Overview of Results

This section provides an overview of the national and regional results for all sectors included in the report. The National Highlights section presents the estimated physical and monetary benefits (avoided impacts) to the U.S. of the global GHG mitigation scenario compared to the Reference scenario in 2050 and 2100.

The Regional Highlights section shows regional impacts that are particularly notable, presenting changes in both the Reference and Mitigation scenarios to highlight the potential benefits of global GHG mitigation. The individual monetized estimates presented in these sections are not aggregated, as there are differences in the types of costs being quantified across sectors; furthermore, not all potential impacts of climate change are represented in this report.

National Highlights

This section provides an overview of the national-scale results presented throughout this report. It presents the estimated physical and monetary benefits (avoided impacts) to the U.S. of global GHG mitigation compared to the Reference scenario in the years 2050 and 2100. Although not available for all sectors, cumulative benefits for the entire 21st century would likely be much larger than the annual estimates presented here. In addition, the individual monetized estimates are not aggregated, as only a subset of climate change impacts is quantified in this report, and there are differences in the types of costs being quantified across the sectors. For detailed information on the results, and a summary of the methodologies used, please refer to the Sectors section of this report.

	In the year 2050, global GHG mitigation is projected to result in...	In the year 2100, global GHG mitigation is projected to result in...
HEALTH		
AIR QUALITY	An estimated 13,000 fewer deaths from poor air quality, valued at $160 billion.*	An estimated 57,000 fewer deaths from poor air quality, valued at $930 billion.*
EXTREME TEMPERATURE	An estimated 1,700 fewer deaths from extreme heat and cold in 49 major U.S. cities, valued at $21 billion.	An estimated 12,000 fewer deaths from extreme heat and cold in 49 major U.S. cities, valued at $200 billion.
LABOR	An estimated avoided loss of 360 million labor hours, valued at $18 billion.	An estimated avoided loss of 1.2 billion labor hours, valued at $110 billion.
WATER QUALITY	An estimated $507-$700 million in avoided damages from poor water quality.†	An estimated $2.6-$3.0 billion in avoided damages from poor water quality.†
INFRASTRUCTURE		
BRIDGES	An estimated 160-960 fewer bridges made structurally vulnerable, valued at $0.12-$1.5 billion.†	An estimated 720-2,200 fewer bridges made structurally vulnerable, valued at $1.1-$1.6 billion.†
ROADS	An estimated $0.56-$2.3 billion in avoided adaptation costs.†	An estimated $4.2-$7.4 billion in avoided adaptation costs.†
URBAN DRAINAGE	An estimated $56 million to $2.9 billion in avoided adaptation costs from the 50-year, 24-hour storm in 50 U.S. cities.†	An estimated $50 million to $6.4 billion in avoided adaptation costs from the 50-year, 24-hour storm in 50 U.S. cities.†
COASTAL PROPERTY	An estimated $0.14 billion in avoided damages and adaptation costs from sea level rise and storm surge.	An estimated $3.1 billion in avoided damages and adaptation costs from sea level rise and storm surge.
ELECTRICITY		
DEMAND AND SUPPLY	An estimated 1.1%-4.0% reduction in energy demand and $10-$34 billion in savings in power system costs.‡	Not estimated.

* These results do not reflect the additional benefits to air quality and human health that would stem from the co-control of traditional air pollutants along with GHG emissions.

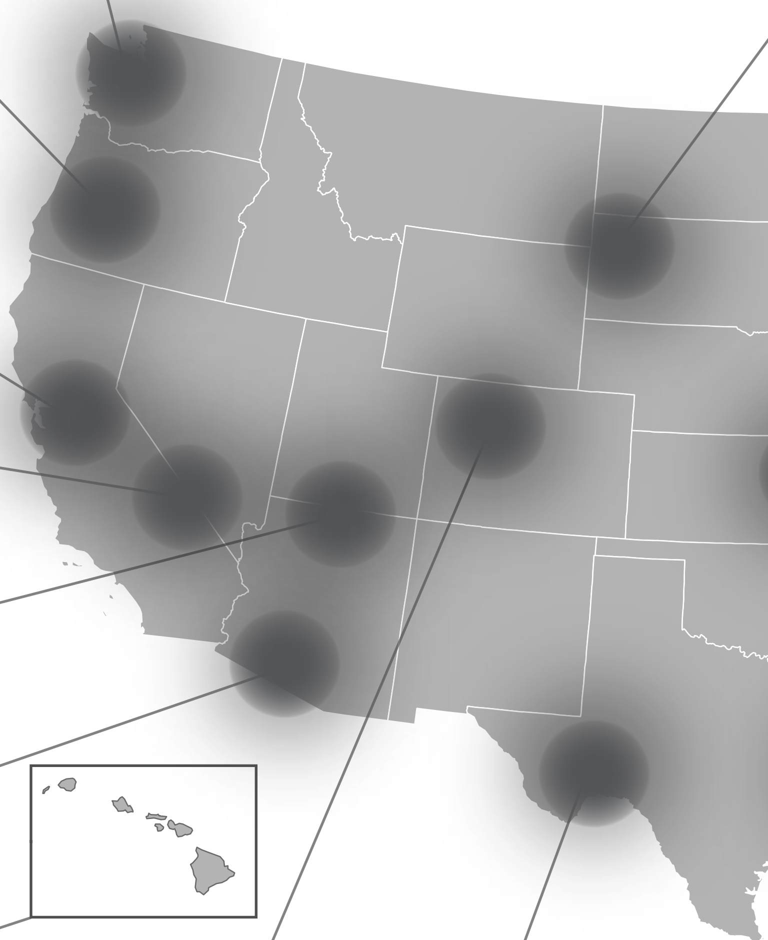
† For sectors sensitive to changes in precipitation, the estimated range of results is generated using projections from two climate models showing different patterns of future precipitation in the contiguous U.S. The IGSM-CAM model projects a relatively "wetter" future for most of the contiguous U.S. compared to the "drier" MIROC model (see the CIRA Framework section of this report for more information).

‡ Estimated range of benefits from the reduction in demand and system costs resulting from lower temperatures associated with GHG mitigation. The electricity section in this report presents an analysis that includes the costs to the electric sector of reducing GHG emissions.

	In the year 2050, global GHG mitigation is projected to result in...	In the year 2100, global GHG mitigation is projected to result in...
WATER RESOURCES		
INLAND FLOODING	An estimated change in flooding damages ranging from $260 million in damages to $230 million in avoided damages.†	An estimated change in flooding damages ranging from $32 million in damages to $2.5 billion in avoided damages.†
DROUGHT	An estimated 29%-45% fewer severe and extreme droughts, with corresponding avoided damages to the agriculture sector of approximately $1.2-$1.4 billion.†	An estimated 40%-59% fewer severe and extreme droughts, with corresponding avoided damages to the agriculture sector of $2.6-$3.1 billion.†
WATER SUPPLY AND DEMAND	An estimated $3.9-$54 billion in avoided damages due to water shortages.†	An estimated $11-$180 billion in avoided damages due to water shortages.†
AGRICULTURE & FORESTRY		
AGRICULTURE	An estimated $1.5-$3.8 billion in avoided damages.	An estimated $6.6-$11 billion in avoided damages.
FORESTRY	Estimated damages of $9.5-$9.6 billion.	An estimated $520 million to $1.5 billion in avoided damages.
ECOSYSTEMS		
CORAL REEFS	An estimated avoided loss of 53% of coral in Hawaii, 3.7% in Florida, and 2.8% in Puerto Rico. These avoided losses are valued at $1.4 billion.	An estimated avoided loss of 35% of coral in Hawaii, 1.2% in Florida, and 1.7% in Puerto Rico. These avoided losses are valued at $1.2 billion.
SHELLFISH	An estimated avoided loss of 11% of the U.S. oyster supply, 12% of the U.S. scallop supply, and 4.6% of the U.S. clam supply, with corresponding consumer benefits of $85 million.	An estimated avoided loss of 34% of the U.S. oyster supply, 37% of the U.S. scallop supply, and 29% of the U.S. clam supply, with corresponding consumer benefits of $380 million.
FRESHWATER FISH	An estimated change in recreational fishing ranging from $13 million in avoided damages to $3.8 million in damages.†	An estimated $95-$280 million in avoided damages associated with recreational fishing.†
WILDFIRE	An estimated 2.1-2.2 million fewer acres burned and corresponding avoided wildfire response costs of $160-$390 million.†	An estimated 6.0-7.9 million fewer acres burned and corresponding avoided wildfire response costs of $940 million to $1.4 billion.†
CARBON STORAGE	An estimated 26-78 million fewer metric tons of carbon stored, and corresponding costs of $7.5-$23 billion.†	An estimated 1-26 million fewer metric tons of carbon stored, and corresponding costs of $880 million to $12 billion.†

Regional Highlights

This section highlights regional impacts of climate change in the U.S. For each sector, the map presents a region where substantial benefits of global GHG mitigation are projected to occur in the years 2050 or 2100.* Note that the geographic scale at which impacts are →

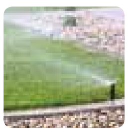


SHELLFISH

Acidification in the Pacific Northwest is already affecting U.S. shellfish harvests. The U.S. supplies of oysters, clams, and scallops are projected to decline 45%, 32%, and 48%, respectively, in the Reference scenario in 2100, compared to 11%, 3%, and 11%, respectively, in the Mitigation scenario.

CARBON STORAGE

The Northwest is projected to experience a 6.1% decrease in terrestrial carbon storage in 2100 under the Reference scenario, compared to a 2.4% decrease in the Mitigation scenario.



WATER SUPPLY AND DEMAND

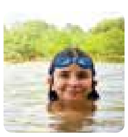
California is projected to incur $4.5 billion in damages in 2100 due to changes in water supply and demand in the Reference scenario. However, climate change under the Mitigation scenario is projected to result in an increase in welfare of $40 million.

LABOR

In 2100, the Southwest is projected to experience a 3.4% decrease in high-risk labor hours worked in the Reference scenario, compared to a decrease of 0.82% in the Mitigation scenario.

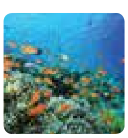
DROUGHT

In the Southwest, the number of severe and extreme droughts is projected to nearly quadruple by the end of the century in the Reference scenario compared to today. In the Mitigation scenario, the incidence of drought is not projected to change substantially from present day.



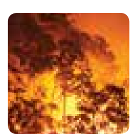
WATER QUALITY

The Southwest is projected to experience water quality damages of approximately $1.8 billion in 2100 under the Reference scenario, compared to $470 million in the Mitigation scenario.



