This Appendix is based upon material provided by the University of Maryland Center for Environmental Science.

Frequently Used Abbreviations and Acronyms

CO_2: Carbon Dioxide
IPCC: Intergovernmental Panel on Climate Change
RCP: Representative Concentration Pathways

Introduction

Science has demonstrated with a high degree of certainty that Earth's climate is being changed by human activities, particularly the emission of heat-trapping gases, generally called greenhouse gases, including carbon dioxide, methane, and nitrous oxide. Science has also provided a reliable description of (1) how further emissions will warm the Earth, (2) how this will alter the climate and have consequences for human society and the natural systems on which it depends, and (3) the amount and timing of reductions in emissions needed to limit climate change in order to avoid its most harmful consequences.

Maryland's **Greenhouse Gas Reductions Act of 2009** requires the State to reduce Statewide greenhouse gas emissions by 25% from 2006 levels by 2020. The Act further directs the Maryland Department of the Environment to report on "the greenhouse gas emissions reductions needed by 2050 in order to avoid dangerous anthropogenic changes to the Earth's climate system, based on the predominant view of the scientific community" on or before 2020.

The **Maryland Climate Change Commission**, established by Executive Order in 2007, was responsible for laying the groundwork for the Greenhouse Gas Reduction Act by developing a Climate Action Plan in 2008. During the 2015 Session the Maryland General Assembly passed House Bill 514, which codified the Maryland Climate Change Commission. House Bill 514 was signed into law by Governor Hogan and became effective on June 1, 2015. Among the actions the Commission is charged to undertake include "maintaining a comprehensive action plan, with 5-year benchmarks, to achieve science-based reductions in Maryland's greenhouse gas emissions." Toward this end, the Commission's Mitigation Working Group requested advice from the **Scientific and Technical Working Group (STWG)** to inform its considerations of the greenhouse gas emissions reductions that should be pursued beyond 2020 in the preparation of the Commission's first annual report, due on November 15, 2015.

The STWG provided its interim appraisal of the scientific basis for setting targets for emissions reductions beyond 2020. This appraisal is founded on the Fifth Assessment of the **Intergovernmental Panel on Climate Change (IPCC)** that was completed in 2014, over five years after the enactment of Maryland's Greenhouse Gas Reductions Act. This reliance is appropriate because the IPCC assessment was both comprehensive (integrating global and regional climate and emission trends, credible evaluation of likely future impacts, and state-of-the-art projections of climate change as a function of global greenhouse gas emissions) and subjected to extensive internal and external review. The IPCC Fifth Assessment is the most through and recent scientific appraisal available of greenhouse gas emissions reduction pathways and is accepted and relied on by nations around the world.

The IPCC Fifth Assessment includes an evaluation of the amount and timing of reductions in greenhouse gas emissions required globally in order to avoid increases in global average temperature and associated climate disruption that would result in dangerous risks to society and the natural systems on which it depends. It is appropriate that these scientifically determined pathways inform the determination of greenhouse gas reduction targets for Maryland. It is also understood that the Commission's recommendations will also take into account additional economic, social and political factors that go beyond the science. For example, in June 2015 the leaders of the Group of Seven industrialized nations agreed to take steps to phase out fossil fuel use by the end of this century. The national commitments the United States will make during the United Nations Conference on Climate Change to be held in Paris in November and December of 2015 will be particularly consequential for Maryland's reduction pathway. These international deliberations have been and will be informed principally by the IPCC scientific assessment.

IPCC Approach

The Intergovernmental Panel on Climate Change (IPCC) is the international body for assessing the science related to climate change. It was initiated in 1988 by the World Meteorological Organization and the United Nations Environment Program to provide policymakers with regular assessments of the scientific basis of climate change, its impacts and future risks, and options for adaptation and mitigation1, IPCC assessments are written by prominent scientists who serve as lead or contributing authors. The assessments undergo multiple rounds of drafting and peer review. The last assessment, completed in 2014, was the IPCC's fifth and had 235 authors from 58 countries and received and considered over 38,000 comments on drafts.

