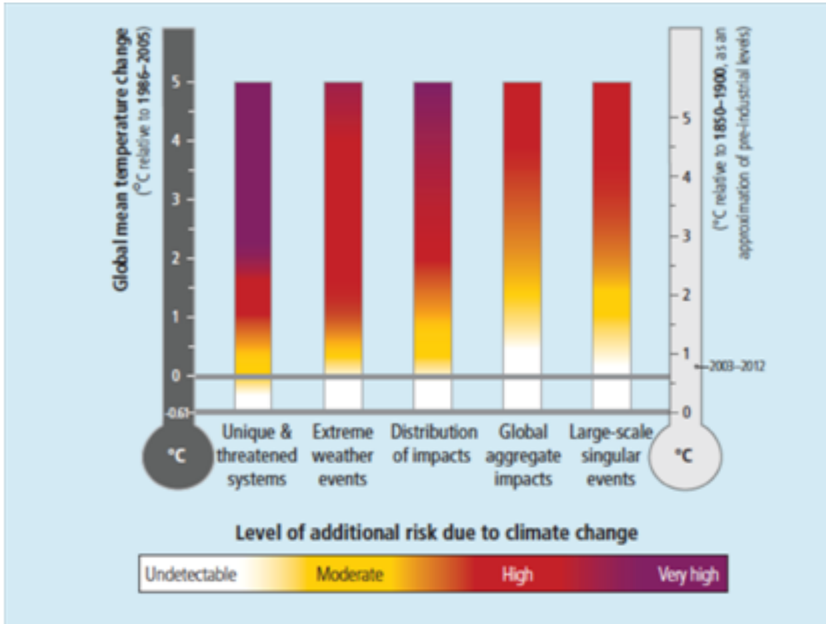

Figure 1. Risks at a global scale for increasing levels of climate change.

Determining the Required Amount and Timing of CO2 Emission Reductions

IPCC WGI used ensembles of different computer simulations to project global average surface temperature change through the 21st century and beyond using four uniform greenhouse gas emission pathway scenarios. These scenarios are called Representative Concentration Pathways (RCP) and range from aggressive reductions in emissions beginning around 2020 and leading to no net emissions before the end of the century (RCP2.6), to continued growth in emissions throughout the rest of the century (RCP8.5). The figure below shows the change in global average temperature (relative to 1986-2005) for these two scenarios as the multi-model means (solid colored lines, with number of models on which they depend indicated) and the 5 to 95% statistical range across the distribution of individual models. In other words, there is very high confidence that the global average surface temperature change would fall within the colored bands around the means. On the right, the means and statistical ranges for the last 20 years of the century are shown for all four RCP scenarios.

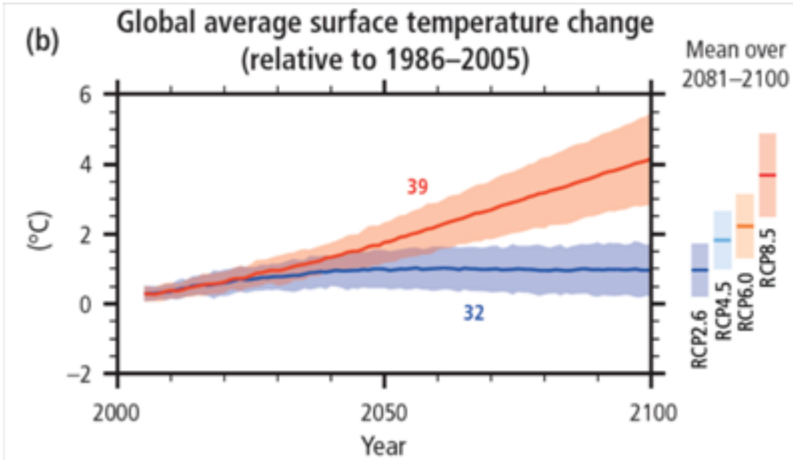

Figure 2. Global average temperature change for RCP scenarios.

It is clear that of the four RCPs only RCP2.6 would result in a high likelihood of keeping the change in global average temperature to less than 2°C—but this is relative to the 1986-2005 average temperature, not the pre-industrial benchmark discussed earlier. Even under RCP4.5, which entails substantial reductions in emissions beginning around mid-century, the change in global average temperature would likely exceed 2°C.