CORAL REEFS

By the end of the century, Hawaii is projected to lose 98% of its current shallow-water coral in the Reference scenario, compared to 64% in the Mitigation scenario.



WILDFIRE

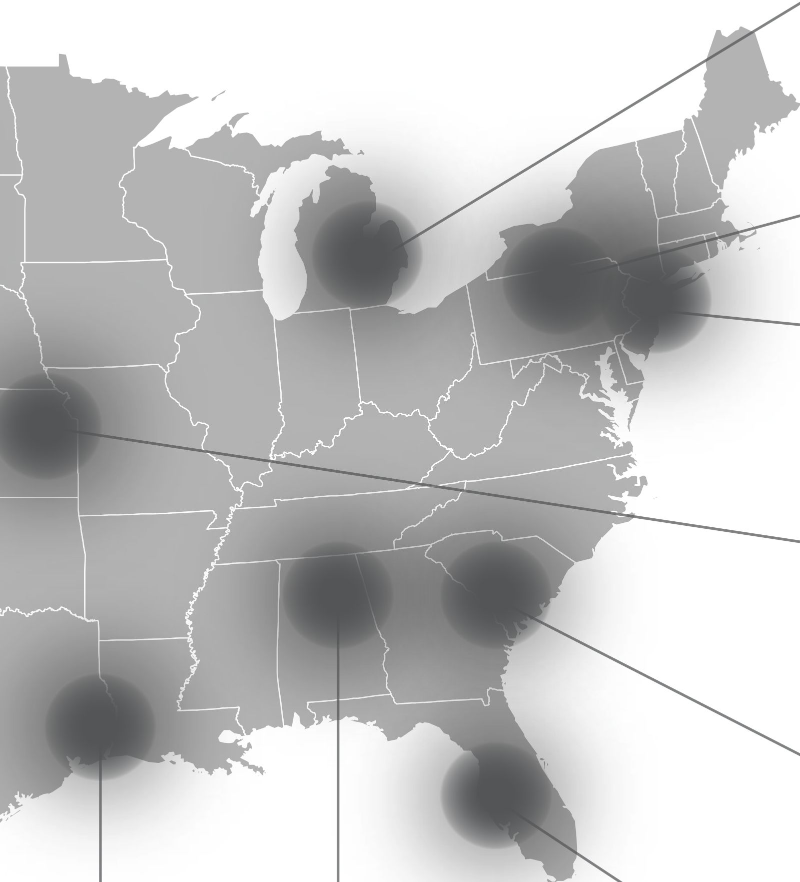
In the Rocky Mountains, an estimated 1.9 million more acres are projected to burn in 2100 under the Reference scenario compared to today. In the Mitigation scenario, an estimated 1.5 million fewer acres are projected to burn compared to today.

INLAND FLOODING

In Texas, projected damages associated with the 100-year flood event are $3.6 billion in 2100 under the Reference scenario, compared to $2.6 billion in the Mitigation scenario.

* Estimates are presented in undiscounted 2014 dollars and rely upon climate projections from the IGSM-CAM climate model. Results using projections from other climate models, such as the MIROC model used throughout this report, could lead to variations in results for some sectors.

quantified in the sectoral analyses vary. For example, some of the analyses calculate impacts for large watersheds, while others use the National Climate Assessment regions. For purposes of highlighting regional impacts, this section approximates the regions.



ROADS

In 2100, the Great Plains region is projected to incur road damages of approximately $3.5 billion in the Reference scenario, compared to $1.1 billion in the Mitigation scenario.

BRIDGES

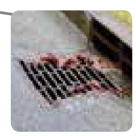
In the Great Lakes region, approximately 520 bridges are projected to be vulnerable in 2100 under the Reference scenario, compared to 65 in the Mitigation scenario.

FRESHWATER FISH

Throughout the Appalachians, global GHG mitigation is projected to preserve approximately 70% of habitat for coldwater fish species (e.g., trout) that would otherwise be lost by the end of the century to rising temperatures from unmitigated climate change.

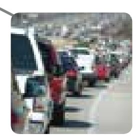
EXTREME TEMPERATURE

Without mitigation, major cities in the Northeast from D.C. to Boston are projected to suffer a combined 2,600 extreme temperature mortalities in 2100, compared to 190 in the Mitigation scenario.



URBAN DRAINAGE

In 2100, major cities analyzed in the Great Plains are estimated to incur $2.1 million per square mile in damages associated with urban drainage systems in the Reference scenario, compared to $750,000 per square mile in the Mitigation scenario.



AIR QUALITY

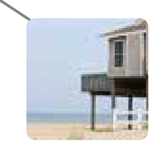
In 2100, areas of the Southeast are projected to experience an annual increase in ozone (O_3) and fine particulate matter ($PM_{2.5}$) of 0.7 ppb and 1 $\mu g/m^{-3}$, respectively. In the Mitigation scenario, the levels of O_3 and $PM_{2.5}$ are projected to decrease by 120% and 88%, respectively, compared to the Reference.

ELECTRICITY DEMAND

The South Central region is projected to experience a 2.0% to 4.2% increase in electricity demand under the Reference scenario in 2050. In the Mitigation scenario, the projected change in demand ranges from -1.4% to 1.6%.

AGRICULTURE

In the Southeast, yields of irrigated soybeans are projected to decrease 23% in 2100 under the Reference scenario. Under the Mitigation scenario, yields are projected to increase 4.7%.



COASTAL PROPERTY

In 2100, the Tampa Bay area is projected to incur $2.8 billion in damages from sea level rise and storm surge in the Reference scenario without adaptation. When adaptation measures are implemented, total costs in 2100 fall to $500 million in the Reference scenario, compared to $450 million in the Mitigation scenario.

Conclusion

Understanding the potential timing and magnitude of climate change impacts in the U.S., and how they could be reduced or avoided through GHG mitigation, informs near- and long-term policies to address these risks. This report describes climate change damages in the U.S. across multiple sectors using a consistent set of scenarios and underlying assumptions.[1] In doing so, the study estimates the physical and economic risks of unmitigated climate change and the potential benefits to the U.S. of reducing global GHG emissions. Importantly, only a small portion of the impacts of climate change are estimated, and therefore this report captures just some of the total benefits of reducing GHGs. Looking across the large number of sectoral impacts described in this report, a number of key findings emerge:

- **Unmitigated climate change is projected to profoundly affect human health, the U.S. economy, and the environment.** The CIRA analyses demonstrate substantial and far-reaching changes over the course of the 21st century—and particularly at the end of the century—with negative consequences for a large majority of the impact sectors. In addition, the analyses suggest that climate change impacts will not be uniform across the U.S., with most sectors showing a complex pattern of regional-scale impacts.
- **Global action to mitigate GHG emissions is projected to reduce and avoid impacts in the U.S. that would otherwise occur in a future with continued high growth in GHG emissions.** Importantly, these benefits are projected to increase over the course of the century. The analyses indicate that risks and impacts over the long term will not be avoided unless there is near-term action to significantly reduce GHG emissions. This report presents benefits for one illustrative global GHG mitigation scenario. More stringent emissions reductions would likely increase the benefits compared to the Reference scenario, and, conversely, less stringent reductions would likely decrease the benefits.
- **Global GHG mitigation substantially reduces the risk of some extreme weather events and their subsequent impacts on human health and well-being by the end of the century.**
- **Adaptation, especially in the infrastructure sector, can substantially reduce the estimated damages of climate change.** For some impacts, such as those described in the Coastal Property section, well-timed adaptation can have a larger effect on reducing the risks of inaction than global GHG mitigation, particularly in the near term, highlighting the need for concurrent mitigation and adaptation actions.

- **For some impacts, the effects of global GHG mitigation can vary across different projections of future climate.** This is particularly true for those sectors sensitive to changes in precipitation. For a few of these sectors, mitigation results in either benefits or disbenefits depending upon the simulated level of future precipitation.[2] By analyzing multiple types of impacts by sector, such as flooding, drought, water quality, and supply/demand in the water realm, and using a range of projections for future precipitation, a more comprehensive understanding of potential impacts and mitigation benefits is gained.

Next Steps

This report represents a significant and important contribution to estimating the multi-sectoral benefits to the U.S. of global GHG mitigation. Although the results presented in this report do not provide comprehensive coverage of all potential impacts, the breadth and depth of the analyses will expand in future work within the CIRA project. Comprehensive and quantitative estimates of climate change impacts are not only needed to evaluate the benefits of GHG mitigation, but also to evaluate the cost-effectiveness of adaptation responses, and to support the improvement of other economic tools used to analyze climate and energy policies. Although CIRA only begins to capture many of the dynamics and uncertainties involved in impact analysis (e.g., interactions among sectoral models), this report provides timely and quantitative estimates as the science continues to advance in this field. Future work to refine projections of how GHG emissions affect the climate, and how these changes affect society and the environment, will improve our understanding and confidence in the estimates presented in this report.

Additional Climate Change Resources

EPA's Climate Change website (www.epa.gov/climatechange) provides a good starting point for further exploration of this topic. From this site, you can:

- Read about greenhouse gas emissions, look through EPA's greenhouse gas inventories, and explore EPA's Greenhouse Gas Data Publication Tool.
- Learn about EPA's regulatory initiatives and partnership programs.
- Find out what you can do at home, on the road, at work, and at school to help reduce greenhouse gas emissions.

Other government and nongovernment websites also provide information about climate change. Here are some examples:

- The Intergovernmental Panel on Climate Change (IPCC) is the international authority on climate change science. The IPCC website (www.ipcc.ch/index.htm) summarizes the current state of scientific knowledge about climate change and includes links to their most recent Fifth Assessment Report.
- The U.S. Global Change Research Program (www.globalchange.gov) is a multi-agency effort focused on improving our understanding of the science of climate change and its potential impacts on the U.S. through reports like the National Climate Assessment.

Finally, other groups are working to estimate the impacts of climate change in the U.S. and/or other world regions. Here are some examples:

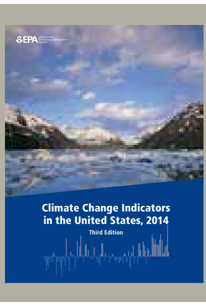
- The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP; https://www.pik-potsdam.de/research/climate-impacts-and-vulnerabilities/research/rd2-cross-cutting-activities/isi-mip) is an international, community-driven modelling effort bringing together impact models across sectors and scales.
- The Risky Business Project (http://riskybusiness.org/) focuses on quantifying and publicizing the economic risks from the impacts of a changing climate in the U.S.
- The European Commission Joint Research Centre's PESETA II project (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis; http://peseta.jrc.ec.europa.eu/) is a consistent multi-sectoral assessment of the impacts of climate change in Europe.