The IPCC Fifth Assessment presents the results of three working groups:

- Working Group I (WGI) addressed *The Physical Science Basis*, including climate observations; ancient climate archives; carbon and other biogeochemical cycles; anthropogenic and natural forces that affect the retention of heat from solar radiation; evaluation of climate models; detection and attribution of climate change; and near and long-term projections of climate change and sea level change.
- Working Group II (WGII) addressed *Impacts, Adaptation and Variability*, including observed impacts; vulnerability and adaptation; future risks and opportunities for adaptation; and managing future risks and building resilience.
- Working Group III (WGIII) addressed *Mitigation of Climate Change*, including approaches to climate change mitigation; trends in stocks and flows of greenhouse gases and their drivers; mitigation pathways and measures; and mitigation policies and institutions.

The determination of appropriate pathways for reductions of greenhouse gases requires the integration of the analyses of all three IPCC working groups. This integration is brought together in separate **Climate Change 2014 Synthesis Report**. The results and graphs presented here come from the Synthesis Report.

Rationale for Limiting Global Warming to 2°C

The degree of global warming and climate disruption we will experience in the future depends on the concentration of greenhouse gases in the atmosphere. These greenhouse gases accumulate in the atmosphere over time. Once released into the atmosphere carbon dioxide, in particular, can persist there for hundreds of years if not taken up by growing vegetation or dissolved in the ocean. Once elevated, the concentrations of these greenhouse gases decline slowly. Complex computer simulations, or models as they are called, estimate the net accumulation of greenhouse gases in the atmosphere and, based on their known heat-trapping properties, estimate the degree of warming over the planet. The higher the accumulated greenhouse gas concentrations, the warmer the average temperature over the surface of Earth (in the air and oceans) will become. Thus, the emissions pathway that we chose to take depends on the degree of warming we are willing to risk.

IPCC WGII assessed the likely consequences of increased global temperature and associated climate disruption in five Reasons for Concern: unique and threatened systems, extreme weather events, distribution of impacts, global aggregate impacts, and large-scale singular events (Figure 1). For each of these criteria WGII rated the global mean temperature change at which risks from climate disruption would be undetectable, moderate, high or very high. Note that Earth has already (2003-2012 average) experienced an increase in global mean temperature of about 0.8°C (1.4°F) when measured from the benchmark of pre-industrial conditions (1850-1900).

Based on the IPCC analysis, risks become moderate for some criteria and high for others as the global mean temperature increase exceeds 2°C (3.6°F). Based on the analyses in both the IPCC Fourth and Fifth Assessment, avoiding an increase of greater than 2°C has become an internationally accepted goal. Some scientists have argued that limiting the increase in global mean temperature to 1.5°C or less would be a more prudent goal and that serious irreversible impacts would occur if that level of warming were exceeded. On the other hand, an increase in global mean temperature of 3°C or more would impose high to very high risks across all of the Reasons of Concern criteria.

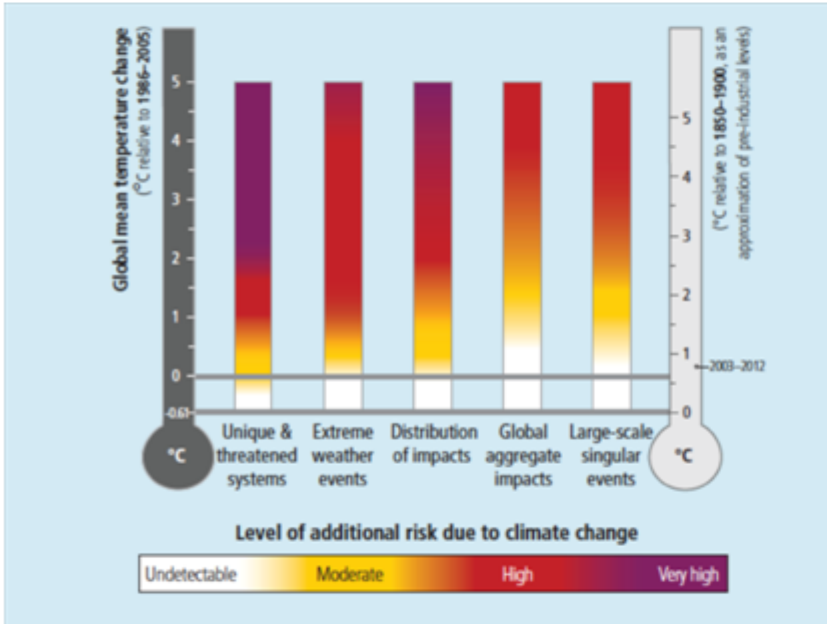

Figure 1. Risks at a global scale for increasing levels of climate change.

