The Unrealistic Objective of Meeting the 2 Degree C Warming Limit
Bruce Parker
January 20, 2015

Most climate scientists believe that if we continue to add greenhouse gases to the atmosphere at the current (and accelerating rate) for the rest of the century the resulting climate change would likely be catastrophic for our civilization. It is generally accepted that in order to have a reasonable chance of avoiding such climate change, we need to limit the total increase in atmospheric temperature to two degrees C (3.6° F) above pre-industrial times. And the current climate models (which assume that anthropogenic greenhouse gas emissions will be the primary driver of the Earth’s temperature this century) suggest that in order to have a reasonable (66%) chance of doing this, we need to limit net worldwide greenhouse gas emissions to about 485 billion tons of carbon (the “carbon budget” after 2011).

The next worldwide agreement on reducing greenhouse gases is expected to be signed in Paris in December 2015, with the agreement taking effect in 2020. The hope is that the countries of the world will voluntarily agree to limit their emissions in such a way that the “carbon budget” will not be exceeded and, as a result, the global temperature increase can be limited to two degrees C. However there are some very serious (and fatal) problems:

- A significant amount of warming will certainly be caused by multiple “feedback effects” from a warmer Arctic (permafrost melt, albedo changes, destabilized methyl hydrates, etc.), and, as a result, the two degree limit will very likely be exceeded even if all greenhouse gas emissions were ended today
- The current climate models do not take into account any significant warming from the “feedback effects”, and, as a result, the 485 GTC (gigatons – or billion of tons – of carbon) “carbon budget” is unrealistically generous
- Even if limiting future emissions to 485 GTC were sufficient to limit warming to 2 degrees C, there is no equitable way to reduce greenhouse gas emissions at a pace fast enough at a cost that we are willing to pay
- Even if the global warming could be stopped at one degree C, the sea level rise would eventually be catastrophic (over 30 feet).

So 2015 will likely go down in history as the year that we finally realized that it will be impossible to meet the 2 degree C limit by simply reducing net anthropogenic greenhouse gas emissions.

It appears that there is only one possible way to prevent the Arctic warming that will lead to a “runaway greenhouse” and the end to civilization as we know it – geoengineering to both block sunlight and to sequester carbon, hopefully stopping the global warming that is being caused by greenhouse gases. We’ll likely lose most ocean-based life (from ocean acidification) and will still have to abandon the major coastal cities, but at least some major parts of the land will still be habitable. Perhaps after the Paris negotiations fail to obtain the pledges needed to meet the 485 billion ton carbon budget (as they must, since the sacrifice needed to meet even the flawed carbon budget is too great), world leaders will consent to some modest geoengineering experiments.
1. “Locked In Global Warming”

The Earth’s temperature has already risen .8 degrees C and will rise at least an additional .2 degrees based on the CO2 already in the atmosphere. Another 1-2.5 degrees C is almost guaranteed by a combination of (A) the additional warming resulting from a summer-time ice-free Arctic Ocean and a retreating snowline, both of which will significantly reduce the Earth’s albedo (see “Melting Arctic Sea Ice and Snowline Retreat” below), (B) the carbon dioxide and methane that will be released from the melting of the Arctic permafrost (see “Permafrost Melting” below), (C) the methane that may be released from methyl hydrates on the ocean floor (see “Methyl Hydrates” below) and (D) the carbon dioxide and methane that will be released from the burning and drying of the peat bogs (see “Peat Bogs” below).