- AVOID (http://www.metoffice.gov.uk/avoid/) is a research program that provides modeling and scientific information to the U.K. Government on avoiding dangerous climate change brought on by greenhouse gas emissions.
- The project on the Benefits of Reduced Anthropogenic Climate Change (BRACE; https://chsp.ucar.edu/brace) focuses on differences in impacts resulting from climate change driven by high and low emissions scenarios.

Observed Climate Change

Climate Change Indicators in the United States: EPA publishes a set of indicators describing trends related to the causes and effects of climate change. Focusing primarily on the U.S., this resource presents compelling evidence that many fundamental measures of observed climate are changing.

Please visit EPA's website for more information: http://www.epa.gov/climatechange/science/indicators/index.html



Endnotes

INTRODUCTION

1 Martinich, J., J. Reilly, S. Waldhoff, M. Sarofim, and J. McFarland, Eds. 2015. Special Issue on "A Multi-Model Framework to Achieve Consistent Evaluation of Climate Change Impacts in the United States." *Climatic Change*.

2 While beyond the scope of this report, analyses of the adequacy of current GHG mitigation efforts, at domestic and global scales, relative to the magnitude of climate change risks are described in the assessment literature. See: 1) Jacoby, H. D., A. C. Janetos, R. Birdsey, J. Buizer, K. Calvin, F. de la Chesnaye, ... and J. West. 2014. Ch. 27: Mitigation. In *Climate Change Impacts in the United States: The Third National Climate Assessment,* J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds. U.S. Global Change Research Program. DOI:10.7930/J0C8276J; and 2) IPCC. 2014. Climate Change 2014: Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, ... and J.C. Minx, Eds. New York, NY: Cambridge University Press.

3 United Nations Framework Convention on Climate Change. 2013. Report of the Conference of the Parties on its nineteenth session, held in Warsaw from November 11-23, 2013. Part one: Proceedings. FCCC/CP/2013/10.

4 CIRA uses sectoral impact models driven by consistent climate and socioeconomic scenarios to analyze both physical impacts and economic damages of climate change at national and regional scales in the U.S. This unique multi-model design allows for 'apples-to-apples' comparisons of impacts and benefits of global GHG mitigation across sectors, but is not comprehensive in scope. The impact estimates presented in this report are consistent with the key findings of the U.S. Global Change Research Program's Third National Climate Assessment. See Section H of the Technical Appendix for this report for a more detailed comparison of key findings.

5 The Social Cost of Carbon (SCC) is a metric that estimates the economic value of impacts associated with the global emission of one ton of carbon dioxide (CO_2) or, conversely, the economic benefit of avoiding or reducing one ton of CO_2 (in dollars per ton of CO_2 in a given year). Unlike CIRA, the SCC draws from models of anticipated climate change impacts and benefits across the entire globe, not just for the U.S. The SCC has already been applied to estimate the global economic benefits of CO_2 emission reductions from certain U.S. regulations, but it does not provide explicit information about how the actual physical impacts in specific sectors of the U.S. may change over time and space. For more information, see: U.S. Interagency Working Group on the Social Cost of Carbon. 2013. Technical support document: Technical update of the social cost of carbon for regulatory impact analysis under Executive Order 12866.

6 The CIRA project estimates the benefits to the U.S. of global action on climate change. Importantly, the costs of GHG mitigation are not assessed in the project. As such, the analysis presented in the report does not constitute a cost-benefit assessment of climate policy. The costs of reducing GHG emissions have been well examined in the scientific literature (see references below), where recent assessments have used multiple economic models to investigate the sensitivity of costs to policy design, assumptions about the availability of low carbon-emitting energy technologies, socioeconomic and demographic changes, and other important sources of uncertainty. The one instance in the CIRA project where mitigation costs are considered is in the electricity sector (see Electricity section for details). For that sector, the impact of climate change on costs to the U.S. electric power system is estimated along with the costs associated with GHG emission reductions in that sector. See: Fawcett, A., L. Clarke, and J. Weyant. 2013. Introduction to EMF 24. *The Energy Journal.* DOI:10.5547/01956574.35.SI1.1; White House Council of Economic Advisors. 2014. The Cost of Delaying Action to Stem Climate Change. Executive Office of the President of the United States; CCSP. 2007. Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations (Part A) and Review of Integrated Scenario Development and Application (Part B). *A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research,* Clarke, L., J. Edmonds, J. Jacoby, H. Pitcher, J. Reilly, R. Richels, ... and M. Webster (Authors). Washington, DC: Department of Energy; Kriegler, E., J.P. Weyant, G.J. Blanford, V. Krey, L. Clarke, J. Edmonds, ... and D.P van Vuuren. 2013. The role of technology for achieving climate policy objectives: overview of the EMF 27 study on global technology and climate policy strategies. *Climatic Change*. DOI:10.1007/s10584-013-0953-7; and Kriegler, E., K. Riahi, N. Bauer, V.J. Schwanitz, N. Petermann, V. Bosetti, ... and O. Edenhofer. 2015. Making or breaking climate targets: the AMPERE study on staged accession scenarios for climate policy. *Technological Forecast and Social Change*. DOI:10.1016/j.techfore.2013.09.021; *Energy Economics*. Volume 31, Supplement 2, Pages S63-S306 (2009). International, U.S. and E.U. Climate Change Control Scenarios: Results from EMF 22. Edited by Leon Clarke, Christoph Böhringer and Tom F. Rutherford.

7 Example of co-benefit literature: IPCC. 2014. Climate Change 2014: Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, ... and J.C. Minx, Eds. New York, NY: Cambridge University Press.

SUMMARY OF KEY FINDINGS

1 This section draws upon conclusions described in the overview paper for the CIRA special issue: Waldhoff, S., J. Martinich, M. Sarofim, B. DeAngelo, J. McFarland, L. Jantarasami, K. Shouse, A. Crimmins, S. Ohrel, and J. Li. 2014. Overview of the Special Issue: A multi-model framework to achieve consistent evaluation of climate change impacts in the United States. *Climatic Change*. DOI:10.1007/s10584-014-1206-0.

2 Changes in extreme weather events across the CIRA scenarios are discussed in more detail in: Monier, E. and X. Gao. 2014. Climate change impacts on extreme events in the United States: an uncertainty analysis. *Climatic Change*. DOI:10.1007/s10584-013-1048-1.

3 See, for example: 1) Ciscar, J-C, A. Iglesias, L. Feyen, L. Szabó, D. Van Regemorter, B. Amelung, … and A. Soria. 2011. Physical and economic consequences of climate change in Europe. *Proc Natl Acad Sci USA*. DOI:10.1073/pnas.1011612108; 2) Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. 2007. Confronting climate change in the U.S. Northeast: science, impacts, and solutions. Report of the Northeast Climate Impacts Assessment. Cambridge, MA: Union of Concerned Scientists; and 3)Hayhoe, K., D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, … and J.H. Verville. 2004. Emissions pathways, climate change, and impacts on California. *Proc Natl Acad Sci USA*. DOI:10.1073/pnas.0404500101.

4 Throughout the report, future benefits—i.e., the annual time series of avoided costs—are discounted at a 3% rate to reflect their value in the present day, which is defined as the year 2015 in this report. In short, discounting provides an equal basis to compare the value of benefits (and costs) that occur in different time periods. The discount rate itself reflects the trade-off between consumption today and consumption tomorrow, meaning that with a positive discount rate, benefits that occur today are worth more than they would be tomorrow. A higher discount rate implies a greater preference for present-day consumption and a lower present value of future damages. A lower discount rate implies a greater value on future damages. That is, the present value of future damages calculated at a 5% rate will be lower than those calculated using a 3% rate. There are many ways to select a discount rate and little consensus about which discount rate is most appropriate, particularly when assessing benefits that span multiple generations. Therefore, we selected 3%, a commonly employed rate in the climate impacts and benefits literature. This rate was also used to calculate two of the U.S. Government's four Social Cost of Carbon estimates (including the central value), which estimate climate damages that occur over long time horizons. In particular, the U.S. Government review found that it was consistent with estimates provided in the economics literature and noted that 3% roughly corresponds to the after-tax riskless interest rate. For a detailed discussion on discount rate selection, please see the Social Cost of Carbon Technical Support Document, available at http://www.epa.gov/oms/climate/regulations/scc-tsd.pdf.

CIRA FRAMEWORK

1 Martinich, J., J. Reilly, S. Waldhoff, M. Sarofim, and J. McFarland, Eds. 2015. Special Issue on "A Multi-Model Framework to Achieve Consistent Evaluation of Climate Change Impacts in the United States." *Climatic Change*.

2 Melillo, J.M., T.C. Richmond, and G.W. Yohe, Eds. 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. Appendix 5: Scenarios and Models. U.S. Global Change Research Program. DOI:10.7930/J0Z31WJ2.

3 While beyond the scope of this report, analyses of the adequacy of current GHG mitigation efforts, at domestic and global scales, relative to the magnitude of climate change risks are described in the assessment literature. See, for example: 1) Jacoby, H. D., A. C. Janetos, R. Birdsey, J. Buizer, K. Calvin, F. de la Chesnaye, ... and J. West. 2014. Ch. 27: Mitigation. *Climate Change Impacts in the United States: The Third National*

Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0C8276J; and 2) IPCC. 2014. Climate Change 2014: Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, ... and J.C. Minx, Eds. New York, NY: Cambridge University Press.

4 A third emissions scenario was applied in most CIRA sectoral analyses, as described and presented in the research papers supporting the project. In 2100, this scenario, called Policy 4.5 in the CIRA project, achieves a radiative forcing of approximately 4.2 W/m^2 with an atmospheric GHG concentration of 600 ppm (CO_2 equivalent). This radiative forcing value reflects GHG radiative forcing (i.e., not including aerosols) and uses a baseline of 1750 (both of which are necessary adjustments for comparing to the IPCC RCPs), therefore making it slightly different than the value reported previously in the CIRA literature (4.5 W/m^2).

