CLIMATE CHANGE in Pennsylvania

IMPACTS AND SOLUTIONS FOR THE KEYSTONE STATE

Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions

CLIMATE CHANGE in Pennsylvania

IMPACTS AND SOLUTIONS FOR THE KEYSTONE STATE

A Climate Impacts Assessment
for Pennsylvania

Union of Concerned Scientists

OCTOBER 2008

The **Union of Concerned Scientists** (UCS) is the leading science-based nonprofit working for a healthy environment and a safer world.

UCS combines independent scientific research and citizen action to develop innovative, practical solutions and to secure responsible changes in government policy, corporate practices, and consumer choices.

The full text of this report and additional technical background information are available at *http://www.climatechoices.org/pa* or may be obtained from:

UCS Publications
2 Brattle Square
Cambridge, MA 02238-9105

Or email *pubs@ucsusa.org* or call (617) 547-5552.

Designed by:
DG Communications, Acton, MA
(www.NonprofitDesign.org)

Contents

Figures & Text Boxes

FIGURES

TEXT BOXES

About This Report

Climate Change in Pennsylvania: Impacts and Solutions for the Keystone State—a collaborative effort between the Union of Concerned Scientists (UCS) and a group of independent experts—applies state-of-the-art methodologies to analyze climate change-related impacts on key sectors in the state of Pennsylvania. The assessment combines its analyses with effective outreach to provide opinion leaders, policy makers, and the public with the best available scientific information upon which to base choices about climate change mitigation and adaptation.

The material presented in this report is based largely on published research conducted through the Northeast Climate Impacts Assessment (NECIA) and on new peer-reviewed research by scientists in Pennsylvania. Most of the NECIA work is presented in greater technical detail in the formal scientific literature, including a special issue of the journal *Mitigation and Adaptation Strategies for Global Change* (2008). In addition, the climate data used in these analyses is available for download at *http://northeastclimatedata.org/*.

This work also builds on the considerable foundation laid by previous research, including the Mid-Atlantic regional assessment carried out under the auspices of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change (*http://www.usgcrp.gov/usgcrp/nacc/*), the Consortium for Atlantic Regional Assessment (*http://www.cara.psu.edu/climate/*), and the recent assessment of climate change impacts on North America by the Intergovernmental Panel on Climate Change.[1]

Of the range of potential climate impacts, this report explores only a small subset. In the future, further assessments conducted under the auspices of the federal government and the Commonwealth of Pennsylvania may build on this work to deepen scientific understanding of Pennsylvania's climate change risks and solutions.

ADVISORS, CONTRIBUTORS & REVIEWERS

The climate and sectoral impact chapters (1–5) of this report greatly benefited from the guidance and contributions of the following experts:

John Arway, Pennsylvania Fish & Boat Commission, Bellefonte, PA

Elizabeth Boyer, Pennsylvania State University, University Park, PA

Donald Brown, Pennsylvania State University, University Park, PA

Hunter Carrick, Pennsylvania State University, University Park, PA

Shi Chen, Pennsylvania State University, University Park, PA

Andrew Cole, Pennsylvania State University, University Park, PA

J. Kent Crawford, U.S. Geological Survey, New Cumberland, PA

David DeWalle, Pennsylvania State University, University Park, PA

Paola Ferreri, Pennsylvania State University, University Park, PA

Ned Fetcher, Wilkes University, Wilkes-Barre, PA

Shelby Fleischer, Pennsylvania State University, University Park, PA

Ann Fisher, Pennsylvania State University, University Park, PA

Bernard Goldstein, University of Pittsburgh Graduate School of Public Health, Pittsburgh, PA

Molly Hesson, CHPlanning, Ltd., Philadelphia, PA

Louis Iverson, USDA Forest Service, Delaware, OH

Klaus Keller, Pennsylvania State University, University Park, PA

C. Gregory Knight, Pennsylvania State University, University Park, PA

Paul G. Knight, Pennsylvania State University, University Park, PA

Mark Maimone, CDM, Woodbury, NY

Michael Mann, Pennsylvania State University, University Park, PA

Stephen Matthews, USDA Forest Service, Delaware, OH

Granger Morgan, Carnegie Mellon University, Pittsburgh, PA

Raymond Najjar, Pennsylvania State University, University Park, PA

Matthew Peters, USDA Forest Service, Delaware, OH

Anantha Prasad, USDA Forest Service, Delaware, OH

C. Alan Rotz, U.S. Department of Agriculture, University Park, PA

Dork Sahagian, Lehigh University, Bethlehem, PA

Michael Saunders, Pennsylvania State University, University Park, PA

Erich Schienke, Pennsylvania State University, University Park, PA

Joseph Sherrick, Pennsylvania Department of Environmental Protection, Harrisburg, PA

James Shortle, Pennsylvania State University, University Park, PA

Christina Simeone, Pennsylvania Department of Environmental Protection, Harrisburg, PA

Mitchell Small, Carnegie Mellon University, Pittsburgh, PA

Susan Stout, USDA Forest Service, Irvine, PA

James Thorne, Natural Lands Trust, Media, PA

Marleen Troy, Wilkes University, Wilkes-Barre, PA

Nancy Tuana, Pennsylvania State University, University Park, PA

Jeanne VanBriesen, Carnegie Mellon University, Pittsburgh, PA

Thorsten Wagener, Pennsylvania State University, University Park, PA

Brent Yarnal, Pennsylvania State University, University Park, PA

Acknowledgments

The production of this report was made possible through the generous support of The Energy Foundation, the Forrest & Frances Lattner Foundation, Mertz Gilmore Foundation, Oak Foundation, Orchard Foundation, Rockefeller Family and Associates, The Scherman Foundation, Inc., Wallace Genetic Foundation, Wallace Global Fund, and Wallace Research Foundation.

The success of this work is credited to Melanie Fitzpatrick, who acted as coordinating scientist, writer, and project manager, and persistently guided this project through its different phases and into completion. Thanks also go to Erika Spanger-Siegfried for her invaluable experience, knowledge, and commitment, which ensured the project stayed on track.

We thank Yvonne Baskin and Steve Marcus for superb editorial support, and David Gerratt and Amanda Wait of DG Communications for their effort in design and layout.

For their expertise and helpful comments, we thank Katharine Hayhoe (Texas Tech University), Jim McCarthy (Harvard University), Justin Sheffield (Princeton University), Lifeng Luo (Princeton University), Cameron Wake (University of New Hampshire), David Wolfe (Cornell University), Daniel Scott (University of Waterloo), and Lewis Ziska (USDA).

For technical contributions to Pennsylvania-specific research, we thank Louis Iverson (USDA Forest Service), Susan Stout (USDA Forest Service), Matthew Peters (USDA Forest Service), Stephen Matthews (USDA Forest Service), Anantha Prasad (USDA Forest Service), Micheal Saunders (Pennsylvania State University), Shelby Fleischer (Pennsylvania State University), Molly Hesson (CHPlanning, Ltd.), Ray Najjar (Pennsylvania State University), Mark Maimone (CDM), Ned Fetcher (Wilkes University), John Arway (Pennsylvania Fish and Boat Commission), J. Kent Crawford (U.S. Geological Survey), and many others. For helpful discussions and advice, we thank Paul G. Knight (Pennsylvania state climatologist) and the organizations of PennFuture, Pennsylvania Environmental Council, National Wildlife Federation, and Environment Pennsylvania. Special thanks to Brian Hill and John Walliser.

We thank Patrick Wallace and Jenna Wallis for their unrelenting assistance, contributions, and technical support of the project. Thanks to Kate Abend, Rachel Cleetus, Steve Clemmer, Nancy Cole, Jeff Deyette, Peter Frumhoff, Kristen Graf, Aaron Huertas, Katharine Lake, Eric Misbach, Lisa Nurnberger, Lance Pierce, Ned Raynolds, John Rogers, Suzanne Shaw, Jean Sideris, Heather Tuttle, Bryan Wadsworth, and everyone at UCS for their contributions, guidance, and support.

Executive Summary

Global climate change is already making a mark on Pennsylvania's landscape, livelihoods, and traditions, and over the coming decades impacts are expected to grow more substantial. They may include longer and more intense summer heat waves, reduced winter snowpack, northward shifts in the ranges of valued plant and animal species, and declining yields of key agricultural crops.

Some further climate change is unavoidable because of human-caused emissions of heat-trapping gases such as carbon dioxide (CO_2), which can persist in the atmosphere for decades or centuries. But the magnitude of warming that occurs during *this* century—and the extent to which Pennsylvanians will need to adapt—depend largely on energy and land-use choices made within the next few years in the state, the nation, and the world. The analyses presented in this report project many striking differences in the scale of climate change impacts, determined by whether the world follows a higher- or lower-emissions pathway.

This report builds on analyses conducted under the auspices of the Northeast Climate Impacts Assessment (NECIA), a collaborative research effort involving more than 50 independent experts. In 2006 and 2007, NECIA released a set of reports that assessed how global warming may further affect the climate of Northeast states, from Pennsylvania to Maine. Using projections from three state-of-the-art global climate models, these reports compared the types and magnitudes of climate changes and certain associated impacts that resulted from two different scenarios of future heat-trapping emissions. The first (the higher-emissions scenario) is a future in which societies—individuals, communities, businesses, states, and nations—allow emissions to continue growing rapidly; the second (the lower-emissions scenario) is one in which societies choose to rely less on fossil fuels and instead adopt more resource-efficient technologies. These scenarios represent strikingly different emissions choices that people may make.

As this report shows, in drawing both from NECIA and new research, the stakes for Pennsylvania's economy and quality of life are great. If higher emissions prevail:

- Many Pennsylvanian cities can expect dramatic increases in the numbers of summer days over 90°F, putting vulnerable populations at greater risk of heat-related health effects and curtailing outdoor activity for many individuals.
- Heat could cause urban air quality to deteriorate substantially, exacerbating asthma and other respiratory diseases.
- Heat stress on dairy cattle may cause declines in milk production.
- Yields of native Concord grapes, sweet corn, and favorite apple varieties may decrease considerably as temperatures rise and pest pressures grow more severe.
- Snowmobiling is expected to disappear from the state in the next few decades as winter snow cover shrinks.
- Ski resorts could persist by greatly increasing their snowmaking, although this may not be an option past mid-century as winters become too warm for snow—natural or human-made.
- Substantial changes in bird life are expected to include loss of preferred habitat for many resident and migratory species.
- Climate conditions suitable for prized hardwood tree species such as black cherry, sugar maple, and American beech are projected to decline or even vanish from the state.

If Pennsylvania and the rest of the world take action to dramatically reduce emissions consistent with or even below the lower-emissions scenario described in this report, some of the consequences noted above may be avoided—or at least postponed until late century, thereby giving society time to adapt. However, as many of the impacts are now unavoidable, some adaptation will be essential.

Pennsylvania—the U.S. state with the third-highest emissions from fossil fuels—has already shown its willingness to act. It has reduced heat-trapping emissions by driving investment in energy efficiency, renewable energy technology, and alternative transportation fuels; it has embraced wind power and other clean energy options (not only for energy generation but also for economic development); and it has moved to the forefront among "green power" purchasers.

But there are many more measures—based on proven strategies and available policies—that the state and its local governments, businesses, public institutions, and individual households can apply to this challenge. They require only the will to do so.

Global Warming Impacts and Solutions in the Keystone State

IMPACTS. Continuing changes in temperature, rainfall, snow cover, and other climate variables will affect the state, from its farmland to its cities.

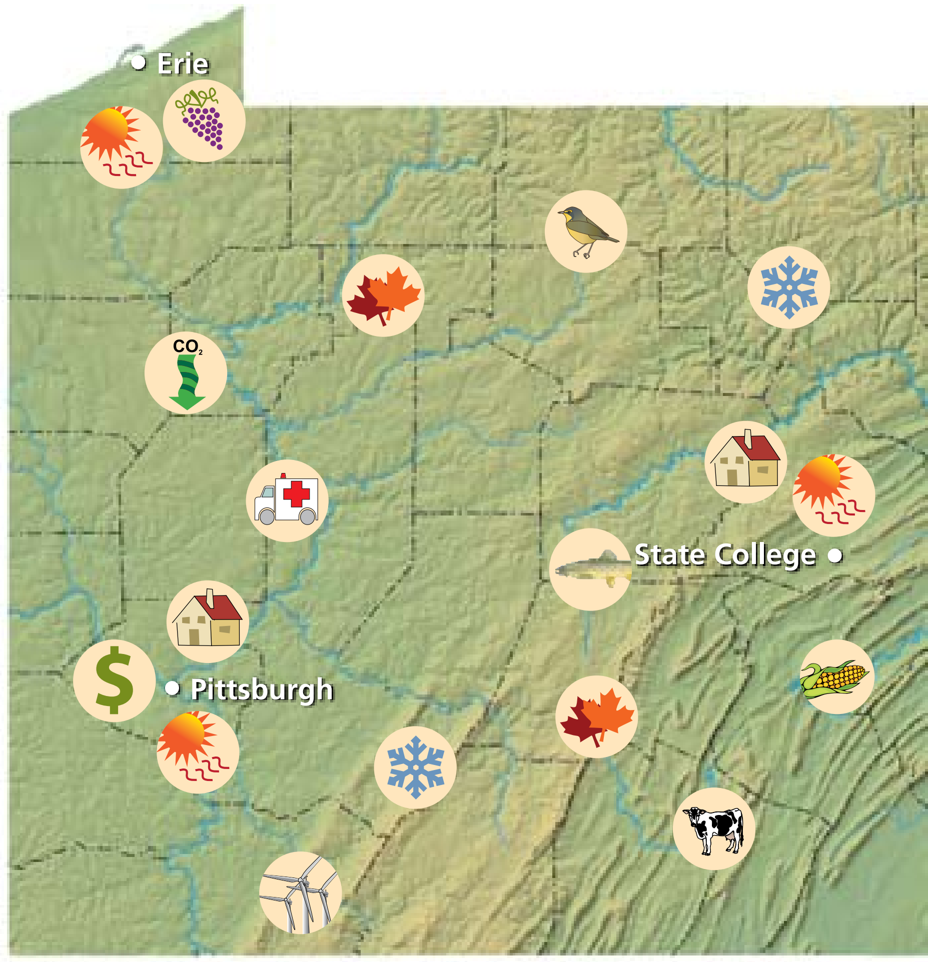
Temperatures exceeding 90°F are projected to become common by mid-century, increasing human health risks such as heat stress, heat exhaustion, and life-threatening heatstroke. Such risks disproportionately affect those who are poor, elderly, very young, suffering from chronic diseases, or otherwise unable to escape the heat.