2. “Busting the Carbon Budget”

It is technically possible for the world to limit net greenhouse gas emissions to 485 GTC this century. With expected emissions of about 127 GTC through 2020 (when the climate agreement is to go into effect), the budget after 2020 will be about 358 billion tons. With global emissions expected to be about 15 GTC in 2020, emissions would have to be reduced around 3.5%/year (starting in 2020) to stay within the budget. Not only are the necessary changes to our energy and agricultural systems unlikely (See “Deep Decarbonization” below), but complicating matters is the fact that the US pledge (about 170 GTC from 2012-2080) is way, way short of what is needed, resulting in over 10 percent of the world’s emissions budget being consumed by a country with 4.3% of the world’s population. (See “US Emissions Reduction Pledge” below). Not to mention that the countries with the largest populations (China, India, etc.) expect their emissions to grow through at least 2030. In addition, most countries are very unlikely to agree to per-capita emissions after 2020 that are significantly less than those of the US. If reasonable emission reduction steps would get us close to meeting the 2 degree C limit, it might be possible to convince people to pay a bit extra to reduce emissions a bit more. But since we are so far short of limiting our emissions sufficiently, asking them to make really significant sacrifices will not work.

3. “Catastrophic Sea Level Rise”

The fact that sea level (at equilibrium) is directly tied to the Earth’s temperature (as long as there are glaciers) should be obvious. Estimates of the expected sea level rise per degree C range from 10 to 20 meters, so if the Earth stopped warming tomorrow, the expected equilibrium sea level would be about 26 feet higher than it is today (.8 * 10 * .3.2). With a two degree warming, we should expect at least 65 feet. Although this will take centuries, a sea level rise of 8 inches to a foot per decade can be expected in the next century. (See “Sea Level Rise” below).
Appendices

A. Melting Arctic Sea Ice and Snowline Retreat

Takeaway

The melting of the summer-time sea ice in the Arctic Ocean and the retreating of the snowline will likely add at least one degree C of warming (considering this would about double the current radiative forcing, and the current radiative forcing has already increased the Earth’s temperature .8 degrees C and is expected to raise it even more).

Summary

The warming caused by the CO2 in the Earth’s atmosphere has already raised the Earth’s atmospheric temperature about .8 degrees C. Since Earth is emitting much less energy that is being absorbed, the temperature would continue to increase even if the atmospheric concentration of CO2 could be limited to the current 400ppm. An equilibrium temperature increase of at least 1 degree C is very likely, and could be much more (perhaps almost 1.5 degrees C). The warming of the Arctic region will cause the Earth’s albedo to decrease, causing serious additional warming.

As the summer-time sea ice in the Arctic Ocean melts the ocean will begin to absorb much more heat. Even thought the Arctic Ocean is relatively small (less that 1% of the Earth’s surface), it will get almost direct sunlight 24 hours a day for several months, and the additional energy absorbed will be the equivalent of about 80% of the atmospheric CO2 that humans have added.

In addition, the “snowline” in the Arctic region will be retreating and the tundra will “darken” as trees replace shrubs. Because the area is so large, the additional energy absorbed will be almost the same as that being absorbed by the Arctic Ocean.

The total additional warming from the above albedo changes is likely at least 1 degree C and could be as much as 2 degrees C.

Details


Professor Wadhams estimates the present summer area of sea ice at 4 million square km, with a summer albedo of about 0.60 (surface covered with melt pools). When the sea ice disappears, this is replaced by open water with an albedo of about 0.10. This will reduce the albedo of a fraction 4/510 of the earth's surface by an amount 0.50. The average albedo of Earth at present is about 0.29. So, the disappearance of summer ice will reduce the global average albedo by 0.0039, which is about 1.35% relative to its present value.

As NASA describes, a drop of as little as 0.01 in Earth’s albedo would have a major warming influence on climate—roughly equal to the effect of doubling the amount of carbon dioxide in the atmosphere, which would cause Earth to retain an additional 3.4 watts of energy for every square meter of surface area.

Based on these figures, Professor Wadhams concludes that a drop in albedo of 0.0039 is equivalent to a 1.3 W/sq m increase in radiative forcing globally.
The albedo change resulting from the snowline retreat on land is similarly large, so the combined impact could be well over 2 W/sq m. By comparison, this would more than double the net 1.6 W/sq m radiative forcing resulting from the emissions caused by all people of the world (see IPCC image below).

B. Permafrost Melting

Takeaway

Carbon released from permafrost soils will likely have a very significant impact on future temperatures (perhaps .5 degrees C by 2100 and certainly more by 2200), and “as of 2011, no climate model incorporates the effects of methane released from melting permafrost, suggesting that even the most extreme climate scenarios in the models might not be extreme enough”.

