red area), a 2°C pathway consistent a 75% chance of keeping warming below 2°C (the thin red line), and a "G8 style" pathway consistent with the proposal of the G8 nations to halve global emissions by 2050 (the thin black line). It also shows (the big numbers) the number of gigatonnes of CO_2 that each step in this sequence of ever less adequate targets would add to total cumulative emissions.

Also note that the recent recession, visible above as a minor emissions dip around 2007-2009, is anticipated by the International Energy Agency to have only a very small impact on the rate at which the remaining budget is consumed .[6] This fact – that so serious a crisis could have so marginal an impact on global emissions – is an extremely important warning, for it clearly implies that the deep emissions cuts we need will not come by way of any modest curtailment of economic activity. But neither can they come by way of a massive decline in economic activity, not while the world's poor and aspiring majorities are still counting on rapid economic growth to lift them out of poverty and, indeed, to deliver them lives of prosperity and dignity. Rather, the radical emission cuts we need can only come by way of a wholesale economic transformation – a fair, global effort that not only accommodates but actually prioritizes the aspirations of the poor and the disenfranchised – and can only correspond to a societal mobilization with few if any peacetime precedents.

Details of the 350 ppm and 2°C pathways

The most important features of these two emergency pathways – both 350 ppm and 2°C – are their highly constrained cumulative emission budgets. Given budgets so constrained, there is not a lot of flexibility. For both pathways, keeping within budget means that a sustainable emissions peak has to come very soon. In the 350 ppm case, if emissions peak by 2011 (as in our representative pathway), then keeping within budget means subsequent emissions have to drop extremely rapidly, soon reaching an annual rate of decline of 10% per year and remaining at this rate for several decades.

Does this rate of decline sound unrealistic? Then consider that, if the 350 pathway is defined to have a global peak that's a mere four years later – if emissions continue to rise until 2015 – then the subsequent decline would have to reach a nearly unimaginable rate of 20% per year. If, that is, we're still to keep within the 2010 – 2050 budget of 420 gigatonnes CO_2. And that, if the peak is further delayed beyond 2020, this entire remaining global carbon budget will be gone – and any even remotely plausible chance of returning to 350 ppm will be gone with it.

Clearly, at this late date, the 350 ppm and 2°C targets would both demand extraordinary efforts. In fact, the climate crisis is now so pressing that all adequately ambitious responses are easily dismissed as being outside the bounds of so-called "political realism." Yet, at the same time, the *failure* to mount an adequately ambitious response – one scaled to the actual threat – would force us to endure irreversible harms, and accept catastrophic risks, and suffer a future in which continued prosperity itself comes to be outside the bounds of realism.

Our approach, in this brief, is to place aside political realism in favor of greenhouse realism, and to imagine that humanity has reached a consensus to act, in time and on the necessary scale. Even having done so, it is clear that the longer the transition is delayed, the less feasible it becomes. Accordingly, our representative 350 pathway is defined to peak in 2011, and our representative 2°C pathway to peak only two years later, in 2013. The new future is one that begins soon. In particular, it doesn't allow for a business-as-usual recovery from the current economic recession. A war mobilization is more like it, only this time without the war.

Here are the details of our two representative pathways:

	350 ppm pathway	***2°C pathway***
Cumulative CO2 budget (2000 to 2050)	750 GtCO2	1000 GtCO2
Remaining CO2 budget (2010 to 2050)	420 GtCO2	670 GtCO2
Year of peak emissions	2011	2013
2020 emissions (as a % below 1990)	- 42 %	- 7 %
2050 emissions (as a % below 1990)	- 100 %	- 86 %
Max annual rate of emissions decline	- 10 % / yr	- 6 % / yr

Note that, in the 350 case, after a long, steady decline (continuing at about 10% annually), emissions in 2040 will have dropped to less than 90% below 1990 levels. The decline continues, with emissions reaching zero by 2050, though we do not mean to imply that emissions remain at zero forever thereafter. In fact, after 2050, Hansen's pathway (which, again, we used as the basis of our own) assumes that enhanced sinks will draw more CO_2 out of the atmosphere than is emitted by fossil fuel combustion or deforestation, yielding a net budget of about *negative* 150 gigatonnes of CO_2 over the second half of the 21st century.[7] It is important to note that, in making this assumption, Hansen is being relatively cautious, in that he avoids appeals to highly speculative technologies or geoengineering fixes. Rather, his discussion of negative emissions refers to reforestation and biochar. Whether these will be available at the scale his scenario requires is uncertain. What is clear is that, given the small size of the total 21st century emissions budget, it's much easier to craft plausible 350 pathways if they include negative emission options.[8]