5 Paltsev, S., J.M. Reilly, H.D. Jacoby, R.S. Eckaus, J. McFarland, M. Sarofim, M. Asadoorian, and M. Babiker. 2005. The MIT Emissions Prediction and Policy Analysis (EPPA) model: version 4. Report 125, MIT Joint Program on the Science and Policy of Global Change. http://globalchange.mit.edu/publications.

6 By 2100 (using a baseline of 1750), the CIRA Reference scenario has a total radiative forcing of 9.8 W/m^2, which appears considerably larger than RCP 8.5. However, the contrast is primarily due to differences in how forcing is calculated by different GCMs used in developing those scenarios. The IGSM radiation code was derived from the GISS climate model, and therefore when calculating radiative forcing due to increased concentrations in the IGSM, forcing functions fit to the GISS code were used rather than the more common approach of using simplified equations, such as those defined in IPCC's Third Assessment Report. Using these simplified equations, total radiative forcing for the CIRA Reference is 8.6 W/m^2, and 3.2 W/m^2 for the Mitigation scenario. Other differences between the IGSM scenarios and the RCPs are due to differences in anthropogenic emissions, natural emissions responses to warming, and atmospheric chemistry.

7 Paltsev, S., E. Monier, J. Scott, A. Sokolov, and J. Reilly. 2013. Integrated economic and climate projections for impact assessment. *Climatic Change*. DOI:10.1007/s10584-013-0892-3. We also note that the Reference scenario is calibrated using historic GHG emissions through 2010; see Paltsev et al. (2013) for more information.

8 Paltsev, S., E. Monier, J. Scott, A. Sokolov, and J. Reilly. 2013. Integrated economic and climate projections for impact assessment. *Climatic Change*. DOI:10.1007/s10584-013-0892-3.

9 Radiative forcing (including CO_2, CH_4, N_2O, PFCs, SF_6, HFCs, CFCs and HCFCs) for the Reference and Mitigation scenarios (see Paltsev et al. 2013), compared to the four RCPs (data from Meinshausen et al. 2011). The negative forcing effects of aerosols are not included. See: Meinshausen, M., S. J. Smith, K. V. Calvin, J. S. Daniel, M. L. T. Kainuma, J.-F. Lamarque, ... and D. van Vuuren. 2011. The RCP Greenhouse Gas Concentrations and their Extension from 1765 to 2300. *Climatic Change*. DOI:10.1007/s10584-011-0156-z.

10 Please see the literature underlying the CIRA project for information on post-processing and bias-correction of climate outputs for use in the sector analyses.

11 Monier, E., X. Gao, J.R. Scott, A.P. Sokolov, and C.A. Schlosser. 2014. A framework for modeling uncertainty in regional climate change. *Climatic Change*. DOI:10.1007/s10584-014-1112-5.

12 Adaptive actions modeled in the sectoral analyses of this report should not be interpreted as recommendations of these particular strategies.

13 Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, ... and R. Somerville. 2014. Chapter 2: Our Changing Climate. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, R.C. Richmond, and G. W. Yohe, Eds. U.S. Global Change Research Program. DOI:10.7930/J0KW5CXT.

14 The U.S. Global Change Research Program's National Climate Assessment (NCA) results are reported for the RCP 8.5 scenario, using a range (5th-95th percentile) of results from a suite of climate models, adjusted to match the same baseline period used for the IGSM-CAM model. The NCA also presents results from the older SRES models: the A2 scenario from SRES was projected to warm by 5-8°F by 2100.

15 Future climate change depends on the response of the global climate system to rising GHG concentrations (i.e., how much temperatures will rise in response to a given increase in atmospheric CO_2). Assumptions about this relationship are referred to as climate sensitivity.

16 IPCC. 2014. Summary for Policymakers. In: Climate Change 2014, Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, ... and J.C. Minx, Eds. New York, NY.

17 IPCC. 2013. Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, ... and P.M. Midgley, Eds. New York, NY.

18 The estimate of warming from the historical period (0.65°C) used in Figure 1 of the Temperature Projections section is slightly less than the IPCC's estimate of 0.85°C because the former utilizes a 30-yr average (1980-2009) to represent the current period.

19 Warming from the historical period (0.65°C) comparing 1880-1909 to 1980-2009 was calculated using the NOAA Global Historical Climatology Network GHCN-3 dataset of Global Land and Ocean Temperature Anomalies (available at http://www.ncdc.noaa.gov/cag/time-series/global/globe/land_ocean/ytd/12/1880-2014.csv). Combined with this historical warming, the 2°C target (relative to preindustrial) is equivalent to a warming of 2.43°F (relative to the 1980-2009 baseline period), as shown in Figure 1 of the Temperature Projections section. This value is consistent with the average of the last two decades of the century (2081-2100) for the CIRA Mitigation scenario: 2.23°F.

20 Monier, E. and X. Gao. 2014. Climate change impacts on extreme events in the United States: an uncertainty analysis. *Climatic Change*, DOI:10.1007/s10584-013-1048-1.

21 Ibid.

22 The CIRA sea level rise scenarios are at the high end of projected sea level rise rates for similar scenarios based on recent publications (Horton et al. 2014, Kopp et al. 2014). However, we also note that the effect of GHG mitigation on reducing the increase in future sea level was found to be larger in these studies. The use of a smaller sea level rise would likely lead to a decrease in total damages, but a larger reduction in sea level rise due to the Mitigation scenario would likely yield larger economic benefits than those presented in this report. See: 1) Horton, B.J., S. Rahmstorf, S.E. Engelhart, and A.C. Kemp. 2014. Expert assessment of sea-level rise by AD 2100 and AD 2300. *Quaternary Science Reviews.* DOI:10.1016/j.quascirev.2013.11.002; and 2) Kopp, R.E., R.M. Horton, C.M. Little, J.X. Mitrovica, M. Oppenheimer, D.J. Rasmussen, B.H.Strauss, and C. Tebaldi. 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future*. DOI:10.1002/2014EF000239.

23 Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, ... and R. Somerville. 2014. Chapter 2: Our Changing Climate. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, R.C. Richmond, and G. W. Yohe, Eds. U.S. Global Change Research Program. DOI:10.7930/J0KW5CXT.

24 Meier, M.F., M.B. Dyurgerov, U.K. Rick, S. O'Neel, W.T. Pfeffer, R. S. Anderson, S.P. Anderson, and A.F. Glazovsky. 2007. Glaciers dominate eustatic sea-level rise in the 21st century. *Science*. DOI:10.1126/science.1143906.

25 Vermeer, M., and S. Rahmstorf. 2009. Global sea level linked to global temperature. *Proceedings of the National Academy of Sciences*. DOI:10.1073/pnas.0907765106.

26 The CIRA sea level rise projections were estimated following the methodology of Vermeer and Rahmstorf (2009). The methodology of Vermeer and Rahmstorf builds off that from Rahmstorf (2007) and is described in detail in those papers. In short, projections were estimated using an empirical relationship between global air temperature and sea level change, including contributions from glaciers and ice sheets. This relationship was then applied to the ambient average air temperature trajectories from the IGSM-CAM model (Paltsev et al. 2013) to project future sea levels.

27 Paltsev, S., E. Monier, J. Scott, A. Sokolov, and J. Reilly. 2013. Integrated economic and climate projections for impact assessment. *Climatic Change*. DOI:10.1007/s10584-013-0892-3.

28 For each scenario, a site-specific, fixed annual rate of land subsidence or uplift is estimated, which combines with the SLR scenario to yield site-specific relative sea level rise. Historical vertical land movement is based on annual average measurements from National Oceanic and Atmospheric Administration (NOAA) tide gauge data from 68 sites with at least 25 years of continuous measurements and linear interpolation of subsidence rates for all cells that lie between the selected sites. An estimated 1.7 mm/year is subtracted from the tide gauge annual average to account for the component of relative sea level rise that is accounted for by 20th century sea level change, yielding the site-specific subsidence/uplift rate.

29 The CIRA approach for calculating relative sea level rise assumes that the difference in rate between global and relative sea level change will continue into the future. Because some physical processes (e.g., changes in differential ocean heating) will likely change in the future at rates different from what is reflected in historical tide gauge data, the CIRA approach does not capture all of these dynamics. For more information, see: Neumann, J., D. Hudgens, J. Herter, and J. Martinich. 2010. The Economics of Adaptation along Developed Coastlines. *Wiley Interdisciplinary Reviews: Climate Change*. DOI:10.1002/wcc.90.

30 Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, ... and R. Somerville. 2014. Appendix 3: Climate Science Supplement. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, T.C. Richmond, and G.W. Yohe, Eds., U.S. Global Research Program. DOI:10.7930/J0KS6PHH.

31 Ibid.

32 Monier, E., X. Gao, J.R. Scott, A.P. Sokolov, and C.A. Schlosser. 2014. A framework for modeling uncertainty in regional climate change. *Climatic Change*. DOI:10.1007/s10584-014-1112-5.

Endnotes

33 Ibid.

34 All three CIRA emissions scenarios contain the same level of global and U.S. population change over time.

35 For each emissions scenario, values represent the ensemble mean of the five IGSM-CAM initializations using a climate sensitivity of 3°C.

36 IPCC. 2013. Climate Change 2013: The Physical Science Basis. *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, ... and P.M. Midgley, Eds. New York, NY: Cambridge University Press.

37 A climate sensitivity of 6°C is considered "low probability" when considering feedbacks expected over the next century. However, there is literature suggesting that slower feedbacks involving ice sheet and vegetation changes can lead to higher "Earth System Sensitivity" on timescales of several centuries, such that a sensitivity of 6°C will have a higher probability on these longer timescales. Additional feedbacks including methane and carbon cycles are not included in the climate sensitivity definition.

38 Mapped values represent the ensemble mean of the five IGSM-CAM initializations with different climate sensitivities under the Reference scenario.

39 All five maps assume a climate sensitivity of 3℃ under the Reference scenario.

40 A method by which the average change produced by running a climate model is combined with the specific geographic pattern of change calculated from a different model in order to approximate the result that would be produced by the second model.

41 Please refer to: 1) Monier, E., X. Gao, J.R. Scott, A.P. Sokolov, and C.A. Schlosser. 2014. A framework for modeling uncertainty in regional climate change. *Climatic Change*. DOI: 10.1007/s10584-014-1112-5; and 2) Flato, G., J. Marotzke, B. Abiodun, P. Braconnot, S.C. Chou, W. Collins, ... and M. Rummukainen. 2013. Evaluation of Climate Models. In: Climate Change 2013: The Physical Science Basis. *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley, Eds. New York, NY: Cambridge University Press.