Summary

The Arctic region is warming at about twice the rate of the global average, causing the temperature of the vast area of permafrost to increase. The warming causes some of the permafrost to thaw, releasing carbon dioxide and methane.
Researchers at the National Snow and Ice Data Center estimate that by 2200, 60% of the Northern Hemisphere's permafrost will probably be melted, which could release around 190 billion tons of carbon into the atmosphere. This amount is about half of all the carbon released in the industrial age. The affect this will have on the rate of atmospheric warming could be irreversible. At the very least, these estimates mean fossil fuel emissions will have to be reduced more than currently suggested to account for the amount of carbon expected to discharge from melting permafrost.

Details

(From the National Climate Assessment - http://nca2014.globalchange.gov/report/our-changing-climate/melting-ice)

Permafrost temperatures are increasing over Alaska and much of the Arctic. Regions of discontinuous permafrost in interior Alaska (where annual average soil temperatures are already close to 32°F) are highly vulnerable to thaw. Thawing permafrost releases carbon dioxide and methane – heat-trapping gases that contribute to even more warming. Recent estimates suggest that the potential release of carbon from permafrost soils could add as much as 0.4°F to 0.6°F of warming by 2100. Methane emissions have been detected from Alaskan lakes underlain by permafrost, and measurements suggest potentially even greater releases from thawing methane hydrates in the Arctic continental shelf of the East Siberian Sea. However, the response times of Arctic methane hydrates to climate change are quite long relative to methane's lifetime in the atmosphere (about a decade). More generally, the importance of Arctic methane sources relative to other methane sources, such as wetlands in warmer climates, is largely unknown. The potential for a self-reinforcing feedback between permafrost thawing and additional warming contributes additional uncertainty to the high end of the range of future warming. The projections of future climate shown throughout this report do not include the additional increase in temperature associated with this thawing.


In total, the northern permafrost region contains approximately 1672 Pg [1,672 billion tons] of organic carbon, of which approximately 1466 Pg, or 88%, occurs in perennially frozen soils and deposits. This 1672 Pg of organic carbon would account for approximately 50% of the estimated global belowground organic carbon pool.


The worrying news, no matter how you dice the de-icing permafrost findings? "There's so much carbon stored in northern permafrost soils that even if, say, 10 percent of that carbon is released through the processes we studied, it would still have a big impact," Cory said. She calculated that "conservative" scenario would raise atmospheric carbon dioxide levels by 75 to 80 parts per million — over and above the effects of continued fossil fuel burning and other causes. And that, she said, would lead to "a lot of warming."


Permafrost stores an immense amount of carbon and methane (twice as much carbon as contained in the atmosphere). In a warming environment, permafrost is expected to degrade, and these gases which have been in storage will be released. This process has already begun in some parts of the world, including western Siberia,
and is expected to increase in earnest by the year 2020. Furthermore, as of 2011, no climate model incorporates the effects of methane released from melting permafrost, suggesting that even the most extreme climate scenarios in the models might not be extreme enough.

Researchers at the National Snow and Ice Data Center estimate that by 2200, 60% of the Northern Hemisphere’s permafrost will probably be melted, which could release around 190 billion tons of carbon into the atmosphere. This amount is about half of all the carbon released in the industrial age. The affect this will have on the rate of atmospheric warming could be irreversible. At the very least, these estimates mean fossil fuel emissions will have to be reduced more than currently suggested to account for the amount of carbon expected to discharge from melting permafrost.

C. Methane Hydrates

Takeaway

Huge amounts of methane are stored around the world in the sea floor in the form of solid methane hydrates. ... Climate warming ... could cause the hydrates to destabilize. The methane, a potent greenhouse gas, would escape unused into the atmosphere and could even accelerate climate change\(^1\).