Global warming could increase the levels of airborne pollen and lung-damaging air pollution. Poor air quality increases the risk of respiratory illnesses such as asthma, chronic bronchitis, and emphysema. Higher temperatures can prolong the pollen-allergy season while elevated CO_2 levels accelerate the productivity of key pollen-allergen sources.

Pennsylvania is the country's fourth-largest producer of apples, grown mostly in the southeastern part of the state. By mid-century under the higher-emissions scenario, only half the winters in the southern part of the state would meet the cold-temperature requirements of popular varieties of apples, including McIntosh and Granny Smith.

Pennsylvania's Concord grape industry, located near Lake Erie, is a major source for the nation's grape juice makers. This native grape requires cold winter temperatures for optimal flowering and fruit production. Under the higher-emissions scenario, warmer temperatures could pose a substantial challenge to Concord grape growers by mid-century.

Currently, summers in Pennsylvania are ideal for growing sweet corn. Under the higher-emissions scenario, many July and August days are projected by mid-century to be substantially hotter than today, thereby reducing the crop's yield and quality.



Dairy farming is the most economically important agricultural industry in Pennsylvania. Under the higher-emissions scenario, dairy farmers face substantial challenges later this century as hot temperatures and heat stress depress milk production.

Suitable forest habitat for maple, black cherry, hemlock, and others is expected to shift northward by as much as 500 miles by late century under the higher-emissions scenario. This will threaten tourism as well as lucrative timber such as world-renowned black cherry.

Warming climate and shifting distributions and quality of forest habitat is expected to cause substantial changes in bird life. As many as half of the 120 bird species modeled in Pennsylvania could see at least 25-percent reductions in their suitable habitat. Species at greatest risk include the ruffed grouse, white-throated sparrow, magnolia warbler, and yellow-rumped warbler.

As global warming drives up air temperatures and changes precipitation patterns, altered seasonal stream flows, higher water temperatures, and diminished shade along stream banks may follow. The native brook trout and smallmouth bass are particularly sensitive to such changes.

The choices we make today will determine the climate that our children and grandchildren inherit. This report portrays two possible futures: a higher-emissions scenario, characterized by continued heavy reliance on fossil fuels; and a lower-emissions scenario, marked by a pronounced shift away from fossil fuels

Under either emissions scenario, the snow season is expected to retreat to the state's highland regions within just the next few decades. By late century, snow cover could be lost entirely in most years. Both the ski and snowmobile industries would be hard hit—snowmobiling harder at first, because it relies heavily on natural snow to cover the trails. Rising winter temperatures are expected to eventually render snowmaking infeasible.

SOLUTIONS. Pennsylvania generates 1 percent of the world's heat-trapping emissions. Significant reductions in the state are essential to achieving deep reductions in CO_2 levels nationally—80 percent below 2000 levels by 2050, as many scientists have called for. Pennsylvania can meet this challenge by reducing emissions in many areas.

Pennsylvania has abundant wind resources. Some large-scale wind installations are in place around the state, especially in the northeast and southwest, but this renewable resource remains largely untapped.

Solar energy could help to meet electricity demand during heavy-use periods and is readily available for deployment in homes and businesses. Pennsylvania has more than five times the solar energy potential of neighboring New Jersey, yet only 1/40th as much installed solar-electric capacity.

Energy efficiency in homes and businesses—both new and old—has large potential to reduce emissions as well as energy costs. Pittsburgh is already a national leader in green-building technology, and many of the state's academic institutions are going green.

Reducing emissions from cars and trucks, which account for 25 percent of the Keystone State's total emissions, requires: (1) better fuel economy; (2) burning fuel with lower carbon content; and (3) reducing vehicle miles traveled through smarter development policies and improved public transportation.

Existing coal-fired power stations may substantially reduce their heat-trapping emissions by replacing some of the coal with biomass such as wood chips or other wood waste. Trees and plants absorb carbon as they grow, and during burning they emit the same amount they absorbed during their lifetimes.

Carbon capture and storage, a potential technique for capturing emissions from coal-fired power plants and storing them underground, has not yet been proven viable. There may be promising sites in many parts of the state, however, for pilot projects.

A rapid transition to a clean energy economy will not happen without strong policies implemented at the municipal, state, and federal levels. For example, setting a price on carbon to help drive the market for clean energy is critical.

A clean-energy economy will bring strong investments and good jobs to the state. This is already being seen in the establishment of wind and solar production plants, the growth in green-building trades, and the emergence of associated maintenance and operations jobs that cannot be done overseas.

Many of these symbols courtesy of the Integration and Application Network (*ian.umces.edu/symbols/*), University of Maryland Center for Environmental Science.

CHAPTER ONE

Introduction: Our Changing Pennsylvania Climate

BACKGROUND

From colonial times to the founding of the United States and its growth into a global power, Pennsylvania's people and resources have played a leading role in shaping the destiny of our country. Endowed with lush forests, fertile soils, extensive coal seams, and navigable rivers, the state created a thriving industrial economy that helped spur the prosperity of a young nation. For much of the past century, Pennsylvania has worked successfully to diversify its economy as the Rust Belt industries of coal, steel, and manufacturing waned.

Today the state owes at least as much to its service industries (such as health care, trade, and tourism) and modern manufacturing sectors (food processing and pharmaceuticals, for example) as to its aging mines, mills, and factories. Despite Pennsylvania's efforts to revitalize, however, many of its cities, towns, and rural regions have not fully recovered from the decline of traditional industries. Climate change will only add to the state's economic challenges while also dramatically altering many aspects of its landscape, character, and quality of life.

Pennsylvania's climate has already begun changing in noticeable ways. Over the past 100 years, annual average temperatures have been rising across the state and annual average rainfall has been steadily increasing in all but the central southern region. Winters have warmed the most, and in many cities across Pennsylvania the numbers of extremely hot (over 90°F) summer days have increased since the 1970s. Decreasing snow cover, a statewide trend, has accelerated its decline in the past few decades. And across the Northeast region spring is arriving earlier, accompanied by changes in the timing of leaf budding and insect migration. All of these changes are consistent with the effects expected from human-caused climate change.

The world's leading climate scientists, working through the Intergovernmental Panel on Climate Change (IPCC), confirmed in February 2007 that it is "unequivocal" that Earth's climate is warming and "very likely" (a greater than 90-percent certainty) that heat-trapping gases from human activities have caused most of the warming experienced during the past 50 years. This latest IPCC assessment corroborates the previous conclusions of 11 national science academies, including that of the United States, that the primary drivers of climate change are tropical deforestation and the burning of fossil fuels (such as coal and oil)—activities that release carbon dioxide (CO_2) and other heat-trapping or "greenhouse" gases into the atmosphere. The resulting CO_2 concentrations, now at their highest levels in at least the past 800,000 years,[2] are largely responsible for annual average temperature increases over the last century of more than 0.5°F in Pennsylvania[3] and 1°F in the mid-Atlantic region.[4]

Pennsylvania, the sixth most populous state in the nation, also boasts one of its largest rural populations. The fortunes of rural areas, many of them dependent on agriculture and forestry and even winter tourism, are defined in many ways by the state's climate. Traditionally, temperature and precipitation have joined forces to turn Pennsylvania's woodlands blazing red-orange each fall, prompting residents and tourists alike to dust off their deer rifles and tune up their snowmobiles. In winter and spring, it is temperature patterns that start the sap rising in the maples and prompt the apple trees to break bud.

In large cities such as Philadelphia and Pittsburgh, temperature has a direct effect on public health and quality of life, especially in summer. Heat waves and heat-amplified air pollution threaten the poor, the ill, and the elderly and cause severe discomfort for all residents.

As the state continues to warm, even more extensive climate-related changes are projected, with the potential to transform aspects of Pennsylvania as we know it. Some of these changes in the climate are now unavoidable. For example, the degree of warming that can be expected over the next few decades—

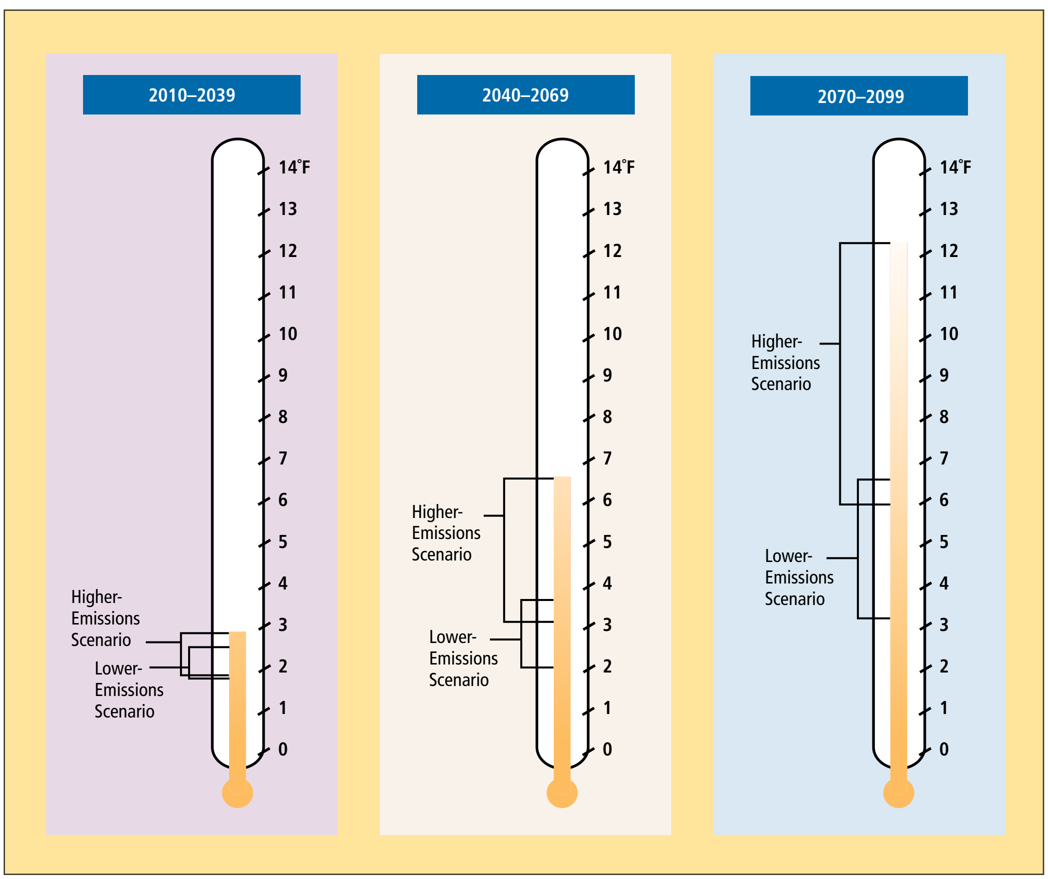
including another 2.5°F above historic levels across the state—is unlikely to be significantly curbed by any reductions in emissions of heat-trapping gases undertaken in Pennsylvania and the rest of the world during that period. These near-term climate changes have already been set in motion by emissions over the past few decades. Two factors explain the delayed response of the climate: many heat-trapping gases can remain in the atmosphere for tens or hundreds of years, and the ocean warms more slowly than the air in response to higher concentrations of such gases. Thus policy makers and communities across Pennsylvania must begin adapting to the unavoidable consequences of this warming.