42 Monier, E., X. Gao, J.R. Scott, A.P. Sokolov, and C.A. Schlosser. 2014. A framework for modeling uncertainty in regional climate change. *Climatic Change*. DOI:10.1007/s10584-014-1112-5.

43 This section draws upon conclusions described in the overview paper for the CIRA special issue: Waldhoff, S., J. Martinich, M. Sarofim, B. DeAngelo, J. McFarland, L. Jantarasami, K. Shouse, A. Crimmins, S. Ohrel, and J. Li. 2014. Overview of the Special Issue: A multi-model framework to achieve consistent evaluation of climate change impacts in the United States. *Climatic Change*. DOI:10.1007/s10584-014-1206-0.

44 For more information on these types of impacts, see: National Research Council. 2013. Abrupt Impacts of Climate Change: Anticipating Surprises. Washington, DC: The National Academies Press.

45 Monier, E., X. Gao, J.R. Scott, A.P. Sokolov, and C.A. Schlosser. 2014. A framework for modeling uncertainty in regional climate change. *Climatic Change*. DOI:10.1007/s10584-014-1112-5.

46 Ongoing studies are investigating the influence of structural uncertainties across sectoral impact models. See: Huber, V., H.J. Schellnhuber, N.W. Arnell, K. Frieler, A.D. Friend, D. Gerten, ... and L. Warszawski. 2014. Climate impact research: beyond patchwork. *Earth System Dynamics.* DOI:10.5194/esd-5-399-2014.

47 For a discussion of interactions among the energy, water, and land use sectors, see: Hibbard, K., T. Wilson, K. Averyt, R. Harriss, R. Newmark, S. Rose, E. Shevliakova, and V. Tidwell. 2014. Ch. 10: Energy, Water, and Land Use. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0JW8BSF.

SECTORS
Health

1 The economic estimates described throughout this report are presented in constant 2014 dollars. The literature underlying the CIRA project presents results primarily in 2005 dollars. This should be noted when comparing the results presented in this report with those in the CIRA literature. Dollar years were adjusted using the U.S. Bureau of Economic Analysis' Implicit Price Deflators for Gross Domestic Product. Source: U.S. Bureau of Economic Analysis, Table 1.1.9 Implicit Price Deflators for Gross Domestic Product, March 27, 2015, http://www.bea.gov/national/index.htm.

2 Throughout the report, future benefits—i.e., the annual time series of avoided costs—are discounted at a 3% rate to reflect their value in the present day, which is defined as the year 2015 in this report. In short, discounting provides an equal basis to compare the value of benefits (and costs) that occur in different time periods. The discount rate itself reflects the trade-off between consumption today and consumption tomorrow,

meaning that with a positive discount rate, benefits that occur today are worth more than they would be tomorrow. A higher discount rate implies a greater preference for present-day consumption and a lower present value of future damages. A lower discount rate implies a greater value on future damages. That is, the present value of future damages calculated at a 5% rate will be lower than those calculated using a 3% rate. There are many ways to select a discount rate and little consensus about which discount rate is most appropriate, particularly when assessing benefits that span generations. Therefore, we selected 3%, a commonly employed rate in the climate impacts and benefits literature. This rate was also used to calculate two of the U.S. Government's four Social Cost of Carbon estimates (including the central value), which estimate climate damages that occur over long time horizons. In particular, the U.S. Government review found that it was consistent with estimates provided in the economics literature and noted that 3% roughly corresponds to the after-tax riskless interest rate. For a detailed discussion on discount rate selection, please see the Social Cost of Carbon Technical Support Document, available at http://www.epa.gov/oms/climate/regulations/scc-tsd.pdf.

3 IPCC. 2014. Summary for Policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, ... and L.L. White, Eds. New York, NY: Cambridge University Press.

4 Luber, G., K. Knowlton, J. Balbus, H. Frumkin, M. Hayden, J. Hess, ... and L. Ziska. 2014. Ch. 9: Human Health. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0PN93H5.

5 U.S. Environmental Protection Agency. 2012. Ground Level Ozone: Health Effects. http://www.epa.gov/groundlevelozone/health.html.

6 Luber, G., K. Knowlton, J. Balbus, H. Frumkin, M. Hayden, J. Hess, ... and L. Ziska. 2014. Ch. 9: Human Health. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0PN93H5.

7 Ibid.

8 U.S. Environmental Protection Agency. 2013. Integrated Science Assessment of Ozone and Related Photochemical Oxidants (Final Report). EPA/600/R-10/076F.

9 U.S. Environmental Protection Agency. 2009. Integrated Science Assessment for Particulate Matter (Final Report). EPA/600/R-08/139F.

10 A climate-induced drop in ozone is caused by increased atmospheric water vapor under a warmer climate. Higher humidity shortens the atmospheric lifetime of ozone in low-NOx (typically less densely-populated) conditions by enhancing its breakdown. Projected reductions in ground-level concentrations over the northern and western parts of the country are largely driven by this decline in background ozone.

11 For comparison, the current national 8-hour daily maximum ozone standard is 75 parts per billion: primary and secondary standard in the form of annual fourth-highest daily maximum 8-hour concentration averaged over 3 years.

12 Changes in ozone and $PM_{2.5}$ concentrations in the Risks of Inaction section and in Figures 1 and 2 are not population-weighted.

13 Luber, G., K. Knowlton, J. Balbus, H. Frumkin, M. Hayden, J. Hess, ... and L. Ziska. 2014. Ch. 9: Human Health. *Climate Change Impacts in the United States: The Third National Climate*

Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0PN93H5.

14 The ranges in mortality estimates are based on ensemble means and reflect the 95% confidence interval in concentration response functions. See Garcia-Menendez et al. (2015) for more information.

15 An additional mortality valuation approach using years of life saved is provided in Garcia-Menendez et al. (2015).

16 Reductions in $PM_{2.5}$ largely drive the change in mortality. However, the contribution of ozone pollution to these estimates increases towards the end of the century and accounts for 40% of the projected life years saved by 2100. See Garcia-Menendez et al. (2015) for more information.

17 For example: 1) Thompson, T.M., Rausch S., Saari R.K., and Selin N.E. 2014. A systems approach to evaluating the air quality co-benefits of U.S. carbon policies. *Nature Climate Change*. DOI: 10.1038/nclimate2342; 2) West, J., S. Smith, R. Silva, V. Naik, Y. Zhang, Z. Adelman, ... and J. Lamarque. 2013. Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. *Nature Climate Change*. DOI: 10.1038/nclimate2009; and 3) U.S. Environmental Protection Agency. 2014. Regulatory Impact Analysis for the Proposed Carbon Pollution Guidelines for Existing Power Plants and Emission Standards for Modified and Reconstructed Power Plants. Office of Air Quality Planning and Standards, Health & Environmental Impacts Division, Air Economics Group. Research Triangle Park, North Carolina.

18 IPCC. 2014. Climate Change 2014: Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, ... and J.C. Minx, Eds. New York, NY: Cambridge University Press.

19 Fine particulate matter constituents analyzed include sulfate, elemental carbon, organic aerosol and ammonium nitrate.

20 Changes in mortality are estimated by applying the differences in daily-maximum 8-hour ozone (8-hr-max ozone) between May and September and daily average $PM_{2.5}$ to the concentration response functions.

21 At the time of this report's release, the U.S. Environmental Protection Agency's Guidelines for Preparing Economic Analyses report recommends a VSL of $7.9 million (2008$), based on 1990 incomes. To create a VSL using 2014$ and based on 2010 incomes, the standard value was adjusted for inflation using BEA implicit price inflator for gross domestic product and for income growth adjustment based on a method described in the user manual of EPA's BenMAP model (pg. 109). The resulting value, $9.45 million for 2010 (2014$), was adjusted to future years by assuming an elasticity of VSL to GDP per capita of 0.4. Projections of GDP and population for the CIRA Reference scenario were employed. Using this approach, the VSL in 2050 is estimated at $12.53 million and $16.39 million in 2100. Finally, we note that the VSL values used in this report differ slightly from those used in Garcia-Menendez et al. (2015), which therefore affects the valuation estimates reported in each. Sources: 1) U.S. Environmental Protection Agency. 2014. Guidelines for Preparing Economic Analyses. National Center for Environmental Economics. http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0568-52.pdf/$file/EE-0568-52.pdf; 2) U.S. Bureau of Economic Analysis, Table 1.1.9 Implicit Price Deflators for Gross Domestic Product, March 27, 2015, http://www.bea.gov/national/index.htm; and 3) U.S. Environmental Protection Agency. 2012. BenMAP Users Manual. Office of Air Quality Planning and Standards.

22 Garcia-Menendez, F., R.K. Saari, E. Monier, and N.E. Selin. (2015) U.S. air quality and health benefits from avoided climate change under greenhouse gas mitigation. Environmental Science & Technology. DOI:10.1021/acs.est.5b01324.

23 Luber, G., K. Knowlton, J. Balbus, H. Frumkin, M. Hayden, J. Hess, ... and L. Ziska. 2014. Ch. 9: Human Health. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0PN93H5.

24 U.S. Environmental Protection Agency. 2014. Climate Change Indicators in the United States. Third edition. EPA 430-R-14-004. www.epa.gov/climatechange/indicators.

25 Ibid.

26 Luber, G., K. Knowlton, J. Balbus, H. Frumkin, M. Hayden, J. Hess, ... and L. Ziska. 2014. Ch. 9: Human Health. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0PN93H5.

27 Ibid.

28 Average results for the 49 cities included in the study.

29 See Mills et al. (2014) and Bierwagen et al. (2010) for details on usage of ICLUS population projections. Sources: 1) Mills, D., J. Schwartz, M. Lee, M. Sarofim, R. Jones, M. Lawson, M. Duckworth, and L. Deck. 2014. Climate Change Impacts on Extreme Temperature Mortality in Select Metropolitan Areas in the United States. *Climatic Change*. DOI: 10.1007/s10584-014-1154-8; and 2) Bierwagen, B.G., D.M. Theobald, C.R. Pyke, A. Choate, P. Groth, J.V. Thomas, and P. Morefield. 2010. National housing and impervious surface scenarios for integrated climate impact assessments. *Proc Natl Acad Sci*. DOI: 10.1073/pnas.1002096107.