Summary

“We calculate that the costs of a melting Arctic will be huge, because the region is pivotal to the functioning of the oceans and climate. The release of methane from the thawing permafrost beneath the Eastern Siberian Sea, off northern Russia, alone comes with an average global price tag of $60 trillion in the absence mitigating action – a figure comparable to the size of the world economy on 2012 (about $70 trillion). The total cost of Arctic change will be much higher.”\(^2\)

“A 50-gigatonne (Gt) reservoir of methane, stored in the form of hydrates, exists in the East Siberian Arctic Shelf. It is likely to be emitted as the sea bed warms, either steadily over 50 years or suddenly.”\(^2\)

Details

2. [http://www.nature.com/articles/499401a.epdf](http://www.nature.com/articles/499401a.epdf)

D. Peat Bogs

Takeaway

“[P]eatlands will quickly respond to the expected warming in this century by losing labile soil organic carbon during dry periods.”\(^1\) Only the amount and timing is not certain.

Summary

“[W]e estimate that climate warming of about 1 °C over the next few decades could induce a global increase in heterotrophic respiration of 38–100 megatonnes of C per year. Our findings suggest a large, long-lasting, positive feedback of carbon stored in northern peatlands to the global climate system.”\(^2\)
Although the expected contribution of carbon dioxide and methane from peat bogs will not be nearly as great as that from other feedbacks, it is just one more example of non-human contributions to a warming world.

Detail

(from http://www.dailyclimate.org/tdc-newsroom/2015/01/peatlands-carbon-burn)

Merritt Turetsky, an ecosystem ecologist at the University of Guelph, Ontario, and colleagues report in Nature Geoscience that peatlands cover between only 2% and 3% of the planet's land surface, but store 25% of the planet's soil carbon.

They cover about 400,000 square kilometers and store 100 billion tons of carbon. The entire pool of atmospheric carbon, in the form of carbon dioxide, adds up to about 850 billion tons.

In a Nature study in 2002, she calculated that a dramatic and sustained forest fire in Indonesia in 1997 may have sent 2.5 billion tons of carbon into the atmosphere – a figure that could have added up to 40% of all the emissions from all the fossil fuel burning that year.

"Tropical peatlands are highly resistant to natural fires, but in recent decades humans have drained peatlands for plantation agriculture," she said. "People cause the deep layers of peat to dry out, and also greatly increase the number of fire ignitions. It's a double threat."

(from Climate Progress - http://thinkprogress.org/climate/2015/01/13/3610618/peat-wetlands-global-warming/)

A 2008 Nature Geoscience study — “High sensitivity of peat decomposition to climate change through water-table feedback” — projected that “a warming of 4°C causes a 40% loss of soil organic carbon from the shallow peat and 86% from the deep peat” of Northern peatlands. On our current emissions path, the world is set to warm well beyond 4°C (7°F). According to the 2008 study, “We conclude that peatlands will quickly respond to the expected warming in this century by losing labile soil organic carbon during dry periods.”

2. http://www.nature.com/nature/journal/v460/n7255/abs/nature08216.html
E. US Emissions Reduction Pledge

Takeaway

The Obama “Climate Pledge” (deemed “ambitious” by the White House) would have the US, with 4.3% of the world’s population, consume 10% of the world’s carbon budget – incredibly short of what is needed. In addition, if emissions from manufacturing goods in China were included, US emissions in 2012 would have been about 8% (528 MTCO2E) higher.

Summary


Building on strong progress during the first six years of the Administration, today President Obama announced a new target to cut net greenhouse gas emissions 26-28 percent below 2005 levels by 2025. At the same time, President Xi Jinping of China announced targets to peak CO₂ emissions around 2030, with the intention to try to peak early, and to increase the non-fossil fuel share of all energy to around 20 percent by 2030.

The new U.S. goal will double the pace of carbon pollution reduction from 1.2 percent per year on average during the 2005-2020 period to 2.3-2.8 percent per year on average between 2020 and 2025. This ambitious target is grounded in intensive analysis of cost-effective carbon pollution reductions achievable under existing law and will keep the United States on the right trajectory to achieve deep economy-wide reductions on the order of 80 percent by 2050.