Toward mid-century and beyond, however, the extent of further warming will be determined by actions taken to reduce emissions—starting now and continuing over the next several decades. While such actions in Pennsylvania alone will not stabilize the climate, the state can nevertheless play a significant role in responding to this global challenge. Pennsylvania contributes one percent of total global emissions of carbon dioxide. Taken together, nine of the states across the Northeast (from Pennsylvania to Maine) were ranked as the world's seventh-highest emitter of CO_2 in 2005—just behind India and Germany and ahead of Canada;[5] Pennsylvania accounted for the lion's share of these emissions. Indeed, of all U.S. states, Pennsylvania is the third highest in emissions from fossil-fuel sources, behind Texas and California.[6]

At the same time, Pennsylvania is also a leader in science, technology, and finance and a historic innovator in public policy. The state is well positioned to successfully reduce emissions and help drive the national and international progress that is essential to avoiding the most severe impacts of climate change.

This chapter summarizes how Pennsylvania's twenty-first century climate is projected to change under two different scenarios, or possible futures, of continued human-caused emissions of heat-trapping gases. Developed by the IPCC,[7] these scenarios represent examples of higher and lower projections of possible future emissions. These scenarios are used in climate models to assess future changes (see box, "Assessing Future Climate Change in Pennsylvania"). It is important to note these scenarios do not represent the

FIGURE 1: Changes in Average Summer Temperature



If emissions of heat-trapping gases continue along the path of the higher-emissions scenario, Pennsylvanians can expect a dramatic warming in average summer temperatures. These "thermometers" show projected increases for three different time periods: the next several decades (2010–2039), mid-century (2040–2069), and late century (2070–2099).

Assessing Future Climate Change in Pennsylvania

In order to project changes in temperature and other climate variables over the coming decades, scientists must address two key uncertainties. The first is directly related to human activity: how much carbon dioxide (CO_2) and other heat-trapping emissions will our industrial and land-use activities produce over the coming century? The second is scientific in nature: how will the climate respond to these emissions (e.g., how much will temperatures rise in response to a given increase in atmospheric CO_2)?

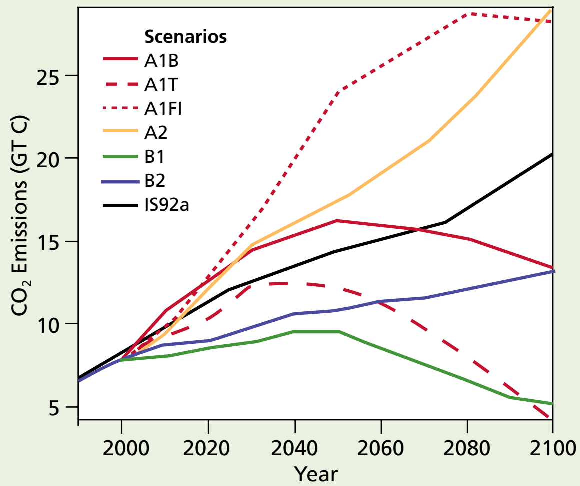
To address the first uncertainty, the IPCC has developed a set of possible futures, or scenarios, that project global levels of emissions of heat-trapping gases based on a wide range of development variables including population growth, energy use, and other societal choices.[8] Analyses in this report use the IPCC's A1fi and B1 scenarios to represent possible higher- and lower-emissions choices, respectively, over the course of the century. The higher-emissions scenario represents a world with fossil fuel-intensive economic growth. Atmospheric CO_2 concentrations reach 940 parts per million (ppm) by 2100—more than triple pre-industrial levels. The lower-emissions scenario assumes a relatively rapid shift to less fossil fuel-intensive industries and more resource-efficient technologies. This causes CO_2 emissions to peak around mid-century, then decline to less than our present-day emissions rates by the end of the century. Atmospheric CO_2 concentrations reach 550 ppm by 2100—about double pre-industrial levels.

To address the second uncertainty—how the climate will respond to increasing emissions—and estimate the range of potential changes in Pennsylvania's climate, researchers used the IPCC's higher- and lower-emissions scenarios as input to three state-of-the-art global climate models, each representing different climate "sensitivities." (Climate sensitivity, defined as the temperature change resulting from a doubling of atmospheric CO_2 concentrations relative to pre-industrial times, determines the extent to which temperatures will rise under a given increase in atmospheric concentrations of heat-trapping gases. The greater the climate sensitivity of the global climate model, the greater the extent of projected climate change for a given increase in CO_2.) The three climate models used to generate the projections described in this study were the U.S. National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory (GFDL) CM2.1 model, the United Kingdom Meteorological Office's Hadley Centre Climate Model version 3 (HadCM3), and the National Center for Atmospheric Research's Parallel Climate Model (PCM).

The first two climate models have medium and medium-high climate sensitivities, respectively, while the third has low climate sensitivity. These three are among the best of the latest generation of climate models. Confidence in using these global models to assess future climate is based on results

CONTINUED ON NEXT PAGE

FIGURE 2: **IPCC Emissions Scenarios**



Projected carbon emissions for the IPCC SRES scenarios. The higher-emissions scenario (A1fi) corresponds to the dotted red line while the lower-emissions scenario (B1) corresponds to the green line.

CONTINUED FROM PREVIOUS PAGE

from a detailed analysis that indicates they are able to reproduce not only key features of the regional climate but also climate changes that have already been observed across Pennsylvania over the last 100 years.

Uncertainties in climate modeling and the workings of the earth-atmosphere system remain, and several lines of evidence suggest that the climate-model projections used in this assessment may be relatively conservative. The models do not, for instance, capture the rapid winter warming observed in Pennsylvania over the past several decades. Projections of sea-level rise discussed in this report may also be quite conservative because they do not account for the rapid rate of decay and melting of the major polar ice sheets currently being observed, nor for the potential for further acceleration of this melting.

Many other changes in climate over short timescales (on the order of 10 years or less) may not be adequately resolved from these models. Climate researchers use projections over spans of 30 years or more to ensure they represent long-term averages and not short-term fluctuations in climate. Some of the well-known short-term fluctuations are due to changes in the strength of the El Niño Southern Oscillation (or its counterpart La Niña) and other patterns of variability in the ocean and atmosphere.

Global climate models produce output in the form of geographic grid-based projections of daily, monthly, and annual temperatures, precipitation, winds, cloud cover, humidity, and a host of other climate variables. The grid cells range in size from 50 to 250 miles on a side. To transform these global projections into "higher-resolution" regional projections (which look at changes occurring across tens of miles rather than hundreds), scientists used well-established statistical and dynamical downscaling techniques. As with global climate models, how well the downscaled models reproduce climate over the past century allows scientists to determine the performance of the models in projecting future climate.

The results of the collaborative climate research cited in this report were presented by the Northeast Climate Impacts Assessment in a report titled *Climate Change in the U.S. Northeast* and in the underlying technical papers.[9]

NOTE: Throughout this report, except where otherwise noted, "historical" refers to the baseline period of 1961–1990; "over the next several decades" is used to describe model results averaged over the period 2010–2039; "mid-century" and "late century" refer to model results averaged over the periods 2040–2069 and 2070–2099, respectively.

full range of possible emissions futures. A number of factors could drive global emissions even higher than assumed in the higher-emissions scenario, while concerted efforts to reduce emissions could move them well below the lower-emissions scenario.

PENNSYLVANIA'S CLIMATE

The Appalachian Mountains sweep diagonally across the Commonwealth of Pennsylvania from southwest to northeast, dividing it into distinct climatic regions. To the northwest lies the Allegheny plateau, which endures more severe winters, higher snowfall, and more frequent rainfall than other parts of the state. Precipitation from this area feeds the headwaters of four of the state's major rivers: the Susquehanna, the Delaware, the Allegheny, and the Monongahela. Central Pennsylvania is a fertile landscape of valleys and ridges that experiences greater extremes in temperature and rainfall and contains many of the heaviest snowfall areas; Somerset County tops the central districts in snowfall, with well over seven feet a year. Southeast Pennsylvania includes the Piedmont plateau and the coastal plain of the Delaware River, which enjoy a milder winter climate but endure longer and hotter summers than the rest of the state. Three of the largest cities—Philadelphia, Pittsburgh, and Harrisburg—are all situated in the more moderate climate regions of the state.

TEMPERATURE PROJECTIONS

Over the last century the annual average temperature in Pennsylvania increased by over 0.5°F.[10] During this coming century, temperatures across the state are projected to continue rising at a much faster rate, driven both by past and future emissions of heat-trapping gases:

- Over the next several decades (2010–2039), annual average temperatures across Pennsylvania are projected to increase by 2.5°F, under either emissions scenario. That average includes a slightly greater increase in winter temperatures (just under 3°F) than in summer temperatures (around 2.5°F), with smaller changes expected in spring and fall.
- By mid-century (2040–2069), differences between the emissions pathways begin to appear. Under the lower-emissions scenario, annual temperatures in Pennsylvania warm by slightly less than 4°F, while under the higher-emissions scenario they warm by more than 5.5°F.
- By late this century (2070–2099), average winter temperatures are projected to rise 8°F above historic levels, and summer temperatures to rise 11°F, if heat-trapping emissions remain high; under a lower-emissions future, the warming is projected to be about half as much.

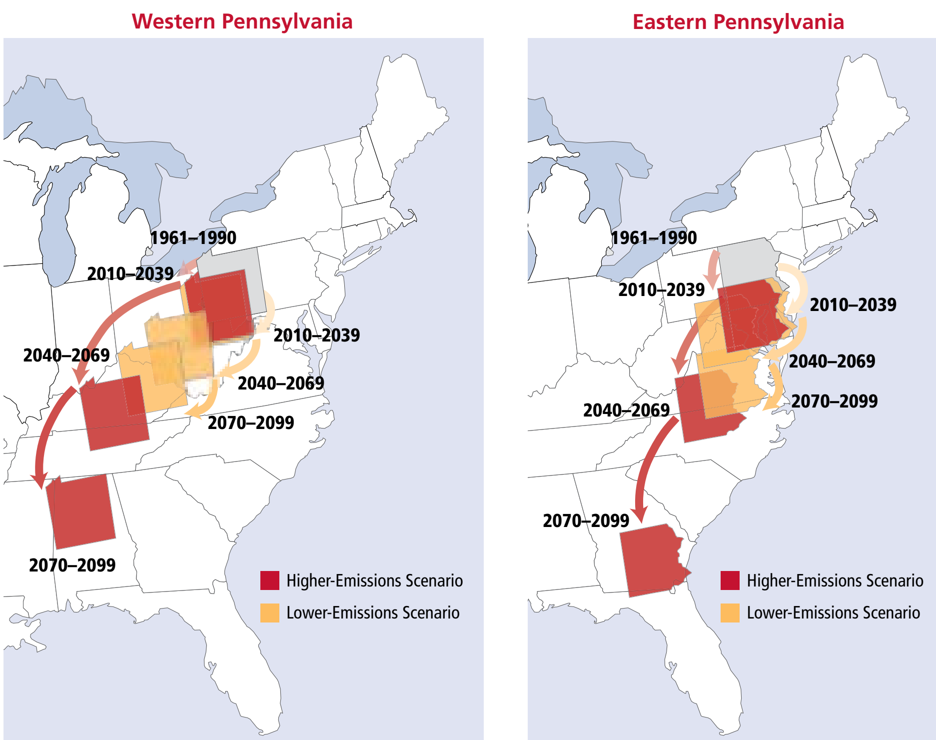
MIGRATING CLIMATE AND HEAT INDEX

How hot or cold it feels depends not only on temperature but also on wind and humidity. As Pennsylvanians know all too well, a sunny winter day with no wind might feel warmer than a damp and windy spring day, while humid summer days can be stifling. Thus heat index—defined as the temperature perceived by the human body based both on air temperature and humidity—can be a better measure of how hot it may "feel."