30 At the time of this report's release, the U.S. Environmental Protection Agency's Guidelines for Preparing Economic Analyses report recommends a VSL of $7.9 million (2008$), based on 1990 incomes. To create a VSL using 2014$ and based on 2010 incomes, the standard value was adjusted for inflation using BEA implicit price inflator for gross domestic product and for income growth adjustment based on a method described in the user manual of EPA's BenMAP model (pg. 109). The resulting value, $9.45 million for 2010 (2014$), was adjusted to future years by assuming an elasticity of VSL to GDP per capita of 0.4. Projections of GDP and population for the CIRA Reference scenario were employed. Using this approach, the VSL in 2050 is estimated at $12.53 million and $16.39 million in 2100. Finally, we note that the VSL values used in this report differ slightly from those used in Garcia-Menendez et al. (2015), which therefore affects the valuation estimates reported in each. Sources: 1) U.S. Environmental Protection Agency. 2014. Guidelines for Preparing Economic Analyses. National Center for Environmental Economics. http://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0568-52.pdf/$file/EE-0568-52.pdf; 2) U.S. Bureau of Economic Analysis, Table 1.1.9 Implicit Price Deflators for Gross Domestic Product, March 27, 2015, http://www.bea.gov/national/index.htm; and 3) U.S. Environmental Protection Agency. 2012. BenMAP Users Manual. Office of Air Quality Planning and Standards.

31 The approach described in Mills et al. (2014) was updated in several ways to develop the results presented here. First, the analysis was expanded from 33 cities to encompass a total of 49 out of 50 of the cities (excluding Honolulu) analyzed in the Medina-Ramon and Schwartz (2007) paper that was the foundation of the Mills et al. (2014) work. Medina-Ramon and Schwartz did not calculate heat mortality response functions for cities where the minimum temperature for the 99 percentile hottest day was equal to or below 20°C (8 cities), or cold mortality response functions where the maximum temperature for the 1 percentile coldest day was greater than or equal to 10°C (7 cities), and the choice was made in the Mills et al. (2014) work to not include those cities in the projections of future mortality. In a warming climate, cities that were too warm to meet the criteria for the cold threshold will continue to be too warm, so the lack of a cold mortality response function will not make a difference. However, most of the cities that were too cool to meet the criteria for the hot threshold are expected to warm enough that their 99 percentile hottest days will exceed 20°C in the future. Therefore, inclusion of cities without a heat mortality response function will lead to an underestimate of the change in future mortality in those cities, and therefore an underestimate of the benefit of GHG mitigation. However, inclusion of a wider range of cities gives a more complete picture of impacts in the U.S. There were a couple of additional updates. The first involved limiting the analysis to the actual counties corresponding to the cities specified in Medina-Ramon and Schwartz, rather than the MSAs used in Mills et al. (2014). This reduces the total population considered within the original 33 cities. The second involved updating to the most recent BenMAP data for the all-age mortality rates in the cities, which resulted in some small differences in the calculations.

32 Mills, D., J. Schwartz, M. Lee, M. Sarofim, R. Jones, M. Lawson, M. Duckworth, and L. Deck. 2014. Climate Change Impacts on Extreme Temperature Mortality in Select Metropolitan Areas in the United States. *Climatic Change*. DOI: 10.1007/s10584-014-1154-8.

33 Walsh, J., D. Wuebbles, K. Hayhoe, J. Kossin, K. Kunkel, G. Stephens, ... and R. Somerville. 2014. Ch. 2: Our Changing Climate. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0KW5CXT.

34 Graff Zivin, J. and M. Neidell. 2014. Temperature and the allocation of time: implications for climate change. *Journal of Labor Economics*, DOI:10.1086/671766.

35 Ibid.

36 This analysis uses the term labor supply to refer to hours worked, but cannot determine whether that choice is driven by employees or employers.

37 Graff Zivin, J. and M. Neidell. 2014. Temperature and the allocation of time: implications for climate change. *Journal of Labor Economics*, DOI:10.1086/671766.

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21 The adaptation costs per square mile, calculated by city, storm, scenario, and year, were aggregated to the regions used in the Third National Climate Assessment and weighted by area. For example, for a region with 2 cities, each with an area of 100 square miles, each city's area is divided by the sum of the areas, resulting in a proportion value of 0.5 for each city. This proportion value is then multiplied by each calculation of per-square-mile adaptation costs (calculated by storm, scenario, and year) to produce a weighted average adaptation cost per square mile.

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28 Underlying vulnerability exists in both the Reference and the Mitigation scenarios within the base or historic period (i.e., today). This vulnerability is depicted for the Reference scenario in Figure 1 as costs occurring in 2000. Removing costs associated with baseline vulnerability yields cost estimates with adaptation of $530 billion under the Reference scenario and $500 billion under the Mitigation scenario. We've included the baseline vulnerability costs in our estimates because they may affect future decisions about coastal development. We also note that some damages to coastal property are due to the effects of land subsidence that occurs regardless of climate change.

29 The CIRA sea level rise scenarios are at the high end of projected sea level rise rates for similar scenarios based on recent publications (Horton et al. 2014, Kopp et al. 2014). However, we also note that the effect of GHG mitigation on reducing the increase in future sea level was found to be proportionally larger in these studies. The use of smaller sea level rise rates would likely lead to a decrease in total damages, but a larger reduction in sea level rise due to the Mitigation scenario compared to the Reference would likely yield larger economic benefits than those presented in this report. See: 1) Horton, B.J., S. Rahmstorf, S.E. Engelhart, and A.C. Kemp. 2014. Expert assessment

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31 The CIRA analysis evaluates risks of inaction and benefits of mitigation through the end of the 21st century. The high degree of inertia in processes leading to sea-level rise (i.e., the oceans and ice sheets respond slowly to warming conditions at the Earth's surface) suggest that the absence of 21st century GHG mitigation is likely to result in sea level rise rates equal to or larger than those experienced this century, with subsequent large and long-term implications for coastal development (Horton et al. 2014 and Levermann et al. 2013 provide projections of sea level rise beyond 2100). Therefore, the difference in sea level change rise between the CIRA Reference and Mitigation scenarios will only increase after 2100. This would likely result in larger GHG mitigation benefits to the coastal property sector, and it is important to note that these benefits would only be realized from GHG reductions occurring in this century. See: Horton, B.J., S. Rahmstorf, S.E. Engelhart, and A.C. Kemp. 2014. Expert assessment of sea-level rise by AD 2100 and AD 2300. *Quaternary Science Reviews* 84:1-6; and Levermann, A., P. Clark, B. Marzeion, G. Milne, D. Pollard, V. Radic, and A. Robinson. 2013. The multimillennial sea-level commitment of global warming. *PNAS*, DOI: 10.1073/pnas.1219414110.

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Electricity

1 The transportation sector accounts for 27 percent of emissions, followed by the residential, commercial, and industrial sectors at 21 percent. The remaining 22 percent of emissions come from biomass and various other sectors. The share of electricity generated by fossil fuels from 2009-2013 was 69% (42% from coal, 26% from natural gas, 0.8% from petroleum). U.S. Department of Energy. 2014. Electric Power Monthly: Table 1.1. Net Generation by Energy Source: Total (All Sectors), 2004-February 2014.

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21 Strzepek, K., G. Yohe, J. Neumann, and B. Boehlert. 2010. Characterizing changes in drought risk for the United States from climate change. *Environ. Res. Lett.* DOI:10.1088/1748-9326/5/4/044012.

22 Boehlert, B., E. Fitzgerald, J. Neumann, K. Strzepek, and J. Martinich. 2015. The Effect of Greenhouse Gas Mitigation on Drought Impacts in the U.S. *Weather, Climate and Society.* DOI: 10.1175/WCAS-D-14-00020.1.

23 The impact estimates for drought on crop-based agriculture both complement and overlap with the FASOM/EPIC estimates of the impact of climate change on agricultural crops. The drought methodology uses an econometric approach grounded in historical expenditures to alleviate historical droughts, and projections of drought occurrence—it addresses a subset of effects on agriculture associated with drought occurrence. The FASOM/EPIC results are more comprehensive in scope and address both droughts and many other aspects of climate change (e.g., changes in the timing of rainfall and extreme heat), and adopt a simulation approach which models specific actions by farmers and in agricultural markets that might be taken to respond to climate impacts.

24 Strzepek, K., J. Martinich, J. Neumann, B. Boehlert, J. Henderson, M. Hejazi, ... and J. Yoon. 2014. Benefits of Greenhouse Gas Mitigation on the Supply, Management, and Use of Water Resources in the United States. *Climatic Change*. DOI: 10.1007/s10584-014-1279-9.

25 Boehlert, B., E. Fitzgerald, J. Neumann, K. Strzepek, and J. Martinich. 2015. The Effect of Greenhouse Gas Mitigation on Drought Impacts in the U.S. *Weather, Climate and Society.* DOI: 10.1175/WCAS-D-14-00020.1.

26 Georgakakos, A., P. Fleming, M. Dettinger, C. Peters-Lidard, T.C. Richmond, K. Reckhow, K. White, and D. Yates, D. 2014. Chapter 3: Water Resources. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, T.C. Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, DOI:10.7930/J0G44N6T.

27 Ibid.

28 Henderson, J., C. Rodgers, R. Jones, J. Smith, K. Strzepek, and J. Martinich. 2013. Economic impacts of climate change on water resources in the coterminous United States. *Mitig Adapt Strateg Glob Change*. DOI:10.1007/s11027-013-9483-x.

29 In-stream flows are modeled such that flows below minimum levels required to sustain vulnerable aquatic species are assessed a penalty. In addition, it should be noted that the agricultural water use simulated in the CIRA Water Supply and Demand model does not link with the model used to estimate impacts in that sector of this report.

30 While the Water Supply and Demand analysis accounts for reactive adaptation in response to changes in water supply, the effects from water resources technology improvements and proactive adaptation planning are not included. Adaptation planning in the water resource sector has increased at the federal level in the U.S., e.g., EPA National Water Program's Response to Climate Change and NOAA's Regional Integrated Sciences & Assessments (RISA) program.

31 Strzepek, K., J. Martinich, J. Neumann, B. Boehlert, J. Henderson, M. Hejazi, ... and J. Yoon. 2014. Benefits of Greenhouse Gas Mitigation on the Supply, Management, and Use of Water Resources in the United States. *Climatic Change*. DOI: 10.1007/s10584-014-1279-9.

32 Henderson, J., C. Rodgers, R. Jones, J. Smith, K. Strzepek, and J. Martinich. 2013. Economic impacts of climate change on water resources in the coterminous United States. *Mitig Adapt Strateg Glob Change*. DOI:10.1007/s11027-013-9483-x.