Since US GHG Emissions (CO₂, Methane, etc.) were 7195 million metric tons CO₂ equivalent in 2005¹, emissions for 2025 are expected 5252 MTCO2E and emissions for 2050 are expected to be 1439 MTCO2E. If emissions are reduced at the rate 1.75%/year from 2012-2025 (reaching the target of 5190 in 2025) and 5.04%/year from 2026 to 2050 (reaching the target of 1422 in 2050) and then continue at the same rate through 2080, the total US emissions through 2080 will be about 175,000 MTCO2E, about 10% of the world’s budget (for 4.3% of the world’s population) – and this pledge is touted as “ambitious” by the Obama administration!

Table 1. Yearly US Greenhouse Gas Emissions bases on the Obama Pledge

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Notes:
- The United States has been responsible for over 25% of total emissions so far.
- If emissions from manufacturing goods in China were included, US emissions in 2012 would have been about 8% (528 MTCO2E) higher (http://www.forbes.com/sites/anaswanson/2014/11/12/heres-one-thing-the-us-does-export-to-china-carbon-dioxide/).
- The IPCC “carbon budget” is 1,000 GTC, with 515 GTC being used through 2011, leaving 485 GTC (1,770,000 MTCO2E) for 2012-2100


F. Sea Level Rise

Takeaway

Up to a 2 degree C increase, the expected equilibrium sea level rise is about 10 meters per degree C (8 feet per degree F), with at least 3 feet of sea level rise expected by 2100.

Summary

After the end of the last glacial maximum, sea levels rose about 10 mm/year on average, and at one point rose at about 30 mm/year. Since the Earth is warming much faster now than it was as the last ice age ended, perhaps 20 mm/year (8 inches/decade, or 7 feet a century) is to be expected in the future. This is about nine times the current rate.

Up to a 2 degree C increase, the expected sea level rise is about 10 meters per degree C (8 feet per degree F) [http://www.roperld.com/science/sealevelvstemperature.htm](http://www.roperld.com/science/sealevelvstemperature.htm), [https://geosci.uchicago.edu/~archer/reprints/archer.2008.tail_implications.pdf](https://geosci.uchicago.edu/~archer/reprints/archer.2008.tail_implications.pdf)

Experts expect the sea level to rise over 3 feet by 2100 for the IPCC high emissions scenario (which is what we are on track for, even if emissions are reduced) [http://www.washingtonpost.com/blogs/wonkblog/wp/2013/11/26/how-high-will-sea-levels-rise-lets-ask-the-experts/](http://www.washingtonpost.com/blogs/wonkblog/wp/2013/11/26/how-high-will-sea-levels-rise-lets-ask-the-experts/)

G. Deep Decarbonization

Takeaway

Although “it is technically feasible to achieve an 80% greenhouse gas reduction below 1990 levels by 2050 in the United States (U.S.)”, many of the necessary changes (very few gasoline-powered cars could be sold after 2030, electric heat would have to constitute the majority of new heating sales by 2020, natural gas would be almost totally replaced by electricity for heating, cooking, and heating water, etc.) just won’t happen. And “technically feasible” does necessarily mean that it is politically or socially feasible. For example, using the projections for US emissions through 2060, the US per-capita allocation would be about 2½ times the “rest of the world” - hardly something that the “rest of the world” would find equitable. And the feedbacks from a warming world will likely take is past the 2 degree C limit anyway.
Summary

“Pathways to Deep Decarbonization in the United States” was published by Energy and Environmental Economics, Inc. (E3), in collaboration with Lawrence Berkeley National Laboratory (LBNL) and Pacific Northwest National Laboratory (PNNL) in November 2014. Its purpose is to examine how the United States might be able to reduce greenhouse gas emissions to levels consistent with limiting the human-caused increase in the Earth’s temperature to less than 2 degrees Celsius (°C).