Uncertainties

In the causal chain that stretches from human activities, to greenhouse-gas emissions, to greenhouse-gas concentrations, to temperature rise, to climate damages, there are all kinds of scientific uncertainties. These make it difficult to set targets definitively or project outcomes precisely. This uncertainty, moreover, has political consequences. For example, it has been welcomed by politicians who wish to pretend to the 2°C goal, even as they advocate emission targets that have very small chances of actually holding the 2°C line.

In all this, the fundamental choice is a global climate objective. What would really protect the climate? Hansen, and more recently the authors of a bracing new paper on "planetary boundaries",[9] have made a compelling case that 350 ppm is a threshold that we don't want to exceed for long. But how long? The pathway we've adopted here is designed to return CO_2 concentrations back to 350 ppm by 2100. But it's quite conceivable that, as time goes by, we'll learn that the Earth's climate system is even less tolerant of elevated CO_2 concentrations than we currently fear, and conclude that we can't let concentrations remain above 350 ppm for that long. Or we might find that the oceanic and terrestrial sinks that we're counting on to absorb our emissions are declining even faster than we currently fear, and conclude that we need even more mitigation. Acknowledging these uncertainties, Hansen presents a second, even more ambitious 350 ppm pathway. It is designed to return emissions to 350 ppm as quickly as possible (by close to 2050), which it does by limiting emissions to nearly half of the 420 gigatonnes of CO_2 budget available in his first pathway (as above). But also, if we're lucky, things might turn out better than expected. Thus, Hansen also presented a third 350 pathway, one that allows about 300 gigatonnes more emissions between 2010 and 2050 than does his central case, and which delays the return to 350 ppm until well after 2100.

In the face of such fundamental uncertainties, two cardinal rules should govern any sane response to the climate crisis. First, stay informed. As the science evolves, keep reviewing and revising the climate target and the pathway it implies. Second, and more importantly, chose a pathway that is robust to bad news. That is, given the irreducible uncertainties of the moment, adopt a course that keeps more ambitious responses within reach should uncertainties resolve for the worse.

We thus stress that our representative 350 ppm trajectory is appropriate for the goal of returning CO_2 to 350 ppm by 2100, but that it should be reviewed and updated as new science emerges. We also claim that this pathway is probably as robust to bad news as it can be. It reflects an extraordinarily ambitious effort, implying economic, technical, and lifestyle changes that are rapid and far-reaching. It has a good chance of spurring many of the same near-term measures that would be needed to reach even more ambitious long term targets. But whether it is robust to the worst possibilities is uncertain.[10]

A divided planet

This discussion has so far focused on global emissions-reduction pathways, but *global* pathways can only tell us so much. The climate crisis, after all, does not simply arise from humanity's failure to heed basic biogeochemical limits. It arises as well from the grim, even implacable fact that we confront these limits within a profoundly divided world. The international North / South impasse, and the fundamental the rich / poor divide that marks all nations – these are not incidental matters.

In fact, the failure of nations to do their fair share to collectively combat the common threat of global warming is entirely unsurprising, as is the resulting international North / South impasse. This impasse, of course, has stymied the negotiations and foreshadows anything but sustained cooperation and solidarity on the global scale. But for all that, it is not hard to understand.

Consider the urgency of the climate predicament, well expressed by the 350 movement, and the emergency mobilization that's needed to stabilize the climate system. Consider again that all serious low-emissions pathways entail momentous transformations, to the point where they can only be imagined by way of a process that William James once called the "moral equivalent of war." Then ask yourself if such a transformations can take place, if they impede the ability of the poor to find economic justice.

In this context, here is one last figure, which we call "the South's dilemma."