Future changes in the average summer heat index could strongly affect quality of life for residents of Pennsylvania. Under the higher-emissions scenario, an average summer day in the region is projected to feel 13°F warmer in eastern Pennsylvania and 15°F warmer in western Pennsylvania by late century than it has historically. The impact of changes in heat index because of global warming can be illustrated by comparing future summers in Pennsylvania with current summers to the south. For example:

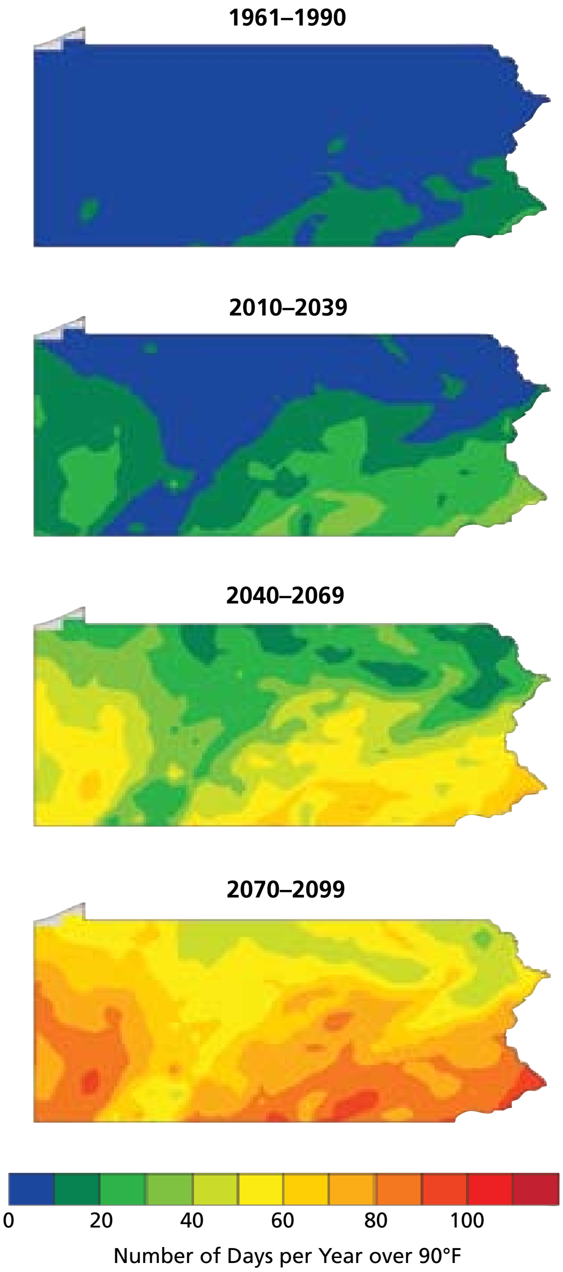
- Mid-century summers in eastern Pennsylvania under a lower-emissions future are projected to resemble those of the Washington, DC, region today,

FIGURE 3: Migrating Climates



Changes in average summer "heat index"—a measure of how hot it actually feels with a given combination of temperature and humidity—could strongly affect quality of life for residents of Pennsylvania in the future. Red arrows track what summers could feel like over the course of the century in western and eastern Pennsylvania under the higher-emissions scenario. Yellow arrows track what the summers could feel like under the lower-emissions scenario.

FIGURE 4: Temperature to Rise across the State



Pennsylvania locales are projected to experience striking increases in the number of extremely hot days over the coming century, especially under the higher-emissions scenario. The most dramatic warming will be in the southwest and southeast regions, where daytime temperatures by late century (2070–2099) could hover over 90°F for nearly the entire summer.

and under a higher-emissions future those of North Carolina.

- By late century, eastern Pennsylvania summers under the lower-emissions future may be closer to those of present-day Virginia, and to southern Georgia if the higher-emissions scenario prevails.
- In western Pennsylvania, mid-century summers under the lower-emissions scenario may resemble those of southern Ohio today, and under a higher-emissions future those of Kentucky.
- By late century, western Pennsylvania summers under lower emissions are projected to approximate those of Kentucky today; under higher emissions, they may resemble summers in Alabama.

HEAT WAVES AND TEMPERATURE EXTREMES

In addition to the rise in annual average temperatures, extreme heat events (extended periods above 90°F) in Pennsylvania are projected to increase in the future. In Philadelphia and other urban areas throughout the state, heat waves already generate headlines each summer and raise public concern. In July 2008, for example, 8 deaths were attributed to a four-day heat wave in Philadelphia.

Currently, Philadelphia and Harrisburg experience on average more than 20 days a year over 90°F, while much of the rest of the state experiences less than two weeks. However, under the higher-emissions future, the number of extremely hot days across Pennsylvania could dramatically increase over the coming century:

- In the next several decades, much of the state can expect substantially more days over 90°F—in most cases, at least a doubling.
- By mid-century, parts of southwestern and southeastern Pennsylvania could experience more than 50 days a year over 90°F.
- By late century, much of the southern half the state is projected to endure more than 70 days a year with temperatures higher than 90°F.

SNOW COVER

Over the last century, the interior regions of Pennsylvania—including the Alleghenies, the Poconos, and the Laurel Highlands—experienced a decline in average seasonal snowfall.[1] In some areas, the average amount of snow received has decreased by several inches since the 1970s.[12]

Historically, these highland regions of Pennsylvania were snow-covered almost half the time during the average winter. As temperatures rise, however, snow is projected to appear later in the winter, melt more quickly, and disappear earlier in the spring, thereby shortening the overall snow season (see Chapter Five).

- In the next several decades, under either emissions scenario, the number of days of snow cover in these areas of the state is projected to be halved.
- By mid-century, much of the snow cover in Pennsylvania is projected to have diminished markedly, with regions currently covered with at least a dusting of snow shrinking by more than three-quarters.
- By late century, the characteristic snow season of Pennsylvania is expected to have disappeared under a higher-emissions future and to have diminished from all but the highest areas under a lower-emissions future.

PRECIPITATION CHANGES

Pennsylvania's climate is becoming wetter. Over the last century, annual precipitation in the state has changed markedly, with increases of between 5 and 20 percent experienced in different regions.[13] Since 1970 the winter, spring, and fall seasons in Pennsylvania have had distinctly more rain, while summers have received slightly less rain.[14] Annual average precipitation for the state rose from just under 38 inches in the early part of the twentieth century to nearly 44 inches by its end.[15] Projections show this trend continuing under both the higher- and lower-emissions futures considered in this report. Over the next several decades and through mid-century, precipitation is expected to increase statewide by more than 5 percent above the historical average and by late century by more than 12 percent under either scenario. Seasonal rainfall is projected to increase both in the spring and fall.

These projected changes in precipitation could enhance water supplies by increasing stream flow and runoff into lakes and reservoirs as well as by boosting the infiltration of surface water into aquifers. However, rising temperatures and changes in stream flow patterns could lead to decreases in water supplies during the summer. Moreover, the timing of precipitation and the form it takes (i.e., snow or rain) strongly influence how much of the total precipitation is actually stored in surface waters and reaches aquifers—versus the amount that runs off, potentially creating flood conditions. In winter and spring, for example, more flooding can be expected simply because of more precipitation.

For other parts of the Northeast region, projections show rainfall becoming more intense and periods of heavy rainfall (defined as more than two inches in a 24-hour period) becoming more frequent. The models used in this study were inconclusive, however, as to whether the increased precipitation that is projected for Pennsylvania will come in heavier or more frequent downpours. Should the state follow the regional trend, extreme rainfall events would be expected to produce more flash flooding, which threatens lives, property, and water-supply infrastructure such as dams. Shifts in the magnitude and timing of rain events could burden communities with erosion, sewage contamination, and other environmental problems.

DROUGHT

The worst recorded drought in Pennsylvania history was during the early 1960s, with the worst year on record being 1964.[16] In addition to its major impacts on agriculture and natural ecosystems, this extended drought greatly reduced water supply.

Drought can be described according to whether there is a lack of rainfall, a lack of soil moisture, low volume of groundwater, or low flow in streams. In this analysis, drought is defined by decreases in soil moisture—from the combination of lower rainfall and higher temperatures. Droughts are classified as short-term (lasting one to three months), medium-term (three to six months), or long-term (more than six months). Historically, short-term droughts occur roughly once every three years over western Pennsylvania and once every two years over eastern Pennsylvania. Medium-term droughts are far less common in Pennsylvania; they have occurred once every 10 years in western parts of the state and rarely in most eastern areas. Long-term droughts have occurred on average less than once every 30 years.

Rising summer temperatures, coupled with little change in summer rainfall, are projected to increase the frequency of short-term droughts. In the north-central mountains and the Poconos, these droughts are projected to occur annually by late century under the higher-emissions scenario, with smaller changes expected under the lower-emissions scenario. These shifts would increase stress both on natural and managed systems across the state. Little or no change is projected in short-term drought frequency in the southwest and southeast portions of the state (see Chapter Three).

CHAPTER TWO

Impacts on Cities and Towns

BACKGROUND

Global warming is expected to increase the risks of many types of climate-related illnesses and even death, especially in Pennsylvania's urban areas. In Philadelphia and other cities and towns throughout the state, extreme heat and air pollution events already generate headlines each summer and raise public concern. In its latest assessment, the IPCC found that as the climate changes, urban areas across North America are likely to suffer more severe and longer heat waves, leading to more cases of heat-related illness and death among the elderly and other vulnerable populations. [17] The assessment also found that global warming is likely to exacerbate lung-damaging air pollution from ground-level ozone and also levels of airborne pollen.

Today's emissions choices will help determine the severity of these risks and also how tolerable the future climate of Pennsylvania's cities will be. If higher emissions prevail, for example:

- Rising temperatures in Pennsylvania's cities could make dangerously hot conditions a frequent occurrence.
- Air quality could deteriorate substantially in the absence of more stringent controls on local pollutants.
- Risks to vulnerable populations could greatly increase and the costs of coping could rise precipitously.

Climate change will also determine the future management challenges that Pennsylvania cities will face. For instance:

- Increased rainfall amounts could drive greater failure of combined sewer systems, unless costly system overhauls are undertaken.[18]
- Accelerated sea-level rise could worsen Philadelphia's water-supply problems by increasing salinity in the Delaware River/Estuary system.[19]

The costs of adapting to such changes could be enormous, particularly for cash-strapped communities.

Outbreaks of many infectious diseases may also be affected by climate change. Proliferation of water-borne pathogens, for instance, is often linked with extreme rainstorms, heavy runoff, and hotter temperatures. Also, the incidence of mosquito-borne diseases such as West Nile virus varies with fluctuations in weather; hotter, longer, and drier summers punctuated by heavy rainstorms may create favorable conditions for more frequent West Nile virus outbreaks.[20]

Rising temperatures in Pennsylvania's cities could make dangerously hot conditions a frequent occurrence.

EXTREME HEAT

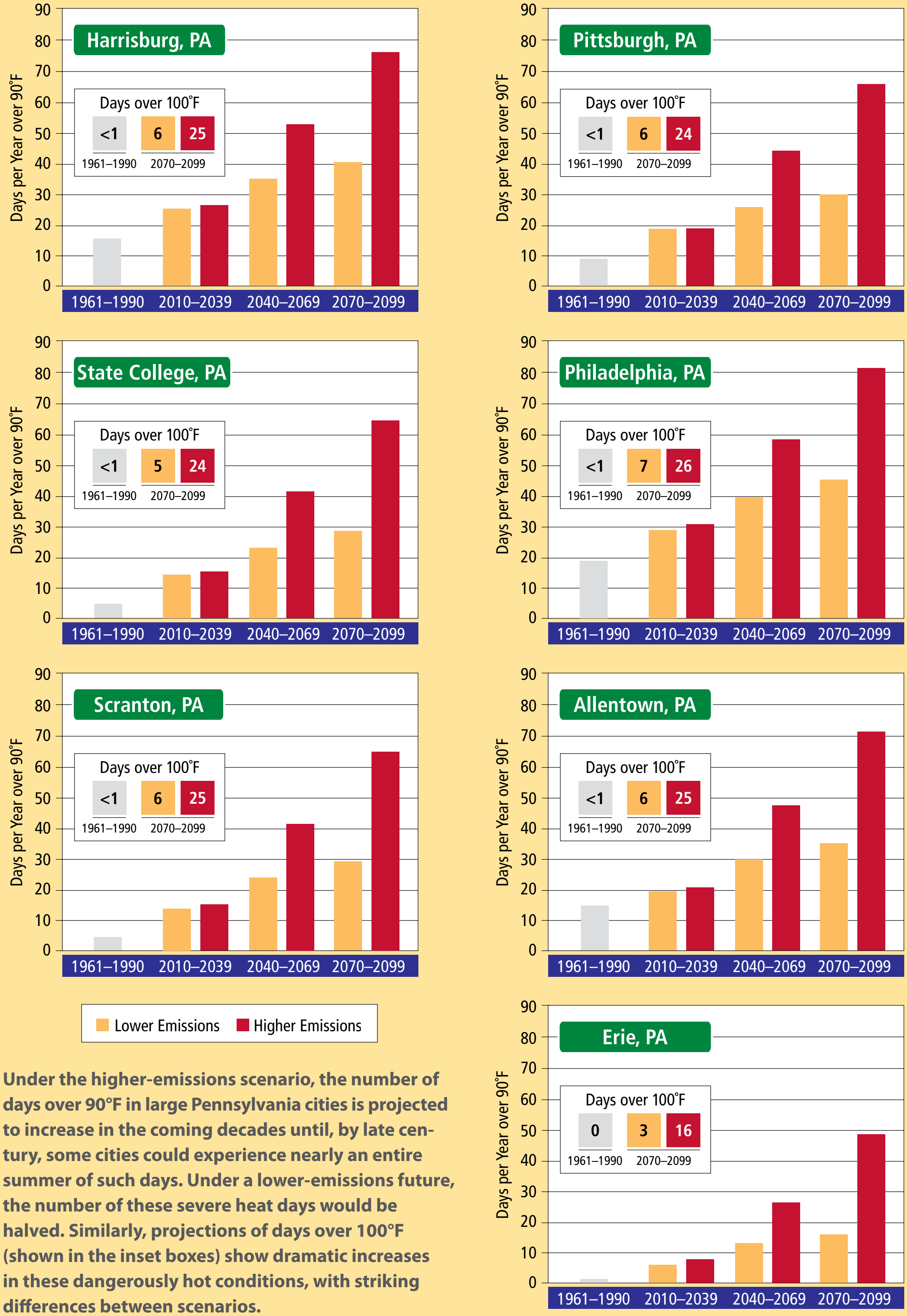
Talk of weather-related illness and death usually brings to mind violent events such as hurricanes and tornadoes. Yet in most years, heat is the leading weather-related killer in the United States.[21] Heat waves are particularly dangerous in cities, both because of the concentration of potentially vulnerable people (the elderly, the poor, those in ill health, children) and the "urban heat island effect" (whereby large expanses of concrete, asphalt, and other heat-absorbing materials cause air temperatures to rise considerably higher than in surrounding fields, forests, and suburbs).