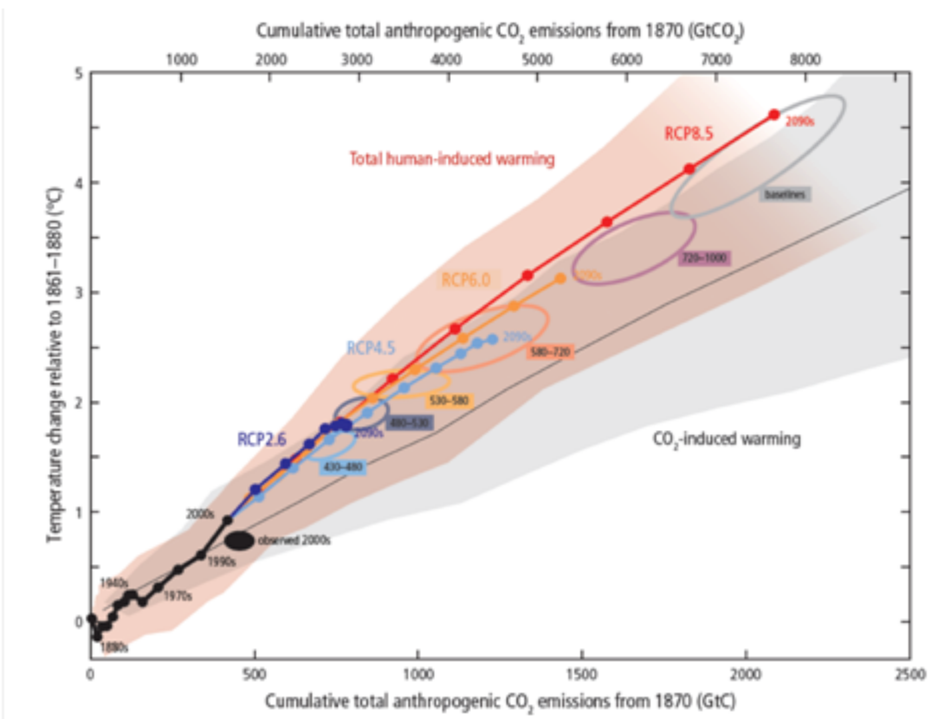

Figure 3. Global mean surface temperature increase as a function of cumulative global carbon dioxide (CO_2) emissions in gigatons of CO_2 ($GtCO_2$) or carbon (GtC).

Another way that the IPCC looked at this relationship of emissions pathways to temperature change was to compare the relationship of the cumulative total CO_2 emission from human

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sources since 1870 to the temperature change. This is appropriate because of the large role of CO_2 in total human induced warming and the long persistence of CO_2 in the atmosphere compared to other greenhouse gases. The relationship of cumulative CO_2 emissions through the century to temperature change is shown below in Figure 3.

This approach allowed to IPCC to consider cumulative emissions in the context of a budget constrained by how much CO_2 can be emitted over time and still keep the temperature change below 2°C. The black dots and lines show the historical pathway up to the 2000s as estimated by hincast computer simulations. Future pathways for the four RCPs used by the IPCC are also shown over the rest of this century. The ellipses show the ranges in total anthropogenic warming in 2100 versus cumulative emissions from a simpler climate model, labeled with the associated concentration ranges of greenhouse gases in parts per million (ppm) of CO_2-equivalents.