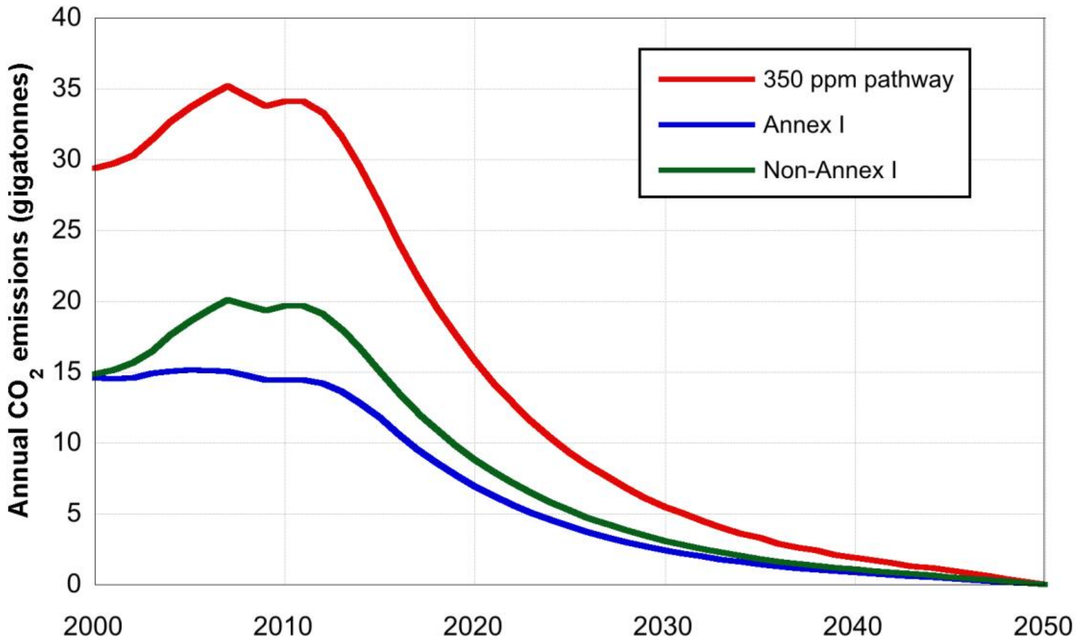


Figure 3. The red line shows a global 350 pathway, the blue line shows developed country (Annex 1) emissions declining more than 50% below 1990 levels by 2020, and to zero by 2050. The green line shows, by subtraction, the severely restricted emissions path that would remain for the developing countries.

Figure 3 shows the same 350 ppm pathway (the red solid line) as is shown in the previous figures. It also reveals the portion of that budget that developed countries would consume (along the blue emissions path) – assuming they undertake fairly strenuous mitigation efforts, sufficient to cut emissions 50% between now and 2020, continue to reduce by 10% annually in the ensuing decades, and then wholly eliminate emissions by 2050. This pathway shows the North undertaking mitigation efforts well beyond the Annex 1 reduction pledges currently on the negotiating table[11] and beyond even the "at least 40% below 1990" demanded by many NGOs. Clearly, such an effort would be quite ambitious by today's standards.

But, still, would it be enough? Simple subtraction[12] gives us the emission pathway (the green line) that would be available to the rest of the world (i.e., the developing world). Reflecting the starkly limited budget left for the South, this pathway implies extraordinarily ambitious reductions in the South. As in the North, its emissions would need to fall 50% from today's levels by 2020, continue dropping by at least 10% each year in the decades following, and be eliminated altogether by 2050. But, very much in contrast to the North, all this would have to happen while, at the same time, most of the South's citizens were struggling out of poverty and desperately seeking a meaningful improvement in their living standards.

Unfortunately, the only *proven* routes up from poverty involve an expanded use of energy and, consequently, a seemingly inevitable increase in fossil fuel use and thus carbon emissions. Indeed, in the absence of environmental constraints, emissions in the South would certainly rise much more rapidly than the North's, as the South's citizens finally gained access to the energy services, built the infrastructure that they have so long needed, and, hopefully, moved toward some sort of parity with the citizens of the North. Which is exactly why, in the absence of a proven alternative route to development, it is extremely difficult for the South to imagine an equitable future in which its emissions decline so precipitously. To be blunt – the South is deeply and *justifiably* concerned that an inequitable climate regime will force a choice between development and climate protection.