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.

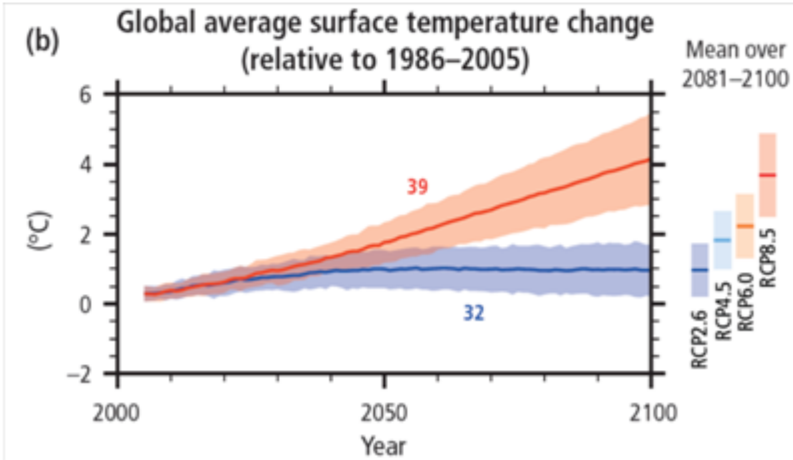

Figure 2. Global average temperature change for RCP scenarios.

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.

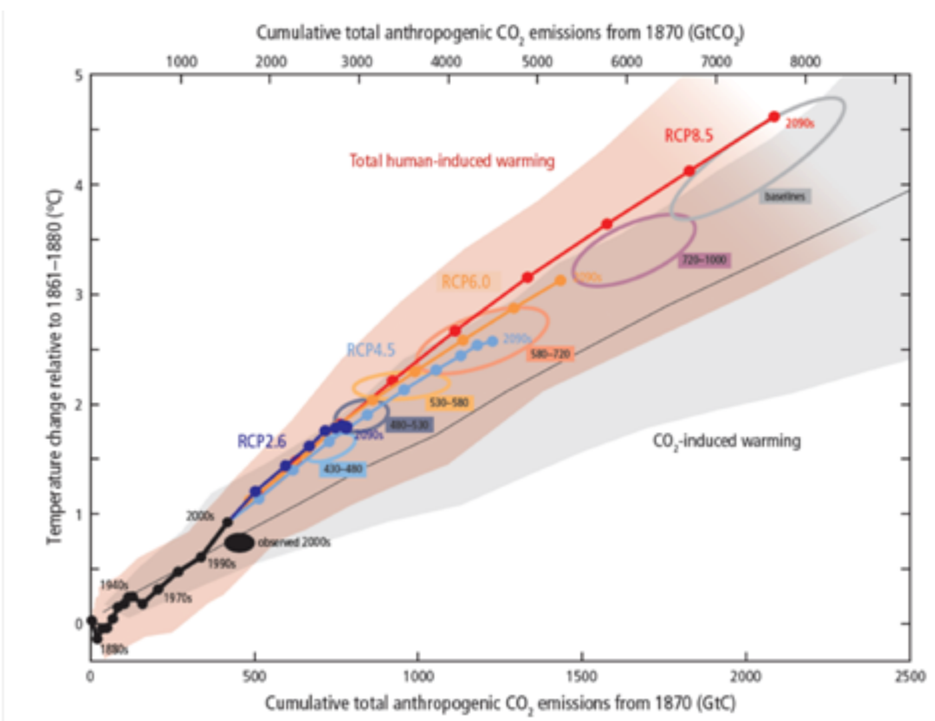

Figure 3. Global mean surface temperature increase as a function of cumulative global carbon dioxide (CO_2) emissions in gigatons of CO_2 ($GtCO_2$) or carbon (GtC).