From the abstract and contents of the report:

- It is technically feasible to achieve an 80% greenhouse gas reduction below 1990 levels by 2050 in the United States (U.S.)
- Multiple alternative pathways exist to achieve these reductions using existing commercial or near-commercial technologies.
- The incremental cost to the energy system equivalent to less than 1% of gross domestic product (GDP) in the base case (perhaps $225 billion per year)
- The changes required to deeply decarbonize the economy over the next 35 years would constitute an ambitious transformation of the energy system.
- Electricity generation would need to approximately while its carbon intensity is reduced to 3---10% of its current level.
  - Deployment of roughly 2,500 gigawatts (GW) of wind and solar generation (30 times present capacity) in a high renewables scenario
  - Deployment of 700 GW of fossil generation with CCS (nearly the present capacity of non-CCS fossil generation) in a high CCS scenario,
  - Deployment of more than 400 GW of nuclear (4 times present capacity) in a high nuclear scenario.
- This study indicates that these changes would not necessarily entail major changes in lifestyle
- Light Duty Vehicles
  - The average fleet fuel economy would need to exceed 100 miles per gallon gasoline
  - 80-95% of miles driven would need to by alternative fuel vehicles (electricity, hydrogen, etc.) (Very few gasoline-powered cars are sold after 2030)
  - Roughly 300 million alternative fuel vehicles would need to be deployed by 2050
- Residential Houses
  - Floor space increase by almost half over by 2050
  - All natural gas furnaces and radiators are replaced with electric radiators and heat pumps (and most are replaced by 2030)
  - Electric heat constitutes the majority of new heating sales by 2020
  - Houses become more insulated (but the amount is not specified)
**Emissions**

Figure ES-1 (from the PDF) shows the percentage of 2005 emissions for the years 2015 to 2050 for the “Mixed Case”.

![Figure ES-1. U.S. Total GHG Emissions for the years 2015-2050, as a Percentage of 2005 Emissions](image)

**Costs**

Costs for 2050 will likely be about 1% of the expected GDP, with a high degree of uncertainty. Costs for the period 2020-2050 will likely be in the range of .8% of GDP.

**Analysis**

**US Emissions**

Assuming that the figure is representative of the various cases, one can estimate that the total expected greenhouse gas emissions after 2011 as about 175,000 million tons of CO2 equivalent (MTCO$_2$e) (assuming a constant CO2 terrestrial sink) as shown in the following table:

**Figure 2 – US Emissions based on Figure ES-1**

<table>
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(Note the cumulative emissions are almost the same as the cumulative emissions based on Obama’s pledge.)

The world’s carbon budget after 2011 is about 485 gigatons of carbon\(^3\), or about 1,777,000 MTCO\(_2\)e. So the US would use about 10% of the world’s “after 2011” carbon budget.

Figure 3 – Summary of World Emissions Where US and EU meet pledges and IPCC budget not exceeded

<table>
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<td>World Totals</td>
<td>33.5</td>
<td>47.8</td>
<td>55.0</td>
<td>15.8</td>
</tr>
</tbody>
</table>

   Rest of the World, assume same rate of increase from 2010 to 2011 as 2000 to 2010 – see #5 below – 46000 + 2 * 9000/10 = 46900; then calculate “Rest of the World”
5. US and Europe - based on pledges  
   Worldwide – EPA Estimates – 37000 in 2000 and 46000 in 2010; Assume same increase for 2020 to get 55000
6. Based on pledges for EU and US - 80% below 1990 by 2050  
   “Rest of the world” calculated to be 30% below 2020 values by 2050 in order to arrive at the IPCC budget of about 1777 GTC (with emission reductions starting in 2021)
7. US emission subtotals from Figure 2  
   EU emissions based on pledge  
   “Rest of the world” emissions calculated in order to arrive at the IPCC budget of about 1777 GTC by 2070 (with emission reductions starting in 2021)

**Costs**

If the 2012 GDP is about $16 trillion and growing to about $40 trillion in 2020 and costs are about .8% of GDP, then total costs for the 38 years will be about 38 * (16 + (40-16) / 2 ) *.008, about $8.5 trillion (about $225 billion per year, about $650/per person/year)