The paths in Figure 3, notwithstanding today's extremely unequal rates of consumption, show emission cuts occurring at comparable rates in the North and the South. By doing so, they depict a 2030 world in which the typical northerner would still consume carbon at four times the pace of the typical southerner. All told, Figure 3 shows the developed countries – with only a fifth of the world's population – consuming nearly half of the remaining, quickly vanishing global emissions budget. And this despite the fact that they are already responsible for the vast majority of past emissions, and – not coincidentally – control most of the world's advanced infrastructure and three-quarters of its income, and thus have a far, far greater ability to manage a rapid greenhouse transition. In fact, a strong case can be made that an alternative set of emissions pathways, one in which northern emissions declined even more quickly than is shown here, would be more plausible, in raw technical and developmental terms, for it would allow a larger share of the very limited remaining emissions budget to be consumed in the South. Which needs it much, much more.

That would help. But the underlying problem is that so little of the global carbon budget remains. There is no future scenario – regardless of how the remaining carbon budget is apportioned – in which the South has sufficient space to avoid a decarbonization transition so rapid that, in anything like a business-as-usual world, it threatens the South's prospects for development. Thus, the only way to secure the earnest engagement of the South is to ensure that it has the assistance necessary to support a decarbonization transition that is rapid and comprehensive, but that nevertheless allows human development to continue unimpeded. Nor is this a novel conclusion, unique to this analysis of the 350 emergency pathway. Indeed, it underlies the UNFCCC commitment by developed countries to provide finance and technological support to developing countries, and it underlies the widespread NGO call for the developed countries to take on "international mitigation obligations" that are just as prominent, official, and legally binding as their domestic mitigation obligations.

Costs and conclusions

An obvious question is "how much would 350 cost?"

Much of the mainstream debate about climate targets has focused on allegedly high costs of targets in the range of 450-550 ppm CO_2-equivalent. Most assessments put the costs of 450 CO_2e pathways (which are far less stringent than 350 CO_2) in the range of 1-3% of Gross World Product, a figure that is considered absurdly high by the opponents of climate policy, but which is only noise in the context of the usual global growth rate projection of 2-3% annually over the coming decades. Very few studies of the economics of 350 ppm CO_2 pathways have been done, but (for example) one such study puts the costs of 350 stabilization at about 3-5% of GWP, depending on the availability of carbon capture and sequestration from fossil fuels and biomass.[13]

Arguably, however, all such estimates miss the point. Under the kind of "war mobilization" that would be required to achieve something like the 350 pathway that we've been discussing here, standard models just don't yield much useful information. In fact, depending on how the necessary investments are funded, the GWP might actually grow. (World War II saw the fastest US GNP growth in history!) The critical point is that an appropriate emergency climate stabilization program will require – in addition to a huge effort to reprioritize investment into low-carbon technologies – a substantial redirection of economic flows, between industrial sectors, between countries, and especially between North and South. In this context, the fundamental obstacles are not economic but political.

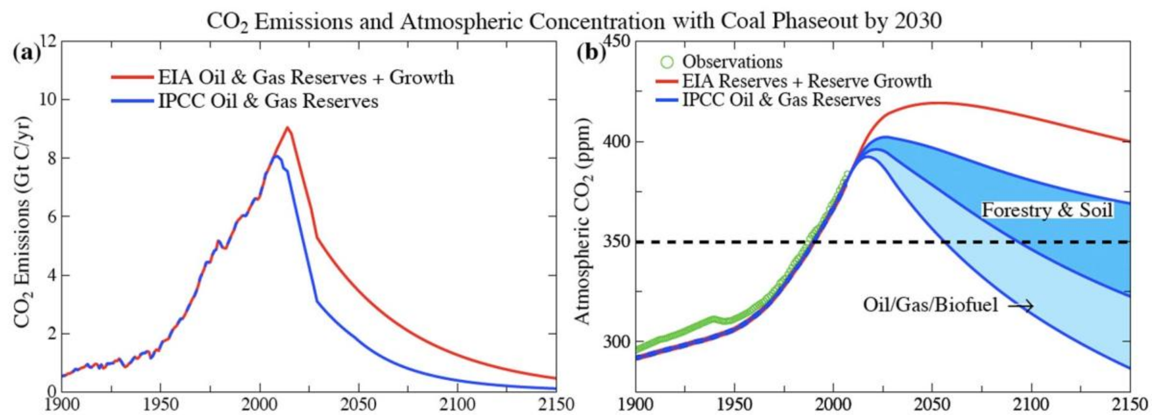
The bottom line? The 350 movement has it right! Our focus must be on the demands of the science, and as that science becomes incontestable, it must shift to the political mobilization that is necessary to meet these demands. This is the realism of the greenhouse age.