The threat from extreme heat is particularly severe in historic cities such as Philadelphia, which hosts some of the nation's oldest housing stock and aging infrastructure and where one in five people live below the poverty level.[22] Given factors such as these, Philadelphia was once known in some quarters as the "Heat-Death Capital of the World."[23] But in 1995 the city launched an extensive public health initiative to save lives during extreme heat, as described below.[24]

Pennsylvania is projected to experience dramatic increases over the coming century in the annual numbers of extremely hot days, especially under the higher-emissions scenario.

- In the next few decades, many Pennsylvania cities can expect substantial increases in the current number of days over 90°F—in most cases, a

FIGURE 5: The Frequency of Extreme Heat: Selected Cities



Under the higher-emissions scenario, the number of days over 90°F in large Pennsylvania cities is projected to increase in the coming decades until, by late century, some cities could experience nearly an entire summer of such days. Under a lower-emissions future, the number of these severe heat days would be halved. Similarly, projections of days over 100°F (shown in the inset boxes) show dramatic increases in these dangerously hot conditions, with striking differences between scenarios.

doubling—suggesting that these cities should identify and implement measures to cope with increased heat.

- Cities such as Allentown, Scranton, and State College have historically averaged fewer than 10 days a year over 90°F. By mid-century, under a higher-emissions future, these towns may endure more than 40 days over 90°F. By late in the century, this number could rise to more than 65 days. It would roughly be halved, however, under a lower-emissions future.
- By late century under the higher-emissions scenario, Philadelphia is projected to face more than 80 days over 90°F and nearly 25 days over 100°F.
- By late in the century under a higher-emissions future, Pittsburgh and Harrisburg could each experience some 25 days over 100°F during the summer, compared to the one or two such days they typically experience at present. Under a lower-emissions future, the number of days per year over 100°F would average roughly seven in total.

Direct human health risks from extreme and unrelenting heat come in the form of heat stress, heat exhaustion, and life-threatening heatstroke, which can occur as the body tries unsuccessfully to cool itself. Heat can also contribute to the premature death of elderly and disabled people or of those who suffer from heart disease or other chronic illnesses.

Cities and individuals can reduce their vulnerability to heat-related illness through public health education, heat-wave warning systems, building insulation, air conditioning, and increased access to cool public buildings.[25] Philadelphia launched its public health initiative—the Heat Health Watch Warning System[26]—after a heat wave in July 1993 that killed more than 100 people.[27] This system combines heat warnings with outreach programs directed at the most vulnerable city dwellers. During a heat alert, health department staff visit elderly residents in their homes and reach out to the homeless, electric utilities are barred from shutting off services for non-payment, and cool-off centers in public places extend their hours.

Philadelphia's experience can serve as a model for other cities, in Pennsylvania and elsewhere, faced with increasing numbers of extreme heat events. Such adaptation measures, however, cannot completely eliminate the threats posed by climate change, especially if the higher-emissions scenario prevails. In July 2008, for example, a four-day heat wave left eight people dead in Philadelphia[28] and subsequent storms caused power outages in Pittsburgh and other state locales.[29]

Allergies on the rise?

Pollen, carried by air currents, coats the surface of a canal. Allergy-related diseases, including pollen allergies, rank among the most common and costly of the chronic illnesses afflicting Americans. Higher temperatures can prolong the pollen allergy season, while elevated CO_2 levels accelerate the productivity of key pollen-allergen sources—including ragweed and loblolly pine.

Adaptation measures such as retrofitting older buildings with air conditioning are important steps but not fail-safe. By late this century, the number of days per year requiring air conditioning could double under the lower-emissions scenario and triple under the higher-emissions scenario. Because hotter temperatures will increase energy demand as the need for air conditioning rises, they also increase the likelihood of electricity blackouts. The subsequent energy cost of cooling the buildings and the potential for increased heat-trapping emissions from fossil fuel energy sources can also carry a steep price, especially under the higher-emissions scenario.

AIR QUALITY

Air pollution from ground-level ozone and fine particulate matter—primary components of smog—is already a serious concern across the region. Pennsylvania hosts parts of four of the nation's 25 most ozone-polluted metropolitan areas.[30] They include:

- New York City-Newark-Bridgeport (encompassing counties in Connecticut, New Jersey, New York, and Pennsylvania)
- Philadelphia-Camden-Vineland (encompassing counties in Delaware, Maryland, New Jersey, and Pennsylvania)

Climate change will determine the future management challenges that Pennsylvania cities will face.

- Pittsburgh-New Castle (Pennsylvania)
- Youngstown-Warren-East Liverpool (encompassing counties in Ohio and Pennsylvania)

Poor air quality puts large numbers of Pennsylvanians at risk from respiratory illnesses such as asthma, chronic bronchitis, and emphysema. More than a million people—one out of every nine adults in Pennsylvania—have been diagnosed with asthma at some point in their lives.[31] So have nearly 10 percent of Pennsylvanian schoolchildren.[32] In 2002 alone, more than 21,000 people in the Commonwealth were hospitalized for asthma, at a cost exceeding $280 million.[33]

In the absence of more stringent air quality regulations, climate change could worsen air pollution in Pennsylvania, particularly under the higher-emissions scenario. Allentown, Philadelphia, Harrisburg, and Lancaster are already among the top 15 on the Asthma and Allergy Foundation of America's (AAFA) 2008 list of "The Most Challenging Places to Live with Asthma."[34] Deteriorating air quality would increase the number of days each year when national ozone standards were unmet and would exacerbate the risk of attacks from asthma and other respiratory and cardiovascular ailments. For example, by late century:[35]

- In the Philadelphia metropolitan region, the number of days failing to meet the federal ozone standard is expected to at least quadruple under the higher-emissions scenario if local vehicular and industrial emissions of ozone-forming pollutants are not reduced.
- Ozone concentrations in Philadelphia are projected to increase roughly 15 to 25 percent under the higher-emissions scenario and 5 to 10 percent under the lower-emissions scenario.

Higher temperatures are also expected to increase the dangers of allergy-related diseases, which rank among the most common as well as the most costly chronic illnesses affecting the U.S. population.[36] Studies show that rising temperatures and shifting precipitation patterns are lengthening the allergy season and changing how plants produce allergens.[37] The CO_2 that causes global warming is also accelerating the growth of particular allergenic-pollen producers such as ragweed, loblolly pines, and poison ivy. Ragweed, for example, produces pollen at a younger age and in greater quantities when CO_2 levels are higher.[38] The plant already grows in the state's heavily urbanized areas, and its response to CO_2 may be a harbinger of what lies ahead for the allergy sufferers across Pennsylvania.

Urban CO_2 levels across the Northeast are already 15 to 25 percent higher than those of rural areas.[39] But within the next several decades under the higher-emissions scenario, CO_2 levels across the entire region would rise to today's urban levels. By late century, CO_2 levels in the region would climb to more than double their present-day urban levels. In contrast, under a lower-emissions future, CO_2 would not reach present-day urban levels across the region until mid-century or later. In response, pollen production in Pennsylvania's urban centers would likely continue to rise but at a gradually declining rate, eventually leveling off.

- As both temperatures and CO_2 levels rise, increases would be expected across Pennsylvania not only in the production of pollen grains but potentially in the allergenic potency of individual pollen grains.

The AAFA list of "The Most Challenging Places to Live with Spring Allergies" ranked Harrisburg, Philadelphia, and Scranton twentieth, twenty-fifth, and twenty-seventh, respectively, among the top 100 U.S. Spring Allergy Capitals in 2008.[40] Increased rates of plant-based allergies may be in store for cities like these as temperatures and CO_2 levels rise.

INFRASTRUCTURE

Public health and safety in Pennsylvania's urban areas is critically dependent on the adequacy of infrastructure such as roads, bridges, railways, buildings, communications systems, water and sewer systems, and other utilities. Most of this infrastructure was built to withstand various historic levels of threat from flooding, drought, storms, and other climate-related extremes. As the frequency or intensity of such events changes, however, certain infrastructure may need costly overhauls or upgrades to protect lives and livelihoods in vulnerable areas.

Sewage and storm water systems. More frequent failures of combined sewer systems (CSSs) in Pennsylvania's cities, caused by greater numbers of rainfall events, could create overflows of untreated sewage that compromise water quality in receiving rivers and streams.[41] CSSs are designed to carry both storm water and sewage flows to treatment plants through the same pipe system. Under dry weather conditions or for smaller storms, the system's capacity is usually sufficient. In larger storms, however, when the volume of storm water and sewage exceeds the capacity of the pipes or the treatment plant, the excess is discharged untreated to surface waters, creating a combined sewer overflow (CSO).[42]

In many older cities such as Pittsburgh, CSOs occur frequently enough (dozens of times a year) to cause regular water-quality violations in receiving streams, particularly regarding bacteria.[43] And increases in seasonal average rainfall, projected for winter, spring, and fall in Pennsylvania, pose substantial risks of increased CSOs to these cities. In general, more precipitation in systems with currently inadequate capacity has the potential to result in:

- More frequent CSOs and associated water-quality violations of bacteria standards for receiving streams. This would result in higher health risks in recreational waters.
- Increased volume of CSOs on an annual basis.
- Greater difficulty in meeting CSO control targets.
- A need to increase collector-system, storage, or treatment-system capacity as weather patterns change.

CSOs are most easily controlled in climates characterized by low-intensity storms that do not result in large and rapid flows into the collection system.[44] If Pennsylvania's climate moves toward more frequent and intense rainfall events, as is projected for the climate of the Northeast region more broadly (see Chapter One), additional municipalities could find their combined sewer systems inadequate.

Many cities with combined sewer systems are already being forced to make enormous investments (separation of storm and sewer pipes can cost, for example, $375,000 for just 600 meters of replaced pipe) in CSO control programs.[45] But assumed volume of rainfall, frequency of rainfall, and runoff are typically based on current climate conditions. If climate change brings the projected increases in seasonal rainfall amounts, to say nothing of increased storm frequency and intensity, the upgrades being undertaken now may not meet their targets in coming decades. This

Infrastructure inadequate in a warming world

Projected increases in rainfall may present major challenges to Pennsylvania cities as municipal combined sewer systems—designed to carry both storm water and sewage to treatment plants through the same pipe system—more often fail during heavy rainfall, causing overflows of untreated sewage that foul water supplies. Such failures may become more common and widespread as more rain falls each year. Upgrades to these systems should account for such projected increases.

could require a second round of major investments, with significant additional costs to municipalities.

Water supply systems. Throughout Pennsylvania, mountain streams, rivers, lakes, and reservoirs are treasured for the recreational opportunities, habitat, and drinking water supplies they offer. But these water resources, already threatened by development and other human pressures (e.g., pollution from mining operations) will be further stressed by climate change. Projected increases in drought frequency would threaten water quantity, while increases in storm intensity could threaten water quality. Communities can begin to implement a wide range of measures to prepare for these changes, including water conservation measures in response to drought.[46]

The most fundamental regulators of water quantity and quality in Pennsylvania are the state's vast public and private forests. As rain falls on the forests, some water evaporates or is taken up by plants, but a significant amount percolates slowly through the soil to replenish groundwater. Groundwater is slowly released to streams and rivers, providing critical flow during dry weather. By protecting existing forests, reclaiming deforested areas, and planting vegetated buffers along streams and creeks, Pennsylvanians can help to ensure clean and abundant water supplies.