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.

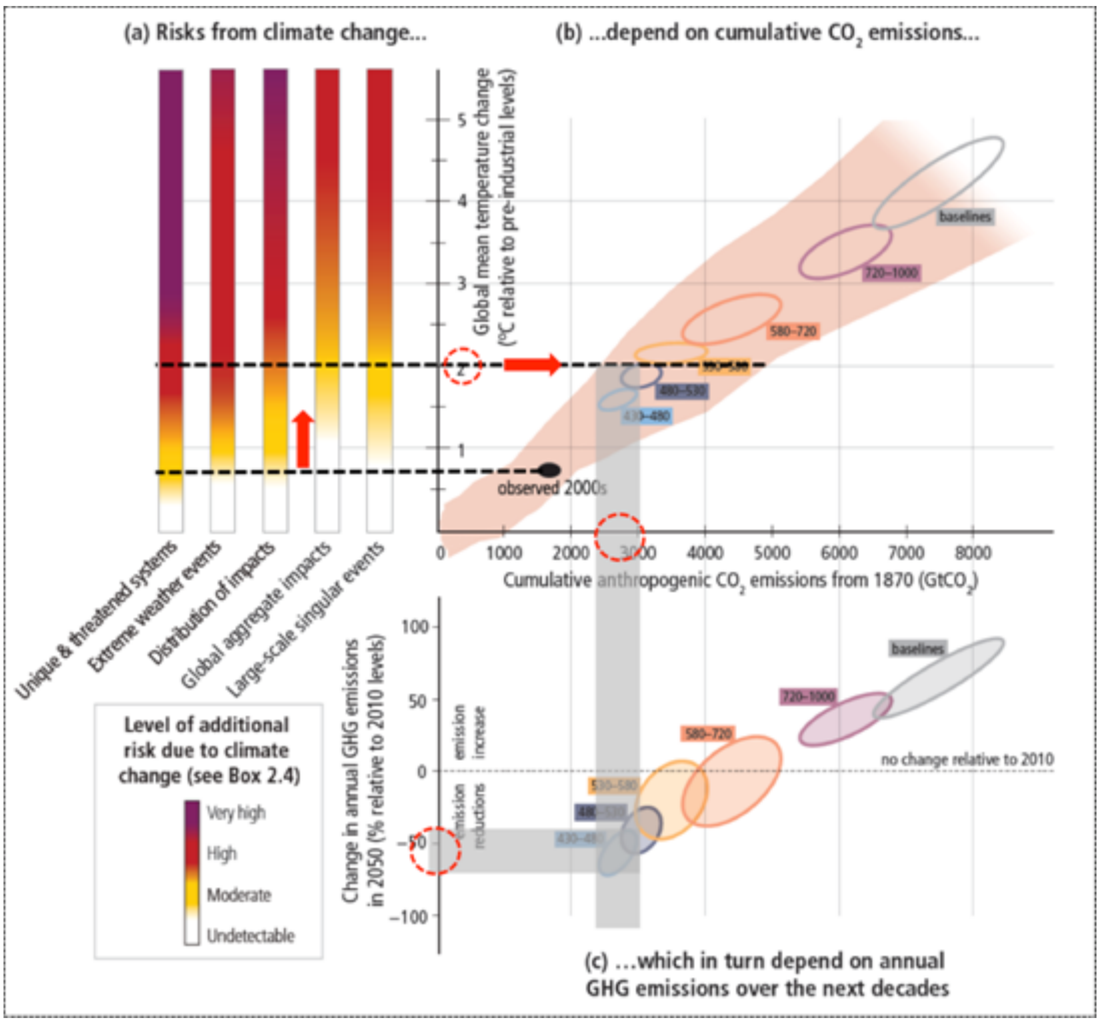

Figure 4. The relationships among risks from climate change, cumulative CO_2 emissions and changes in annual greenhouse gas emissions by 2050.

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

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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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