See http://gdrights.org/2009/10/20/a-350-ppm-emergency-pathway for copies and updates of this brief, as they become available, and for downloadable versions of the underlying data. Address correspondence to gdrs_authors@googlegroups.com

[1] See for example Andrew Revkin, "Campaign Against Emissions Picks Number," *New York Times*, October 24, 2009. http://www.nytimes.com/2009/10/25/science/earth/25threefifty.html?scp=1&sq=350&st=cse

[2] Hansen, J., M. Sato, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo, D. L. Royerm and J. C. Zachos (2008). "Target Atmospheric CO2: Where Should Humanity Aim?" *The Open Atmospheric Science Journal* **2**: 217-231. www.columbia.edu/~jeh1/2008/TargetCO2_20080407.pdf

Hansen and colleagues put the design of pathways targeting 350 ppm in the context of a detailed analysis of likely long-term climate sensitivity. The core of their policy scenario is shown in their Figure 6, reproduced below. In the accompanying text, they document the assumptions (particularly about carbon capture, land-use emissions and sink enhancement) that lead to the alternative emissions and concentration pathways shown. Cumulative emissions are not reported, and the chart (left panel) in fact shows only fossil emissions, rather than the net CO_2 emissions (from all sources) which enter into the atmosphere. As shown on the right panel, however, returning to 350 by 2100 under this scenario requires the dark blue "wedge" of forestry and soil sequestration, yielding about 6.5 gigatonnes of negative CO_2 emissions annually. (Note that the Y axis in the left panel is GtC; multiply by 44/12 to convert to CO_2)



g. (6). (**a**) Fossil fuel CO_2 emissions with coal phase-out by 2030 based on IPCC [2] and EIA [80] estimated fossil fuel reserves. (**b**) Re-lting atmospheric CO_2 based on use of a dynamic-sink pulse response function representation of the Bern carbon cycle model [78, 79].

Reproduced from Hansen et al. 2008.

[3] The IEA's 2009 BAU pathway projects fossil-fuel CO_2 emissions rising to about 40 gigatonnes in 2030 (see note 6 below). We adjust it by including 6 gigatonnes annually of land use emissions, a figure comparable to the Global Carbon Project's best estimate (http://www.globalcarbonproject.org/carbonbudget/07/index.htm).

[4] Meinshausen, M., N. Meinshausen, W. Hare, S. C. B. Raper, K. Frieler, R. Knutti, D. J. Frame and M. R. Allen (2009). "Greenhouse-gas emission targets for limiting global warming to 2°C." *Nature* **458**: 1158-1163. (http://www.nature.com/nature/journal/v458/n7242/full/nature08017.html). Meinshausen et al do a sophisticated statistical analysis to ground the calibration of their model (version 6.0 of MAGICC, an intermediate-complexity climate model that has often been used in the IPCC's scenario analyses due to its capacity to mimic the response of various general circulation models). The key results are shown in their Table 1, reproduced below. Although they also show graphically the spread of CO_2 concentrations associated with their model runs, they don't report them in a way that allows easy analysis in cumulative emissions terms. For example, their figures only report out to 2100.