Because the provision of high-quality and plentiful drinking water supplies is a critical priority for any state facing an uncertain climate future, the protection of source waters will be a central focus for state forest protection, watershed management, and storm water management plans.[47]

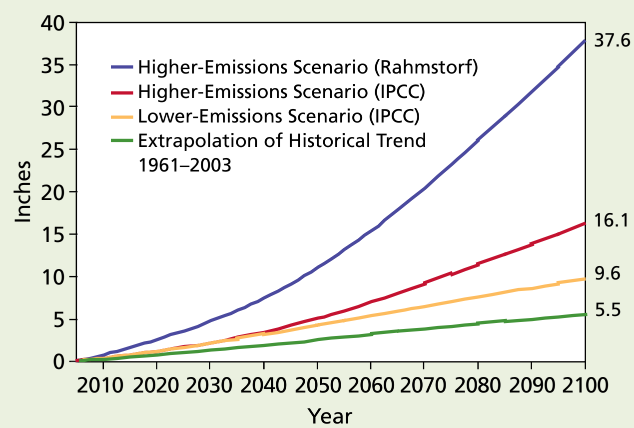
Sea-Level Rise and the Delaware Estuary

When one thinks of Pennsylvania, the ocean seldom comes to mind. Yet Pennsylvania's one connection to the sea, the Delaware Estuary, is one of the state's—and indeed, the nation's—most valuable economic and ecological resources.[48] The estuary is home to the largest freshwater port in the world, the Delaware River Port Complex, which includes docking facilities in Pennsylvania, New Jersey, and Delaware[49] that generate $19 billion annually and receive 70 percent of the oil shipped to the East Coast. The combined Delaware River/Estuary system also provides drinking water to 15 million people (including millions of Pennsylvanians), supplies water for industrial processes, and receives effluent from municipal and industrial wastewater treatment plants.[50]

Because fresh water from inland watersheds and salt water from the Atlantic Ocean meet and mix in the estuary, its chemistry and character will be affected by climate-driven changes in upstream precipitation as well as in sea-surface temperatures and sea level.[51]

Increasing global temperatures drive sea-level rise by two different mechanisms: thermal expan-

FIGURE 6: Projected Rise in Global Sea Level Relative to 2005



This graph depicts the average or mid-range of a number of different sea-level rise (SLR) simulations: a continuation of recent observed SLR rates (green line), the mid-range of the most recent IPCC projections under the lower-emissions scenario (yellow line), the mid-range of the recent IPCC projections under the higher-emissions scenario (red line), and the mid-range of a more recent set of projections under the higher-emissions scenario (blue line).

Smog blankets Philadelphia

Residents of the country's tenth most ozone-polluted metropolitan area are sadly accustomed to smog—a potent combination of ground-level ozone and fine particulate matter. Such conditions are projected to become more commonplace, particularly under the higher-emissions scenario, unless local vehicle and industrial emissions of ozone-forming pollutants are greatly reduced.

sion of seawater as it warms and increasing inflow of water from melting ice sheets and glaciers.

As the planet warms, the IPCC conservatively projects that sea levels will rise between 7 and 14 inches worldwide under the lower-emissions scenario and between 10 and 23 inches under the higher-emissions scenario during the century ahead. [52]

Through its impact on the Delaware Estuary, sea-level rise has the potential to affect the economy, infrastructure, and drinking water supply for millions of people living in southeastern Pennsyvania. Power stations, wastewater treatment plants, drinking water treatment plants, food and beverage manufacturers, and oil refineries are just a few of the facilities susceptible to changes in water elevation and water quality in Pennsylvania.

As sea level rises and salt water reaches farther inland, river salinity can change. The salinity level is a defining characteristic of the Delaware Estuary, as it regulates plant and animal distributions as well as human uses of the estuary. The salt line—technically 250 milligrams per liter (mg/L) chloride—is the boundary between high-salinity and low-salinity waters, where fresh water that travels down the Delaware River from as far away as New York's Catskill Mountains mixes with saline water from Delaware Bay.[53] Sea-level rise in the Delaware Estuary may drive the salt line northward toward Philadelphia.[54]

Pennsylvania's drinking water and industrial intakes along the Delaware River are dependent on the low-salinity waters north of the salt line. Waters south of the salt line are far too saline for drinking water supply and industrial processes. But during drought periods, the salt line moves north toward Philadelphia, jeopardizing water quality for multiple users. At the Philadelphia Water Department intake, average chloride concentration is approximately 21 mg/L. Chloride concentrations above 50 mg/L—possible as sea level rises—could cause health problems for water users with high blood pressure, those on dialysis, and those on restricted-sodium diets. [55] Meeting such a threat may require costly new approaches to water management. In the interim, adaptation to unavoidable sea-level rise could include improved monitoring of salinity and other changes in the Delaware Estuary.[56]

CHAPTER THREE

Impacts on Agriculture

BACKGROUND

From the stone barns and rolling fields of Lancaster County to the maple syrup and Christmas tree farms of the Allegheny Plateau to the vineyards that rim Lake Erie's shore, agriculture remains a scenic centerpiece of Pennsylvania's identity. Despite heavy migration to urban areas over the past half century, Pennsylvania retains one of the largest rural populations in the United States. Some 59,000 farms, many of them small and family-run, nestle among the state's hills, forests, rivers, and burgeoning suburbs, maintaining an agricultural tradition that in many areas goes back 200 years or more.[57]

Dairying is the top agricultural industry in the state, with a 2002 commodity value of $1.4 billion.[58] Major cash crops include mushrooms, vegetables, grains (such as corn and soybeans), and fruits (including grapes and apples). Continuing changes in temperature, rainfall, severe weather events, and even the atmospheric levels of CO_2 will affect, both positively and negatively, Pennsylvania's crops and livestock as well as the pests, pathogens, and weeds that threaten them. The IPCC's most recent assessment, for example, projects that "moderate climate change" will likely increase yields of crops such as corn and soybeans by 5 to 20 percent over the next few decades, thanks to warmer temperatures, a longer growing season, and the "fertilizer effect" of higher levels of CO_2.[59]

Other global warming impacts, however, may outweigh such benefits. For example, as temperatures increase, the state's prized sweet-corn crop may face reduced yields because of summer heat stress, increased infestations of corn earworms, and diseases such as Stewart's wilt. Hotter summers without an increase in summer rainfall could require that traditionally rain-fed crops be irrigated. High-value Concord grapes and favorite apple varieties such as McIntosh and Granny Smith may no longer experience the winter chilling required for optimal fruit production and may also face increased pressures from pests such as the grape berry moth. Without adequate coping measures, increasing summer heat stress on dairy cattle is projected to bring declines in milk production.

Although farmers have often proven adaptable to changing weather patterns and market demands, they face greater uncertainty, risk, and expense as the pace and scope of climate change increase. The economic pressures will be felt both by large operations and small family farms, often threatening traditional livelihoods and unique lifestyles such as those of the Amish.

Although farmers have often proven adaptable to changing weather patterns and market demands, they face greater uncertainty, risk, and expense as the pace and scope of climate change increase.

Shifts in the rural economy may also accelerate the conversion of farmlands to suburbs, thereby reducing valued open space and compromising historic landscapes and popular tourist attractions. Climate change will change the character not only of farmed landscapes but also of Pennsylvania's gardens, forests, and other natural areas as the climate grows less suitable for many common flowers, shrubs, and trees while opening opportunities for species, both welcome and unwelcome, from warmer regions. For example, the treasured mountain laurel, Pennsylvania's state flower and the namesake of the state's annual Laurel Festival in ruggedly beautiful Tioga County, may eventually withdraw northward into New York as the climate becomes unsuitable to its survival.[60]

DAIRY

Climate change may negatively affect dairy farming—by far the most economically important agricultural industry in Pennsylvania—and other livestock operations by raising the intensity and frequency of

FIGURE 7: **Added Pressure on the Dairy Industry**

This map shows the degree to which milk production in July is projected to decline by late century (2070–2099) under the higher-emissions scenario. Pennsylvania's key dairy-producing regions are projected to experience heat conditions that could drive average losses in milk production of 10 to 20 percent.

summer heat stress. Although many factors, including quality of feed and feed management, come into play, extreme heat can depress dairy cows' milk production and birthing rates. The optimal temperature for milk production ranges from 40°F to 75°F, depending on the humidity (when humidity is high, heat stress can occur at a lower temperature within that range).[61] Despite the state's historically moderate summers, heat stress in cattle already costs Pennsylvania farmers an estimated $50.8 million per year,[62] and these losses may rise along with summer temperatures.

- Without new investments in methods to cool cattle, increasing summer heat stress under the higher-emissions scenario is projected to depress milk production in Pennsylvania at least 10 percent by mid-century. Under the lower-emissions scenario, this level of decline is not expected until late in the century.
- By late in the century under the higher-emissions scenario, milk production in parts of the state could decline as much as 20 percent.[63]

Higher temperatures depress milk production

Dairy cows are being sprayed to help keep them cool. Under the higher-emissions scenario, dairy farmers face substantial reductions in milk production later this century as very hot days become more commonplace. Adaptation options include the installation of cooling systems in dairy facilities.

GRAPES

A narrow 60-mile-long strip of land sandwiched between Lake Erie and the foot of the Allegheny Plateau is known as the Concord Grape Belt, and its vineyards have made Pennsylvania the third-largest producer of this native American fruit.[64] Most of the Concord crop goes to Welch's, a storied company that pioneered the manufacture of nonalcoholic grape juice in 1869;[65] Welch's is now a subsidiary of the grower-owned cooperative—including growers in Pennsylvania—that supplies its grapes. The state's Concord grape industry employs nearly 1,000 people and pumps $181 million a year into Erie County alone.[66]

Climate change may extend the frost-free period, reducing the share of Concord grape harvests currently lost to frost. But warmer winters could be detrimental to the Concord grape, while making the Concord Grape Belt increasingly suitable for European wine grapes. Concord grapes require a high number of chilling hours (that is, cumulative hours below about 45°F) each winter, on the order of 1,800 hours, for optimal flowering and fruit production.[67] By contrast, European grapes typically require fewer than 500 hours.[68]

- By mid-century under the higher-emissions scenario, the Concord Grape Belt may achieve the 1,800-chilling-hour requirement in just one out of two winters;[69] under such conditions, reduced grape harvests would be expected half of the time.
- By mid-century under the lower-emissions scenario, the Concord Grape Belt would still achieve 1,800 chilling hours in four years out of five.[70]
- By late century, however, even under the lower-emissions scenario, the region would meet this high chilling threshold for Concord grapes in only three out of five years.[71]

Thus, although the long-term outlook for the Concord grape in Pennsylvania is questionable, following the lower-emissions pathway may keep the industry viable for extra decades and allow more time for growers to adapt. Adaptation in this case could mean switching to new grape varieties; at least one heat-tolerant juice-grape variety, Sunbelt, has properties similar to the crop currently grown in the Concord Grape Belt. Such measures come at a price, however. The cost to grape growers of replacing one grape variety with another averages $2,500 per acre. Compounding these costs is the fact that new grape vines do not reach full productivity until the fourth year, yielding no crop or just a partial one during the first three years.

Native grapes in a non-native climate

Pennsylvania's thriving Concord grape industry—a major source for the nation's grape juice makers—employs nearly 1,000 people in Erie County alone. This native grape requires sufficiently cold winter temperatures for optimal flowering and fruit production. Under the higher-emissions scenario, warmer temperatures could pose a substantial challenge to Concord grape growers by mid-century.

For grape growers, a further complication of climate change is that warming is expected to bring increased damage from the grape berry moth,[72] which is already a significant pest in Pennsylvania vineyards. Its larvae burrow into and feed on the grapes, ruining some fruit directly and allowing bunch rot diseases (causing extensive mold to form on grape clusters) to take hold. Currently, the pest goes through two or three generations a year, depending on the weather.[73] Under the higher-emissions scenario, by late century the Concord Grape Belt of northwestern Pennsylvania will average about one extra generation a year of the grape berry moth,[74] prolonging pressure from this pest closer to harvest time. Most growers prefer not to apply pesticides at this point in the grape-growing season;[75] in the future, though, they face the risk of significantly increased damage to their crop. Under the lower-emissions scenario, the region may experience only slightly higher grape berry moth damage.

As Pennsylvania's climate changes, another adaptation strategy for grape growers could be to switch from juice to wine grapes—a potentially lucrative move, but one accompanied by its own risks. Growers may need, for instance, to substantially increase pest management efforts. A broad transition to wine grapes could also hail a shift in the culture and economy of the northwestern part of the state.

APPLES

Pennsylvania was the country's fourth-largest producer of apples in 2006, with a crop worth nearly $60 million[76] cultivated mostly in the southeastern region of the state. Like native grapes, certain popular varieties of apples grown in Pennsylvania, such as McIntosh and Granny Smith, require relatively long periods (about 1,000 hours)[77] of winter chill for optimal fruit production. Indeed, most of the apple varieties grown in the state require between 800 and 1,200 chilling hours.[78]

- Under the higher-emissions scenario, by mid-century the 1,000-chilling-hour requirement may be met in 70 to 80 percent of winters[79] in the southern portions of the state—but only in 50 to 60 percent of winters in the extreme southeastern region, which includes Adams County, the state's major apple-producing area.
- By late century under higher emissions, only the most northern portions of Pennsylvania may be able to count on 1,000 chilling hours each winter.[80]
- Under the lower-emissions scenario, adequate chilling conditions may be retained statewide until late in the century.[81]

Pennsylvania orchards could adapt by switching to other fruits or to apple varieties more tolerant of warmer winters. If lower emissions prevail, farmers would have more time to plan for the future and invest in new varieties when it is time to replace their aging trees.

CORN

Corn is grown in every county in Pennsylvania, although production is highest in the southeastern and central regions. About two-thirds of the field-corn crop is harvested for grain while the other third is grown as forage for dairy and beef cattle.[82] Sweet corn is grown throughout the state, often on small family farms and as part of diversified vegetable operations. Both for field and sweet corn, pollination occurs during a roughly two-week window in August, depending on planting date and variety. Normal development of kernels can be negatively affected by high temperatures and drought conditions. Temperatures above 90°F during this period reduce the viability of the pollen, resulting in poor ear fill, reduced yield, and lower quality. High temperatures during the maturing of the kernels, moreover, can reduce the eating quality of sweet corn.