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1 Hatfield, J., G. Takle, R. Grotjahn, P. Holden, R.C. Izaurralde, T. Mader, E. Marshall, and D. Liverman. 2014. Ch. 6: Agriculture. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J02Z13FR.

2 U.S. Congress. 2013. The Economic Contribution of America's Farmers and the Importance of Agricultural Exports. http://www.jec.senate.gov/public/?a=Files.Serve&File_id=266a0bf3-5142-4545-b806-ef9fd78b9c2f.

3 Ibid.

4 Joyce, L.A., S.W. Running, D.D. Breshears, V.H. Dale, R.W. Malmsheimer, R.N. Sampson, B. Sohngen, and C.W. Woodall. 2014. Ch. 7: Forests. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/JOZ60KZC.

5 Hatfield, J., G. Takle, R. Grotjahn, P. Holden, R.C. Izaurralde, T. Mader, E. Marshall, and D. Liverman. 2014. Ch. 6: Agriculture. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, 150-174. DOI:10.7930/J02Z13FR.

6 Joyce, L.A., S.W. Running, D.D. Breshears, V.H. Dale, R.W. Malmsheimer, R.N. Sampson, B. Sohngen, and C.W. Woodall. 2014. Ch. 7: Forests. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/JOZ60KZC.

7 Hatfield, J., G. Takle, R. Grotjahn, P. Holden, R.C. Izaurralde, T. Mader, E. Marshall, and D. Liverman. 2014. Ch. 6: Agriculture. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, 150-174. DOI:10.7930/J02Z13FR.

8 Joyce, L.A., S.W. Running, D.D. Breshears, V.H. Dale, R.W. Malmsheimer, R.N. Sampson, B. Sohngen, and C.W. Woodall. 2014. Ch. 7: Forests. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/JOZ60KZC.

9 A wetter future climate, as projected under the IGSM-CAM for many crop-growing parts of the U.S., will tend to reduce water stress such that some yields may increase even with higher temperatures. In the EPIC modeling, irrigated crops are assumed to be able to meet their water needs regardless of climate change effects on precipitation, so a wetter/hotter climate scenario just increases their temperature stress without reducing their water stress. This tends to make impacts on rainfed crops more negative than for irrigated yields. In addition, the ability of climate models to simulate precipitation as severe storms or as heavy rainfall rather than frequent drizzle is an emerging area of research in the climate modeling community. As such, the results presented here should be interpreted with acknowledgement of this uncertainty.

10 Hatfield, J., G. Takle, R. Grotjahn, P. Holden, R.C. Izaurralde, T. Mader, E. Marshall, and D. Liverman. 2014. Ch. 6: Agriculture. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, 150-174. DOI:10.7930/J02Z13FR.

11 The EPIC simulations assume that crops can be irrigated at a level that eliminates water stress. A particular concern for climate change is that in areas where the need for irrigation is greatest due to reduction in precipitation, the supply of water for irrigation will also be reduced. To fully consider this risk requires integration of crop modeling with hydrologic modeling for projections of future water supply, which was not modeled in this biophysical crop yield analysis.

12 Joyce, L.A., S.W. Running, D.D. Breshears, V.H. Dale, R.W. Malmsheimer, R.N. Sampson, B. Sohngen, and C.W. Woodall. 2014. Ch. 7: Forests. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/JOZ60KZC.

13 Mills, D., R. Jones, K. Carney, A. St Juliana, R. Ready, A. Crimmins ... and E. Monier. 2014. Quantifying and Monetizing Potential Climate Change Policy Impacts on Terrestrial Ecosystem Carbon Storage and Wildfires in the United States. *Climatic Change*, DOI:10.1007/s10584-014-1118-z.

14 The results in Figure 2 from the EPIC model show projected crop yields that do not reflect production and market adjustments.

15 Williams, J.R. 1995. The EPIC Model. In Computer Models in Watershed Hydrology, V.P. Singh (ed.), pp. 909-1000. Highlands Ranch, CO: Water Resources Publication.

16 Thomson, A.M., R.A. Brown, N.J. Rosenberg, R.C. Izaurralde, and V. Benson. 2005. Climate Change Impacts for the Conterminous USA. Part 3: Dryland production of grain and forage crops. *Climatic Change*. DOI:10.1007/1-4020-3876-3.

17 The EPIC simulations assume that crops can be irrigated at a level that eliminates water stress. A particular concern for climate change is that in areas where the need for irrigation is greatest due to reduction in precipitation, the supply of water for irrigation will also be reduced. To fully consider this risk requires integration of crop modeling with hydrologic modeling for projections of future water supply, which was not modeled in this biophysical crop yield analysis.

18 The analysis uses climate projections from all five initializations of the IGSM-CAM. Given the sensitivity of the EPIC and MC1 models to natural variability, the use of the five initializations of the IGSM-CAM climate model, each of which has an equally plausible future climate, aids in understanding and constraining the potential magnitude of crop and vegetation changes in the future. Please refer to the Levels of Certainty section of this report for more information.

19 Mills, D., R. Jones, K. Carney, A. St Juliana, R. Ready, A. Crimmins ... and E. Monier. 2014. Quantifying and Monetizing Potential Climate Change Policy Impacts on Terrestrial Ecosystem Carbon Storage and Wildfires in the United States. *Climatic Change*, DOI:10.1007/s10584-014-1118-z.

20 The change in forest yield was assumed to be equal to the percentage difference in net primary productivity between future years and the average for the baseline (1980-2009).

21 While beyond the scope of this analysis, the effects of CO_2 fertilization on forest growth and productivity may be limited by the availability of nitrogen, which could influence the results estimated here.

22 Beach, R., Y. Cai, A. Thomson, X. Zhang, R. Jones, B. McCarl,… and B. Boehlert. (In press). Climate change impacts on US agriculture and forestry: benefits of global climate stabilization. *Environmental Research Letters*.

23 Hatfield, J., G. Takle, R. Grotjahn, P. Holden, R.C. Izaurralde, T. Mader, E. Marshall, and D. Liverman. 2014. Ch. 6: Agriculture. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J.M. Melillo, Terese (T.C.) Richmond, and G.W. Yohe, Eds., U.S. Global Change Research Program, 150-174. DOI:10.7930/J02Z13FR.

24 Consumer and producer surplus are used to estimate impacts on total economic welfare. Consumer surplus is the monetary gain obtained by consumers because they are able to purchase a product for a price that is less than the highest price that they would be willing to pay. Producer surplus or producers' surplus is the amount that producers benefit by selling at a market price that is higher than the least that they would be willing to sell for.

25 Beach, R., D. Adams, R. Alig, J. Baker, G. Latta, B. McCarl, ... and E. White. 2010. Model documentation for the Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG). Prepared for U.S. Environmental Protection Agency.

26 EPIC, MC1, and FASOM results in the Agriculture and Forestry sections using the IGSM-CAM climate projections represent the average of the five initializations.

27 FASOM has perfect foresight of future climate change effects, and thus can optimize near term land owner behavior. The model also simulates changes in agricultural and forestry commodities beyond those modeled in EPIC (9 crops) and MC1 (hard and softwoods).

28 This analysis does not reflect climate change impacts on international forests and agriculture, which would also affect relative returns to different uses of land and trade patterns and therefore affect land use decisions. Also, numerous uncertainties remain regarding issues such as future changes in crop technology, energy policy, and other interactions that could affect market outcomes.

Endnotes

29 FASOM-GHG is optimized to maximize consumer and producer surplus in the base, but re-adjusts production and consumption patterns to re-optimize in response to changes in potential yields.

30 FASOM directly models changes to productivity on private timberland, although timber from public lands enters the market exogenously based on public lands policy. Impacts on productivity due to climate change are only applied to the private timberland.

31 Boehlert, B., K. Strzepek, S. Chapra, Y. Gebretsadik, M. Lickley, C. Fant, ... and J. Martinich. 2015. Climate change impacts and greenhouse gas mitigation effects on U.S. water quality. *Journal of Advances in Modeling Earth Systems.* DOI:10.1002/2014MS000400.

32 Beach, R., Y. Cai, A. Thomson, X. Zhang, R. Jones, B. McCarl,… and B. Boehlert. (In press). Climate change impacts on US agriculture and forestry: benefits of global climate stabilization. *Environmental Research Letters*.

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1 Groffman, P. M., P. Kareiva, S. Carter, N. B. Grimm, J. Lawler, M. Mack, V. Matzek, and H. Tallis, 2014: Ch. 8: Ecosystems, Biodiversity, and Ecosystem Services. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 195-219. DOI:10.7930/J0TD9V7H.

2 Ibid.

3 Melillo, J.M., T.C. Richmond, and G.W. Yohe, Eds. 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program. DOI:10.7930/J0Z31WJ2.

4 The impacts modeled in COMBO do not include non-climate stressors, such as overfishing or water pollution, and do not account for the ability of large-scale reefs to contain important refugia for resilient corals that could potentially be used in coral restoration efforts. Together, these factors have the ability to adjust the estimates presented in this report upwards or downwards.

5 Doney, S., A. A. Rosenberg, M. Alexander, F. Chavez, C. D. Harvell, G. Hofmann, M. Orbach, and M. Ruckelshaus. 2014. Ch. 24: Oceans and Marine Resources. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0RF5RZW.

6 Buddemeier, R.W., P.L. Jokiel, K.M. Zimmerman, D.R. Lane, J.M. Carey, G.C. Bohling, and J.A. Martinich. 2008. A modeling tool to evaluate regional coral reef responses to changes in climate and ocean chemistry. *Limn Oceanogr Methods*. DOI: 10.4319/lom.2008.6.395.

7 Buddemeier, R.W., D.R. Lane, and J.A. Martinich. 2011. Modeling regional coral reef responses to global warming and changes in ocean chemistry: Caribbean case study. *Climatic Change*. DOI:10.1007/s10584-011-0022-z.

8 The values presented in this section differ slightly from those presented in Lane et al. (2014) due to differences in aggregating coral cover changes annually or monthly.

9 Lane, D.R., R.C. Ready, R.W. Buddemeier, J.A. Martinich, K.C. Shouse, and C.W. Wobus. 2013. Quantifying and valuing potential climate change impacts on coral reefs in the United States: Comparison of two scenarios. *PLoS ONE*. DOI:10.1371/journal.pone.0082579.

10 Ibid.

11 Lane, D., R. Jones, D. Mills, C. Wobus, R.C. Ready, R.W. Buddemeier, E. English, J. Martinich, K. Shouse, and H. Hosterman. 2014. Climate change impacts on freshwater fish, coral reefs, and related ecosystem services in the United States. *Climatic Change*. DOI: 10.1007/s10584-014-1107-2.