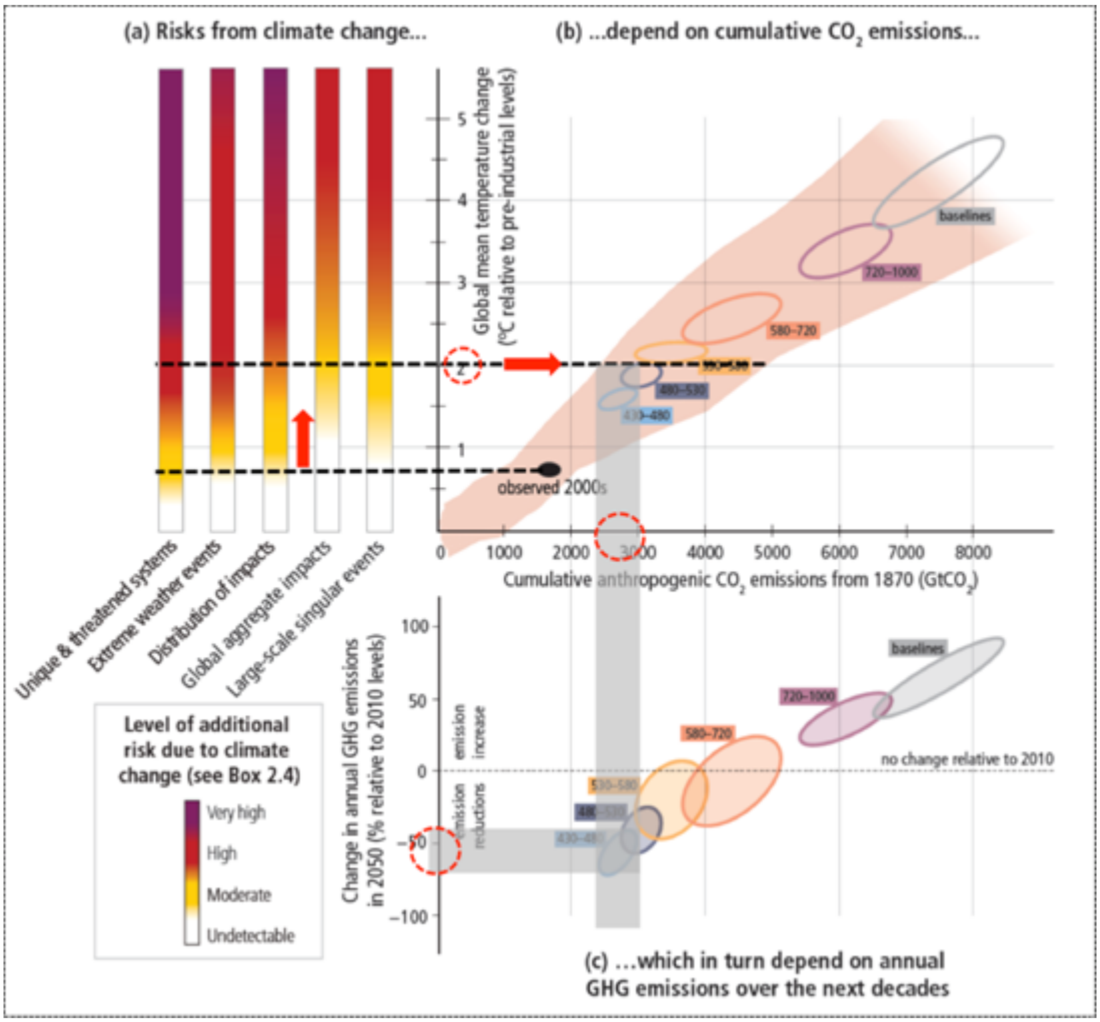

Figure 4. The relationships among risks from climate change, cumulative CO_2 emissions and changes in annual greenhouse gas emissions by 2050.

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This cumulative emissions approach allowed the IPCC to determine the reductions in greenhouse gas emissions that would be required over the few next decades in order to achieve a given greenhouse gas concentration range by the end of the century. This synthesis is shown in Figure 4, which relates the risks from climate change [(a) from Figure 1] with cumulative CO_2 emissions though this century [(b) from Figure 3]. From these cumulative emissions the amount of change in greenhouse gas emissions over the next decades that are required in order to achieve these cumulative amounts is then determined (c).

So, for example, if one wanted to insure that it the global mean temperature increase line would not likely cross 2°C, this would require constraining anthropogenic greenhouse gas concentrations to about 450 (430-480) ppm CO_2-eq. Thus, this would require constraining cumulative CO_2 emissions through this century to less than 3000 $GtCO_2$. This is equivalent to the RCP2.6 scenario. Achieving that objective would, in turn, require reducing annual greenhouse gas emissions somewhere between 41 to 72% (compared to 2010) by 2050, with the range reflective of the uncertainties included in the analyses of computer simulations.

From the extensive IPCC analyses using this approach the likelihood of staying below a specific increase in global mean temperature over the 21st century as a function of greenhouse gas emissions pathways is summarized in Table 1.

Table 1. Key characteristics of the scenarios assessed by IPCC. For all parameters the 10^{th} and 90^{th} percentile of the scenarios is shown.