Currently, the number of days when the temperature exceeds 90°F in August ranges from 5 to 10 across Pennsylvania. Projections of the number of such days in various parts of the state provide a useful indicator of how heat stress may affect future corn yields.

Summer and sweet corn: The perfect combination

Sweet corn, often grown on small farms and sold fresh at roadside stands, is a favorite food of summer. In states like Pennsylvania, summer climate conditions are ideal for sweet corn to pollinate, grow, and develop its unique taste. Under the higher-emissions scenario, many July and August days are projected by mid-century to be substantially hotter than today, thereby reducing the yield and quality of Pennsylvania sweet corn.

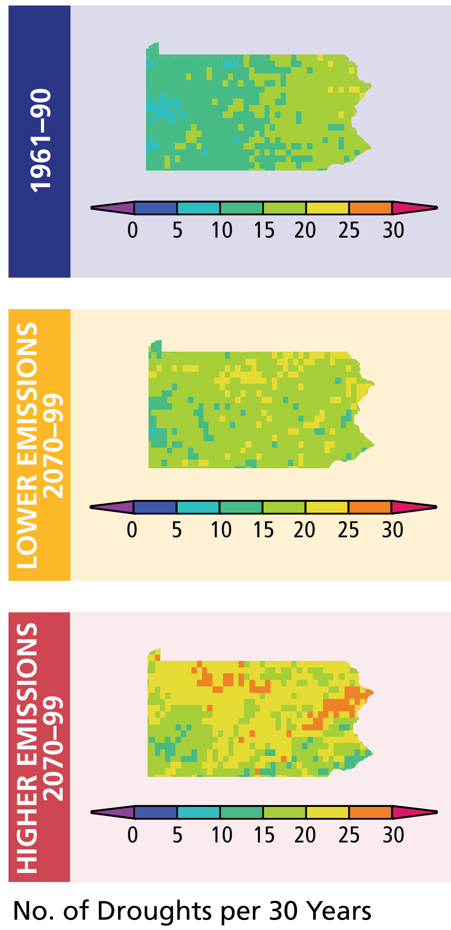
- In the next several decades, under the higher-emissions scenario, projected temperatures in August show that 90°F may be exceeded on 10 to 20 days.
- By late in the century under the higher-emissions scenario, most August (as well as July) days in Pennsylvania are projected to exceed 90°F.
- By comparison, under the lower-emissions scenario the number of days with temperatures above these thresholds would be halved.

Warmer winters are projected to increase infestations of marginally overwintering insect pests such as corn earworms and the flea beetles that carry Stewart's wilt, a bacterial disease that can ruin corn crops.[83] Southern Pennsylvania cornfields already experience moderate to severe flea beetle outbreaks in a typical year.

- By mid-century under both emissions scenarios, most of Pennsylvania's cornfields could experience consistent pressure from flea beetle/Stewart's wilt outbreaks.

Corn earworms overwinter in regions to the south of Pennsylvania, where the soil does not freeze, and they move into the state in spring. Milder winters could permit higher rates of survival in nearby areas, allowing larger populations of earworms to reach the state's cornfields earlier in the season—a process that may already be under way, given the high pest levels experienced in 2007. Corn earworms infest all types of corn, but they are of more concern to sweet-corn growers because of consumer demand for insect-free produce. If corn earworms continue to arrive earlier and at densities at or above those experienced in 2007, Pennsylvania sweet-corn fields may require major increases of insecticide spraying.[84]

FIGURE 8: Short-term Drought



Rising summer temperatures, coupled with little change in summer rainfall, are projected to increase the frequency of short-term (1–3 month) droughts. Historically, short-term droughts occur roughly once every three years over western Pennsylvania and once every two years over eastern Pennsylvania. In the highland areas of Pennsylvania, including the north-central mountains and the Poconos, these droughts are projected to occur annually by late century under the higher-emissions scenario, with smaller changes expected under the lower-emissions scenario.

OTHER CROP IMPACTS

Milder winters and an extended growing season may be a boon to growers of tomatoes, melons, and other cold-sensitive produce crops. Yet many of these same crops will face increasing summer heat stress, drought, and threats from weeds and pests. Like sweet corn, grain crops such as wheat and oats tend to have lower yields in hot summers. Heat stress at certain periods of their development can also reduce tomato yields and fruit quality.[85] Indeed, under the higher-emissions scenario, most July days in Pennsylvania late this century are projected to exceed the heat-stress threshold for the majority of crops currently grown in the state.[86]

Projections for an increase in spring rainfall may delay planting, damage young crops, and exacerbate soil erosion. On the other hand, more frequent droughts during the growing season—projected under the higher-emissions scenario—could make irrigation essential for currently rain-fed high-value crops.

Although milder winters may be a boon to some crops, they are expected to have negative effects on maple syrup production. Warmer temperatures shorten the tapping season and diminish the quantity and quality of sap flow—indeed, per-tree production is already declining in the Northeast.[87] In addition, climate change will make current sugar maple habitat in the state less suitable, especially under the higher-emissions scenario[88] (see also Chapter Four).

Warmer temperatures may affect the profitability of the state's mushroom industry. Pennsylvania is the country's largest mushroom-producing state, harvesting one-third of the fresh mushrooms and two-thirds of those that are processed.[89] Mushrooms are also the largest cash crop in the state,[90] with a sales value approaching $400 million;[91] some 80 percent of Pennsylvania's mushroom farms are located in its southeastern corner, Chester County.[92] The crop is

Keeping mushrooms cool

Pennsylvania produces one-third of the nation's fresh mushrooms and two-thirds of its processed mushrooms. Because mushrooms require a narrow range of cool temperatures, they are grown indoors under climate-controlled conditions. While warmer winters should mean lower heating bills for such "mushroom houses," the costs of maintaining the cooling required in summer—a substantial industry expense—could increase greatly in coming decades as summer temperatures rise.

cultivated indoors in cool climate-controlled "mushroom houses" because temperatures must be strictly regulated in the final growth stage. Warmer winters should mean lower heating costs for such facilities. However, the costs of maintaining cool conditions in summer—a substantial industry expense—could increase greatly in coming decades.

- By late century under the higher-emissions scenario, cooling degree-days (a measure of the length of time at temperatures over 65°F) in the state may more than double, requiring a substantial increase in electricity used for cooling mushrooms.
- Under the lower-emissions scenario, cooling degree-days increase by less than half that amount.

Finally, as noted above, pest problems and also weed damage are expected to escalate with warmer temperatures, which would increase pressures on farmers to use more pesticides and herbicides. One particular concern is that milder winters may allow the northward spread of invasive weeds such as kudzu,[93] a highly aggressive vine that currently infests 2.5 million acres of cropland, fields, and forests in the American South. Kudzu has already made some inroads into Pennsylvania.

- Projections show that by mid-century under either emissions scenario, suitable habitat for kudzu and other aggressive weeds could extend throughout Pennsylvania.

PENNSYLVANIA FARMING TRADITIONS

Pennsylvania's 59,000 farms average 131 acres in size, making it a region dominated by relatively small and often family-owned farms. Many have been carefully cultivated for more than 200 years, with limited soil degradation and depletion. By far the most productive agricultural region is the southeast—led by Lancaster County, home to the world's second-largest Amish settlement. Climate change may add to the pressures on the traditional lifestyle of the Amish as well as other small farm owners throughout the state.

The Amish, who began migrating to Pennsylvania in the 1700s, form an integral part of the state's cultural heritage and contemporary tourism industry. Over the past few decades, Amish communities have become less dependent on agriculture as their main livelihood, adopting other means of support such as carpentry and handicrafts. Nevertheless, the family farm (typically three to five acres) plays an integral role in feeding families, teaching youngsters, and passing on Amish culture, which stresses traditional

A longer growing season comes with a price

Milder winters and an extended growing season may benefit the cultivation of tomatoes and other cold-sensitive produce. However, crops would face increasing summer heat stress, drought, and threats from weeds and pests. As problems from weeds and pests escalate, farmers such as this grape grower may feel pressure to use more herbicides and pesticides—measures that are not only costly but also pose risks to human and environmental health.

Pennsylvania farmers face increasing uncertainty and risk

The richness and scenic beauty of Pennsylvania's agricultural countryside define the state's character as much as its urban skylines. Although farmers have often proven adaptable to changing weather patterns and market demands, they face greater uncertainty, risk, and expense as the pace and scope of climate change increase.

practices such as horse-drawn plowing that are not dependent on fossil fuels.

Lancaster County is the object of strong land-use demands, particularly from encroaching urban sprawl of the Philadelphia metropolitan area. These development pressures, in combination with the projected climate change impacts on agriculture—from heat stress in dairy cows to increased pest pressure—could pose significant challenges to Amish communities attempting to sustain their traditional practices in Pennsylvania.

CHAPTER FOUR

Impacts on Forests

BACKGROUND

Pennsylvania acquired its name—Latin for "Penn's woods"—in the seventeenth century from its seemingly endless expanse of ancient beech, hemlock, oak, and maple forests. These forests, remaining vital to the state's economy and identity over the centuries, have made Pennsylvania the country's number-one producer of hardwoods, supported the nation's third-largest state park system, sustained the largest free-roaming elk herd in the East, and supplied residents and tourists alike with myriad opportunities for hiking, fishing, birding, biking, hunting, and other outdoor pursuits.

Rampant timber harvesting had reduced forest coverage to its lowest point—30 percent of the landscape—by the early 1900s, but Pennsylvania's forests have been expanding ever since; today, nearly 60 percent of the state is forested.[94] Pennsylvania's varied terrain and its position at a latitude where northern and southern species mingle allow it to support more than 100 native tree species. Most prevalent among them are the hardwoods such as red maple, black cherry, red oak, and sugar maple—which supply 90 percent of the state's sawtimber—and softwoods such as eastern hemlock, white pine, and red pine.[95]

The forest-products industry generates revenues of more than $5.5 billion annually and employs 90,000 workers in more than 3,000 businesses from sawmills to paper plants to furniture-manufacturing enterprises.[96] But the character of Pennsylvania's forests and their contribution to its economy are poised to undergo major changes in this century, depending on our emissions choices. One of the most iconic and economically important tree species at risk, particularly under higher emissions, is the prized black cherry, which supports a thriving timber and veneer industry that supplies materials to fine furniture, flooring, cabinetry, and wall paneling manufacturers throughout the state.

Climate plays a major role in determining suitable habitat for trees, as well as for other plants and wildlife. As the climate warms, the areas that best meet each species' requirements will shift northward by as much as hundreds of miles. But because long-lived trees may persist for many decades in declining conditions, it remains highly uncertain what Pennsylvania's forests will look like by late century.

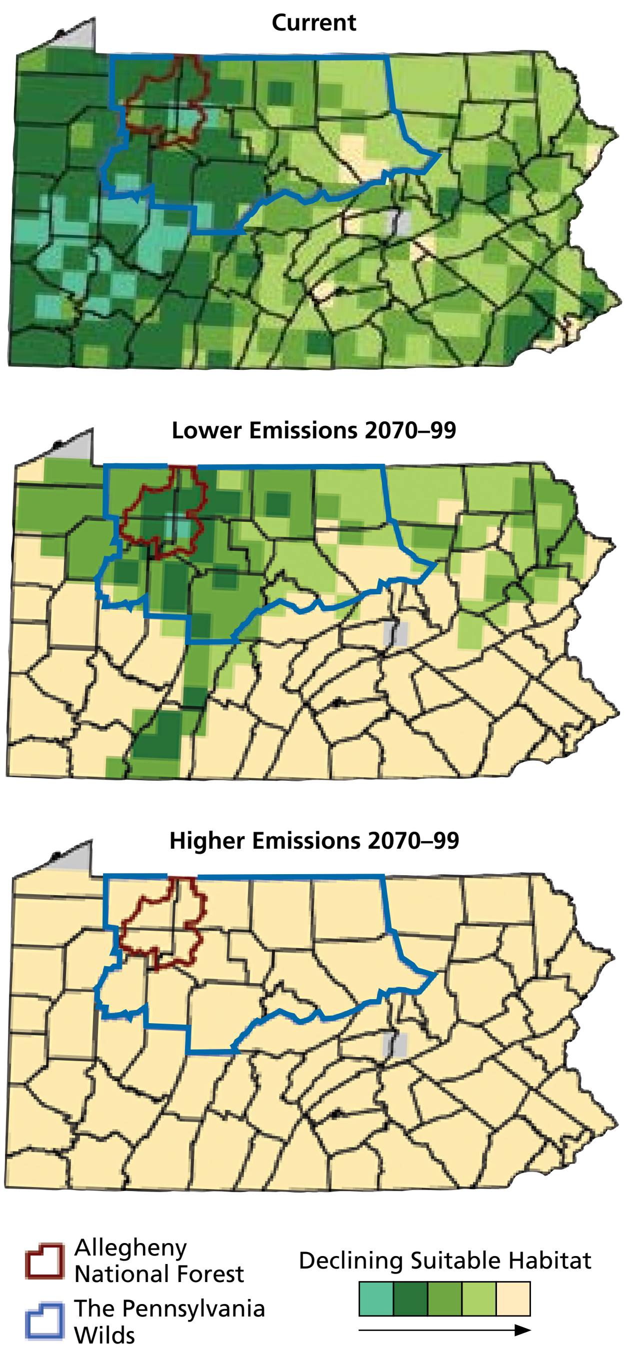
> **One of the most iconic and economically important tree species at risk, particularly under higher emissions, is the prized black cherry, which supports a thriving timber and veneer industry.**

Pennsylvania's silviculture (tree-growing) industry may face major risks and long-term management challenges, particularly under the higher-emissions scenario, as it attempts to adapt to the eventual decline of habitat for economically important trees such as black cherry. Park and wildlife managers could also face changes in recreational opportunities and the loss of critical wildlife habitats, including those of prized bird species such as the ruffed grouse.