Table 1 | Probabilities of exceeding 2 °C

Indicator	Emissions	Probability of exceeding 2 °C*	
		Range	Illustrative default case‡
Cumulative total CO_2 emission 2000–49	886 Gt CO_2	8–37%	20%
	1,000 Gt CO_2	10–42%	25%
	1,158 Gt CO_2	16–51%	33%
	1,437 Gt CO_2	29–70%	50%
Cumulative Kyoto-gas emissions 2000–49	1,356 Gt CO_2 equiv.	8–37%	20%
	1,500 Gt CO_2 equiv.	10–43%	26%
	1,678 Gt CO_2 equiv.	15–51%	33%
	2,000 Gt CO_2 equiv.	29–70%	50%
2050 Kyoto-gas emissions	10 Gt CO_2 equiv. yr^{-1}	6–32%	16%
	(Halved 1990) 18 Gt CO_2 equiv. yr^{-1}	12–45%	29%
	(Halved 2000) 20 Gt CO_2 equiv. yr^{-1}	15–49%	32%
	36 Gt CO_2 equiv. yr^{-1}	39–82%	64%
2020 Kyoto-gas emissions	30 Gt CO_2 equiv. yr^{-1}	(8–38%)†	(21%)†
	35 Gt CO_2 equiv. yr^{-1}	(13–46%)†	(29%)†
	40 Gt CO_2 equiv. yr^{-1}	(19–56%)†	(37%)†
	50 Gt CO_2 equiv. yr^{-1}	(53–87%)†	(74%)†

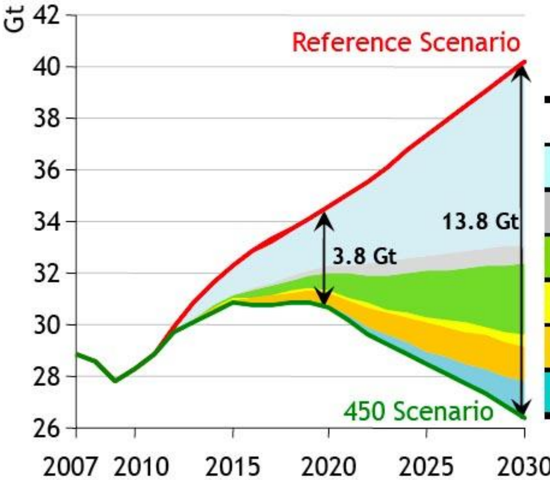
* Range across all priors reflecting the various climate sensitivity distributions with the exception of line 12 in Fig. 3a.
† Note that 2020 Kyoto-gas emissions are, from a physical perspective, a less robust indicator for maximal twenty-first century warming with a wide scenario-to-scenario spread (Supplementary Fig. 1c).
‡ Prior chosen to match posterior of ref. 19 with uniform priors on the TCR.

Reproduced from Meinshausen et al. (2009)

Meinshausen et al. do not report on model runs that match the 750 gigatonnes cumulative that are the net emissions in Hansen et al.'s central scenario. But they do note (see http://sites.google.com/a/primap.org/www/nature) that such a pathway would be expected to have a higher chance of staying below 2ºC. A simple power law extrapolation based on their Table 1 suggests that that risk would be on the order of 5-30%, with a central estimate ("Illustrative Default") of about 15%.

[5] In July, the G8 leaders meet in the Italian town of L'Aquila and announced the goal of reducing global emissions by 50% by 2050, with the wealthy countries making 2050 cuts of 80%. This pathway, which we estimate produces CO_2 emissions of about 1500 gigatonnes for the 200-2050 period, would (based on the Meinshausen et al. calculations shown in the table above) give only about a 50% chance of staying below 2ºC.

[6] While it's hard to estimate near-past global CO_2 emissions precisely, several estimates of the recession-induced emissions decline have already been published. We take our model of the drop here from the International Energy Agency, whose forthcoming *World Energy Outlook 2009* projects a roughly 4% drop between 2007 and 2009, and a subsequent return to 2007 levels by 2011 followed by a further 15% rise to 2015. Also note (see the figure below reproduced from IEA's public pre-release at the Bangkok UNFCCC meeting in October 2009) that the IEA is still using, as its low-emissions reference pathway, a "450" policy scenario which peaks in 2015, is flat to 2020, and declines to 2030 by about 1.5% annually (at which point emissions still exceed 1990 levels by close to 20%).



Share of abatement %	2020	2030
Efficiency	65	57
End-use	*59*	*52*
Power plants	*6*	*5*
Renewables	18	20
Biofuels	1	3
Nuclear	13	10
CCS	3	10

Reproduced from IEA (2009), available at http://www.worldenergyoutlook.org/2009_excerpt.asp

[7] According to Hansen et al. (2008, note 2 above), "It is assumed that uptake of carbon via reforestation will increase linearly until 2030, by which time reforestation will achieve a maximum potential sequestration rate of 1.6 GtC per year (S28). Waste-derived biochar application will be phased in linearly over the period 2010-2020, by which time it will reach a maximum uptake rate of 0.16 GtC/yr (77). Thus after 2030 there will be an annual uptake of 1.6 + 0.16 = 1.76 GtC per year, based on the two processes described." Converting from GtC to $GtCO_2$ (multiply by 44/12) gives about 6.5 $GtCO_2$ per year, or about 325 $GtCO_2$ from 2050-2100. This more than compensates for fossil emissions, which total about 175 $GtCO_2$ over the same period. This yields a net budget of about negative 150 $GtCO_2$.