12 U.S. Environmental Protection Agency. 2014. Climate change indicators in the United States. Third edition. EPA 430-R-14-004.

13 Doney, S., A. A. Rosenberg, M. Alexander, F. Chavez, C. D. Harvell, G. Hofmann, M. Orbach, and M. Ruckelshaus. 2014. Ch. 24: Oceans and Marine Resources. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0RF5RZW.

14 In early life stages, some species will have higher mortality rates and more developmental abnormalities under acidification conditions expected over the next several decades. In addition, adult shellfish tend to grow more slowly and have thinner, more fragile shells under these conditions.

15 National Marine Fisheries Service Commercial Landings for the years 1990-2010. http://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/annual-landings/index.

16 Doney, S., A. A. Rosenberg, M. Alexander, F. Chavez, C. D. Harvell, G. Hofmann, M. Orbach, and M. Ruckelshaus. 2014. Ch. 24: Oceans and Marine Resources. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0RF5RZW.

17 Ibid.

18 Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center. Program Developed for CO2 System Calculations: CO2SYS. http://cdiac.ornl.gov/oceans/co2rprt.html.

19 Moore, C. 2015. Welfare estimates of avoided ocean acidification in the U.S. mollusk market. *Journal of Agricultural and Resource Economics* 40(1): 50-62.

20 Ibid.

21 Groffman, P. M., P. Kareiva, S. Carter, N. B. Grimm, J. Lawler, M. Mack, V. Matzek, and H. Tallis. 2014. Ch. 8: Ecosystems, Biodiversity, and Ecosystem Services. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0TD9V7H.

22 Ibid.

23 Horton, R., G. Yohe, W. Easterling, R. Kates, M. Ruth, E. Sussman, ... and F. Lipschultz. 2014. Ch. 16: Northeast. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0SF2T3P.

24 Global GHG mitigation is projected to preserve 230,000 acres of coldwater fish habitat in 2100 under the MIROC climate projections. For all freshwater fishing guilds, the total damages in 2100 are estimated at $1.7 billion in the Reference scenario and $200 million in the Mitigation scenario.

25 This analysis does not project changes to fish distribution in lakes and reservoirs, as these bodies provide thermal stratification/refugia, and are oftentimes heavily managed (i.e., water level and fish stocking).

26 Jones, R., C. Travers, C. Rodgers, B. Lazar, E. English, J. Lipton, ... and J. Martinich. 2012. Climate Change Impacts on Freshwater Recreational Fishing in the United States. *Mitigation and Adaptation Strategies for Global Change*. DOI: 10.1007/s11027-012-9385-3.

27 Lane, D., R. Jones, D. Mills, C. Wobus, R.C. Ready, R.W. Buddemeier, ... and H. Hosterman. 2014. Climate change impacts on freshwater fish, coral reefs, and related ecosystem services in the United States. *Climatic Change*. DOI: 10.1007/s10584-014-1107-2.

28 Jones, R., C. Travers, C. Rodgers, B. Lazar, E. English, J. Lipton, ... and J. Martinich. 2012. Climate Change Impacts on Freshwater Recreational Fishing in the United States. *Mitigation and Adaptation Strategies for Global Change*. DOI: 10.1007/s11027-012-9385-3.

29 Groffman, P. M., P. Kareiva, S. Carter, N. B. Grimm, J. Lawler, M. Mack, V. Matzek, and H. Tallis. 2014. Ch. 8: Ecosystems, Biodiversity, and Ecosystem Services. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0TD9V7H.

30 National Interagency Fire Center. 2013. Federal Firefighting Costs (Suppression Only). https://www.nifc.gov/fireInfo/fireInfo_documents/SuppCosts.pdf.

31 Groffman, P. M., P. Kareiva, S. Carter, N. B. Grimm, J. Lawler, M. Mack, V. Matzek, and H. Tallis. 2014. Ch. 8: Ecosystems, Biodiversity, and Ecosystem Services. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0TD9V7H.

32 Joyce, L. A., S. W. Running, D. D. Breshears, V. H. Dale, R. W. Malmsheimer, R. N. Sampson, B. Sohngen, and C. W. Wood. 2014. Ch. 7: Forests. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0Z60KZC.

33 Ibid.

34 Change in annual acres burned at end of century (2085-2114) compared to the historic baseline (2000-2009).

35 National Interagency Fire Center. 2013. Federal Firefighting Costs (Suppression Only). https://www.nifc.gov/fireInfo/fireInfo_documents/SuppCosts.pdf.

36 Joyce, L. A., S. W. Running, D. D. Breshears, V. H. Dale, R. W. Malmsheimer, R. N. Sampson, B. Sohngen, and C. W. Wood. 2014. Ch. 7: Forests. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0Z60KZC

37 Comprised of the following Geographic Area Coordination Center regions: Northern Rockies, Rocky Mountain, Southwest, Eastern Great Basin, Western Great Basin, Northwest, California North, and California South.

38 Percent changes calculated by comparing acres burned under the Reference scenario at the end of the century (average of 2085-2114) compared to the historic baseline (average of 2000-2009).

39 Fuel management costs are estimated at $15 billion under the Reference and $12 billion under the Mitigation scenario through 2100 (average across all IGSM-CAM initializations, 2014$, discounted at 3%), corresponding to avoided costs (benefits) of $3.4 billion under the Mitigation scenario.

40 Fuel management costs were not estimated using the MIROC climate model.

41 The CIRA results simulated in the MC1 vegetation model suggest a substantial change to the wildfire regime we experience today. For example, unmitigated climate change is projected to increase area burned by wildfire annually by approximately 45% in California by the end of the century, 64% in the Mountain West, and 95% in the Northwest. Given the sensitivity of the MC1 climate model to natural variability, the use of the five initializations of the IGSM-CAM climate model, each of which has an equally plausible future climate, aids in understanding and constraining the potential magnitude of vegetation changes in the future.

42 Because the IGSM-CAM projects a wetter future for a majority of the nation, pattern-scaled output from two additional climate models were simulated in MC1 to encompass a broader range of possible climate futures. While all three sets of climate projections show increases in the area burned by wildfire compared to the historic period, only the IGSM-CAM and MIROC climate model results are presented in this report. For an in-depth discussion of the results, see: Mills, D., R. Jones, K. Carney, A. St Juliana, R. Ready, A. Crimmins, ... and E. Monier. 2014. Quantifying and Monetizing Potential Climate Change Policy Impacts on Terrestrial Ecosystem Carbon Storage and Wildfires in the United States. *Climatic Change.* DOI:10.1007/s10584-014-1118-z.

43 National Wildfire Coordinating Group. 2011. Historical incident ICS-209 reports. http://fam.nwcg.gov/fam-web/hist_209/report_list_209.

44 Lee, C., C. Schlemme, J. Murray, and R. Unsworth. 2015. The cost of climate change: ecosystem services and wildland fires. *Ecological Economics*. DOI:10.1016/j.ecolecon.2015.04.020.

45 Mills, D., R. Jones, K. Carney, A. St Juliana, R. Ready, A. Crimmins, ... and E. Monier. 2014. Quantifying and Monetizing Potential Climate Change Policy Impacts on Terrestrial Ecosystem Carbon Storage and Wildfires in the United States. *Climatic Change.* DOI:10.1007/s10584-014-1118-z.

46 Lee, C., C. Schlemme, J. Murray, and R. Unsworth. 2015. The cost of climate change: ecosystem services and wildland fires. *Ecological Economics*. DOI:10.1016/j.ecolecon.2015.04.020.

47 Joyce, L. A., S. W. Running, D. D. Breshears, V. H. Dale, R. W. Malmsheimer, R. N. Sampson, B. Sohngen, and C. W. Wood. 2014. Ch. 7: Forests. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0Z60KZC.

48 Galloway, J. N., W. H. Schlesinger, C. M. Clark, N. B. Grimm, R. B. Jackson, B. E. Law, ... and R. Martin. 2014. Ch. 15: Biogeochemical Cycles. C*limate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0X63JT0.

49 Joyce, L. A., S. W. Running, D. D. Breshears, V. H. Dale, R. W. Malmsheimer, R. N. Sampson, B. Sohngen, and C. W. Wood. 2014. Ch. 7: Forests. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program. DOI:10.7930/J0Z60KZC.

50 Change from the 2000-2009 average to the 2095-2104 average.

51 USDA Forest Service. 2012. Future of America's Forest and Rangelands: Forest Service 2010 Resources Planning Act Assessment. Gen. Tech. Rep. WO-87. Washington, DC.

52 See Mills et al. (2014) for a detailed examination of the differences between the MC1 simulations using the two climate projection methods (IGSM-CAM and MIROC pattern-scaled climate models), as well as a discussion of the drivers behind these differences.

53 Oregon State University. 2011. MC1 dynamic vegetation model. http://www.fsl.orst.edu/dgvm/.

54 Given the sensitivity of the MC1 climate model to natural variability, the use of the five initializations of the IGSM-CAM climate model, each of which has an equally plausible future climate, aids in understanding and constraining the potential magnitude of vegetation changes in the future.

55 U.S. Interagency Working Group on Social Cost of Carbon. 2013. Technical support document: technical update of the social cost of carbon for regulatory impact analysis under Executive Order 12866. http://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf.

56 Mills, D., R. Jones, K. Carney, A. St Juliana, R. Ready, A. Crimmins, ... and E. Monier. 2014. Quantifying and Monetizing Potential Climate Change Policy Impacts on Terrestrial Ecosystem Carbon Storage and Wildfires in the United States. *Climatic Change*, DOI:10.1007/s10584-014-1118-z.

CONCLUSION

1 The few efforts to date that have estimated multi-sector impacts in a consistent framework include the European Commission's PESETA project (http://peseta.jrc.ec.europa.eu), and the Risky Business Initiative (http://riskybusiness.org), a project focusing on economic risks in the U.S. Integrated assessment models, such as FUND (http://fund-model.org), are also being used to estimate the multi-sector social costs of GHG emissions.

2 The use of a climate model that generates a relatively higher amount of future precipitation may strongly influence results in a particular sector. For example, inland flooding damages may be larger under these wetter climate projections compared to those under a drier model. This same sensitivity of sectoral results to the choice of climate model could affect a different part of the water sector in complementary ways, such that drought damages could be smaller compared to those under a drier model.

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