<table>
<tr><th rowspan="2">CO_2-eq Concentrations in 2100 (ppm CO_2-eq)[f]
Category label (conc. range)</th><th rowspan="2">Subcategories</th><th rowspan="2">Relative position of the RCPs[d]</th><th colspan="2">Change in CO_2-eq emissions compared to 2010 (in %)[c]</th><th colspan="4">Likelihood of staying below a specific temperature level over the 21st century (relative to 1850–1900)[d,e]</th></tr>
<tr><th>2050</th><th>2100</th><th>1.5°C</th><th>2°C</th><th>3°C</th><th>4°C</th></tr>
<tr><td><430</td><td colspan="8">Only a limited number of individual model studies have explored levels below 430 ppm CO_2-eq[j]</td></tr>
<tr><td>450
(430 to 480)</td><td>Total range[a,g]</td><td>RCP2.6</td><td>−72 to −41</td><td>−118 to −78</td><td>More unlikely than likely</td><td>Likely</td><td rowspan="6">Likely</td><td rowspan="8">Likely</td></tr>
<tr><td rowspan="2">500
(480 to 530)</td><td>No overshoot of 530 ppm CO_2-eq</td><td></td><td>−57 to −42</td><td>−107 to −73</td><td rowspan="6">Unlikely</td><td>More likely than not</td></tr>
<tr><td>Overshoot of 530 ppm CO_2-eq</td><td></td><td>−55 to −25</td><td>−114 to −90</td><td>About as likely as not</td></tr>
<tr><td rowspan="2">550
(530 to 580)</td><td>No overshoot of 580 ppm CO_2-eq</td><td></td><td>−47 to −19</td><td>−81 to −59</td><td rowspan="3">More unlikely than likely[i]</td></tr>
<tr><td>Overshoot of 580 ppm CO_2-eq</td><td></td><td>−16 to 7</td><td>−183 to −86</td></tr>
<tr><td>(580 to 650)</td><td>Total range</td><td rowspan="2">RCP4.5</td><td>−38 to 24</td><td>−134 to −50</td></tr>
<tr><td>(650 to 720)</td><td>Total range</td><td>−11 to 17</td><td>−54 to −21</td><td rowspan="2">Unlikely</td><td>More likely than not</td></tr>
<tr><td>(720 to 1000)[b]</td><td>Total range</td><td>RCP6.0</td><td>18 to 54</td><td>−7 to 72</td><td rowspan="2">Unlikely[h]</td><td>More unlikely than likely</td></tr>
<tr><td>>1000[b]</td><td>Total range</td><td>RCP8.5</td><td>52 to 95</td><td>74 to 178</td><td>Unlikely[h]</td><td>Unlikely</td><td>More unlikely than likely</td></tr>
</table>

Limiting the increase in global mean temperature to 1.5 °C is unlikely under any emissions pathway that has been studied. Limiting the increase to 2°C would only be more likely than not if greenhouse gas emissions were reduced by at least 42% by 2050, but greater reductions are required to make this confidently likely. IPCC analyses not shown in this table further suggest that annual global greenhouse gas emissions would have to be reduced by about 25% by 2030 to achieve this pathway. This pathway would also require reducing net emissions to near-zero (by 78-118%) by 2100. Emissions reductions of greater than 100% implies that the rate of carbon sequestration (either by organic growth or capture and storage) would have to exceed emissions. Even to limit the increase in global mean temperature to 3°C (5.4°F) would entail reducing greenhouse gas emissions 24-38% by 2050 and near carbon neutrality by the end of the century.

Implications for Setting Maryland's Goals

It is important to understand that the IPCC's analyses are for global mean temperatures and global greenhouse gas emissions. Realized warming for Maryland will differ from the global average; in fact, because of our relatively high latitude, it is very likely to be greater. Furthermore, warming in Maryland will be controlled by global emission and not Maryland's own emissions. Of course, Maryland contributes only a small part of annual global greenhouse gas emissions, but a disproportionately large share on a per capita basis. Because of the higher per capita emissions rates in the United States it will be reasonably expected in international negotiations that U.S. commitments should be toward at least the higher end if not beyond the 41 to 72% reductions required by 2050 to avoid exceeding the 2°C warming goal, based on the IPCC analysis. On the other hand, per capita emissions in Maryland (11 metric tons per year) are less than the average for the United States (17 metric tons per year), so it might be argued that emission reductions in more energy intensive states should be more aggressive than that for Maryland. These considerations go beyond what the IPCC scientific analyses tell us.

In May 2015 the United States government submitted its intended nationally determined contribution to the United Nations, indicating that the U.S. had taken steps to reduce its GHG emissions by 17% below the 2015 baseline and intended to achieve an economy-wide target of reducing emissions by 26-28% by 2025, making best efforts to reduce emissions by at least 28%. If that trend in emissions reduction were continued, it would result in an 80% reduction in emissions by 2050. If, for example, Maryland achieves its goal of reducing GHG emissions by 25% by 2020 and plans to reduce emissions to 72% of 2006 levels by 2050, a 40% reduction by 2030 would be required assuming steady progress (i.e., a linear trend in emission reductions).

The leaders of the Group of Seven nations agreed in June 2015 to limit global warming to 2°C and declared their support for 40 to 70% reductions in greenhouse gas emissions by 2050 (compared to 2010 levels). A month earlier California, Vermont, Oregon and Washington joined in a nonbinding "Under 2 MOU" with states and regions in Germany, the United Kingdom, Brazil, Germany, Mexico, Spain, Columbia and Canada that commits them to either reduce greenhouse gas emissions by 80-95% by 2050 or achieve a per-capita annual emissions target of less than 2 metric tons per year.

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