[8] It's important to realize that net negative emissions requires not only some kind of sequestration, as through land use, but the near total elimination of fossil fuel emissions. Negative land use emissions are consistent with positive net emissions. The practicality and cost of massive sequestration through agriculture and forestry remains uncertain and controversial, and economic free-air capture is even more speculative. Ackerman et al. (2009) cite these as reasons to *not* rely on negative net emissions in the creation of a 350 pathway, and indeed the scenarios they model all have emissions drop to zero (at different years) but not below. Ackerman, F., E. A. Stanton, S. J. DeCanio, E. Goodstein, R. B. Howarth, R. B. Norgaard, C. S. Norman, K. A. Sheeran (2009). "The Economics of 350: The Benefits and Costs of Climate Stabilization." Economics for Equity and Environment, www.e3network.org.

[9] Rockström, J., W. Steffen, K. Noone, Å. Persson, F. S. Chapin, III, E. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. Schellnhuber, B. Nykvist, C. A. De Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R. W. Corell, V. J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J. Foley. 2009. *Planetary boundaries: exploring the safe operating space for humanity*. Ecology and Society 14(2): 32. See http://www.ecologyandsociety.org/vol14/iss2/art32/ and, for additional material and links, the Stockholm Resilience Center website at http://www.stockholmresilience.org/ research/researchnews/tippingtowardstheunknown.5.7cf9c5aa121e17bab42800021543.html

[10] Indeed, our representative 350 pathway, though more stringent than the 2ºC pathway, has a significant chance of leading to a temperature increase of over 2ºC – if, that is, we are "unlucky" in terms of the climate sensitivity or carbon cycle feedbacks. See note 4 above.

[11] For example, the UNFCCC Secretariat (2009) has estimated that reduction pledges by Annex 1 countries sum to a patently inadequate 17-24% reduction below 1990 levels by 2020. A second technical analysis (AOSIS, 2009)

estimates the combined Annex 1 pledge to be 10-16%. Both of these estimates date from August 2009, three months before the milestone Copenhagen Conference of Parties to the UNFCCC, and will soon be superseded by more definitive numbers.

[12] By consuming 180 gigatonnes CO_2 between now and 2050 out of a total global budget of 420 gigatonnes, the Annex 1 countries would leave only 240 gigatonnes CO_2 for the South.

[13] Azar, C., K. Lindgren, E. Larson and K. Möllersten (2006). "Carbon Capture And Storage From Fossil Fuels And Biomass — Costs And Potential Role In Stabilizing The Atmosphere." *Climatic Change* 74: 47-79. Ackerman et al. (2009, see note 8 above) review this and several other studies, including a recent report from the Potsdam Institute for Climate Impact Research (Knopf, B., O. Edenhofer, H. Turton, T. Barker, S. Scrieciu, M. Leimbach, L. Baumstark and A. Kitous (2008), "Report on First Assessment of low stabilization scenarios") which reports modeled costs for stabilization at 400 ppm CO_2 equivalent as remaining under 2.5% cumulative GWP losses to 2100. (Interestingly, one of the models reported in Knopf et al. reports GWP gains from rapid mitigation, in part because it assumes – quite plausibly – that labor, R&D capacity and other resources are underutilized.) While these and other studies give grounds to believe that very low emissions pathways are not economically prohibitive, none model a short term (e.g., 2010-2020) decline of CO_2 emissions that is as rapid as that postulated here or in the Ackerman et al. scenarios, all of which have emissions falling by more than 50% between now and 2020. For example, the "400 ppm CO2-e" emissions pathway in the Knopf et al. study has cumulative fossil fuel emissions of about 1100 gigatonnes from 2000 to 2050, far higher than the cumulative emissions in our 350 ppm pathway.