TREES

The character and appearance of Pennsylvania's forests may change dramatically over the coming century as the centers of suitable habitat for many now-prevalent tree species—including those of the maple, beech, and birch hardwoods that generate the state's brilliant fall foliage—shift northward. Projections show that habitat across the U.S. Northeast may shift as much as 500 miles north by late century under the higher-emissions scenario and up to 350 miles north under the lower-emissions scenario.[97] Species such as maple and cherry, which are currently abundant and help to define the northern hardwood forest types in Pennsylvania, are those projected to show the greatest changes in habitat suitability.[98] Even as the optimal climate

FIGURE 9: **Changing Forest Habitat: Black Cherry Trees**



Warming may threaten Pennsylvania's black cherry—a timber valued by the state's highly skilled furniture makers—by reducing its suitable habitat across the state. If we follow the lower-emissions scenario, loss of suitable black cherry habitat would be limited to just over half the current area by the end of this century, compared with a loss of over 80 percent if we follow a higher-emissions pathway. (Note: areas without data are shown as gray on the map.)

zones shift northward, many species may be able to persist in the state throughout the century.[99] But others may decline noticeably in number and importance as they succumb to climate stress, increased competition, and other pressures.[100]

- In the Pennsylvania Wilds vacation region—a 12-county area of rugged, rural, and relatively undeveloped terrain in north-central Pennsylvania's Big Woods—habitat suitability for signature species such as black cherry, sugar maple, and American beech is projected to decrease this century.[101]
- If the higher-emissions scenario prevails, climate conditions suitable to key fall foliage species are expected to disappear from the state entirely by late century. Habitat losses are expected even under the lower-emissions scenario, although they are expected to be less rapid and extensive.[102]

Other factors besides climate that may influence the nature and pace of future tree distributions include pests and pathogens (e.g., gypsy moth, emerald ash borer, sudden oak death), changes in soil chemistry, changes in disturbance events such as fire, and invasive tree, shrub, and insect species. A number of observed trends, including the northward expansion of invasive pests, can be enhanced by rising temperatures.

Some common hardwoods, such as white oak and to a lesser extent black oak and black gum, are expected to gain suitable habitat in Pennsylvania as the climate warms.[103] How quickly such species might expand their ranges in the state is unpredictable, however. Oaks in particular have proven difficult to regenerate, even in good habitat, and forest managers may face challenges facilitating their migration under new growing conditions.[104]

Habitat declines and other pressures are also expected for some of the state's major softwood species:

- Warming may threaten stands of hemlock (the state tree) by reducing suitable habitat for these trees.[105] Under the higher-emissions scenario, hemlock is projected to lose two-thirds of its current suitable habitat, while under the lower-emissions scenario it could lose less than half.
- The hemlock is already under pressure from a fatal pest known as the hemlock woolly adelgid, which under either emissions scenario is projected to continue its northward expansion throughout Pennsylvania and reach well into New England.[106]

BIRDS

Pennsylvania is home to hundreds of species of breeding birds and an important stop for waterfowl and other migratory birds along the Atlantic Flyway. But a warming climate, as well as shifting distributions and quality of forests and other natural habitats, are expected to drive substantial changes in bird life—from the woods warbler species popular with bird-watchers to prized game species such as the ruffed grouse (Pennsylvania's state bird)—during the twenty-first century. The greatest changes are projected under the higher-emissions scenario, including habitat declines of many songbirds, such as the American goldfinch and the song sparrow.[107]

The forested northern portions of Pennsylvania could experience some of the greatest losses in suitable bird habitat across the northeastern United States.

- The forested northern portion of Pennsylvania could experience some of the greatest losses in suitable bird habitat across the northeastern United States.
- As many as half of the 120 bird species modeled in Pennsylvania could see at least 25-percent reductions in their suitable habitat because of changes in climate and vegetation this century, with the greatest potential losses occurring in habitat for migratory birds.
- Species at the greatest risk from changing climate and loss of their preferred habitat in Pennsylvania include the ruffed grouse, white-throated sparrow, magnolia warbler, and yellow-rumped warbler.
- As abundance of these familiar bird species declines, new species are expected to extend their ranges into Pennsylvania.

INDUSTRIES AND LIVELIHOODS

Pennsylvania produces more than 1 billion board feet of hardwood lumber[108] each year, about 10 percent of the nation's total hardwood output.[109] Roughly 1.2 million acres of the state's 16.1 million acres of timberland is black cherry,[110] yielding some 127 million board feet of black cherry annually.[111] The value of black cherry shipments to sawmills in 2006 came to more than $200 million. Logging provided an estimated 750 jobs in the state in 2004, with black cherry logging accounting for almost 130 of them. In

Wildlife habitat on shifting ground

Pennsylvania is home to hundreds of species of breeding birds and an important stop for waterfowl and other migratory birds along the Atlantic Flyway. As changes in temperature combine with urban sprawl and other land-use pressures, ecological links begin to break, triggering impacts that are difficult to predict. What is clear, however, is that the greatest losses in species habitat are projected under the higher-emissions scenario; songbirds such as the white-throated sparrow (top) and American goldfinch (middle) and prized game species such as the ruffed grouse (bottom) are among those birds especially at risk.

addition, nearly 700 of the 4,000 sawmill jobs in the state can be attributed to black cherry processing.

Pennsylvania forests are home to 43 percent of the black cherry growing stock on U.S. timberlands.[112] Thus the health of companies throughout North America that use black cherry wood, such as cabinet and furniture manufacturers, is linked to the fate of the state's hardwood forests. This small but important sector of the timber industry is particularly vulnerable to climate change, especially under the higher-emissions scenario.

- Under higher emissions, suitable habitat for the black cherry tree is expected to disappear from the state altogether by late century.[113]
- Some habitat shrinkage is projected even under the lower-emissions scenario, though black cherry is expected to remain relatively abundant.[114]

Declines in black cherry habitat would greatly exacerbate stresses on forest-based industries such as timber harvesting, processing, and manufacturing that are key to the economy of the northwestern part of the state. Communities that have traditionally relied on black cherry—e.g., for employment and tax revenue—are staking their economic health on an increasingly vulnerable resource. Following a lower-emissions pathway could help maintain the viability not only of the black cherry industry but also the manufacturing businesses that depend on it.

If oaks and other hardwood species proliferate as black cherry declines, harvest of some of these lower-valued species may replace a portion of the diminished revenues, but not all. For example, today northern red oak sells for an average of $295 per thousand board feet in Pennsylvania while black cherry averages $1,064 per thousand board feet. Based on these current values, replacing the black cherry harvest losses expected under the higher-emissions scenario with northern red oak would result in major declines in annual timber industry revenue.

Changes in the land

The state's deep and productive forests define Pennsylvania for residents and tourists alike—hunters, fishers, hikers, bird-watchers, and leaf-peepers. But under the higher-emissions scenario, suitable habitat for sugar maple, beech, and birch trees—responsible for the state's brilliant fall foliage—could disappear entirely by late century. As climate conditions continue to shift in the state, these hardwoods could become more susceptible to direct climate stress, pests, disease, and increased competition from more suitable species.

Pennsylvania Fisheries: Sensitive to Warmer Waters

As climate change drives up air temperatures, average water temperatures in Pennsylvania's lakes and streams will also rise. Two popular species of resident sport fish—trout and smallmouth bass—are particularly sensitive to such temperature changes.

Native brook trout (the state fish), as well as introduced brown and rainbow trout, are coldwater species that are actively managed by the Pennsylvania Fish and Boat Commission in 14,000 miles of streams. Trout are especially sensitive to water temperature and stream flow changes during reproduction and early life stages (egg to fry survival). Adult brook trout, for example, live in a narrow temperature range (32–75°F), and spawning and embryo survival require water temperatures below about 50°F. Thus projected warming in many areas of the state may not only compromise spawning or embryo survival in fall and spring but also be lethal to adult trout during summer. This trend could be exacerbated by a decline in tree species, such as hemlock, that often line the banks of streams, shading and cooling them.

Smallmouth bass, native to the Great Lakes and Pennsylvania's western rivers, are now common throughout most of the state's larger cool-water streams. The Susquehanna River is widely recognized by recreational anglers as one of the best bass fisheries in the northeastern United States. But because water temperature is considered the factor most critical to the range of smallmouth bass,

Anglers' favorite species at risk

With more than 14,000 miles of streams, Pennsylvania boasts some of the best fishing spots in the Northeast. But the survival of cold-water species such as native brook trout—the state fish—and brown and rainbow trout is threatened. Projected climate changes could alter seasonal stream flow, raise water temperatures, and diminish shade along stream banks.

rising temperatures can be expected to alter its distribution in the Susquehanna and similar habitats. Moreover, changes in the frequency, duration, and magnitude of spring floods can affect the spawning success of the species; flow changes in the state's rivers can also increase summer water temperatures and reduce oxygen concentrations, creating conditions inhospitable to smallmouth bass.

CHAPTER FIVE

Impacts on Winter Recreation

BACKGROUND

Millions of residents and tourists alike head for the woods and hills of Pennsylvania each winter, lured by more than 30 ski areas, 3,000-plus miles of public snowmobile trails,[115] and frozen lakes that offer skating, ice fishing, and ice boating. Winter recreation in the Commonwealth, from sledding in the city parks of Pittsburgh to riding horse-drawn sleighs through the frosty woods of the Poconos, traditionally revolves around snow. However, the face of winter in Pennsylvania is expected to change rapidly and profoundly this century as winter temperatures continue to rise.

Climate change is projected, both under lower- and higher-emissions scenarios, to cause a dramatic decline in the average number of snow-covered[116] winter days across Pennsylvania (see Chapter One). Under either emissions scenario, the snow season in the state is expected to retreat to the highland regions within just the next few decades. By late century it could be lost entirely in most years. If lower emissions prevail, parts of the state may preserve a modest snow season throughout this century, but projections still show a rapid decline in all but the highest-elevation areas.

Hardest hit would be the snowmobile industry, which pumps an estimated $160 million into the Pennsylvania economy each winter.[117] It is projected to all but disappear by mid-century under either of our two emissions pathways. The state's snowmobile season has already shrunk in recent years to less than a month in many areas.

Skiing and snowboarding are better positioned than snowmobiling to adapt because resorts do not have to rely solely on natural snow. Pennsylvania's ski areas may have to depend more heavily on snowmaking in the coming decades. Under the higher-emissions scenario, even this may not be an option by mid-century as temperatures grow too warm for snowmaking. Under the lower-emissions scenario, these changes may come more slowly and not be realized until late century.

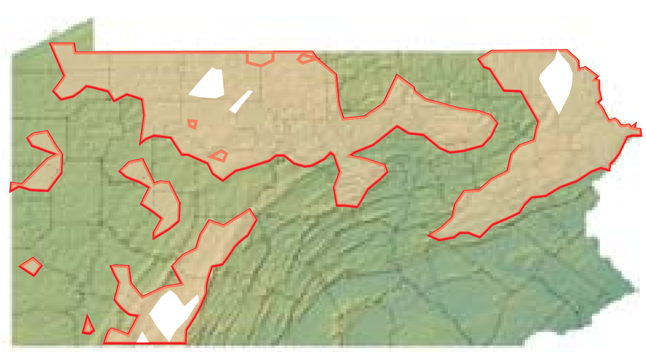
The heavy costs to winter recreation industries could reverberate through tourism and other sectors of the economy statewide. Loss of other treasured winter pastimes, from snowshoeing and cross-country skiing to tubing and sledding, may have less impact on the economy than on the state's quality of life during wet but increasingly snowless winters.

Although these projections for winter may seem extreme, they are in fact likely to be conservative because the climate models used in this analysis have consistently underestimated the rapid winter warming and snowpack decline observed in recent decades.

SNOWMOBILING

Snowmobiling is the most vulnerable of the region's economically important winter-recreation activities because it requires too large an area to rely on machine-made snow. Within the next several decades, snowmobiling opportunities are projected under both of

FIGURE 10: Snowmobiling Disappears?



Historic Area (1961–1990)

Next Several Decades (2010–2039)

The red borders on this map delineate the main regions in the state that historically are covered with six inches of snow for at least 15 days each winter. The white areas show projections for this same level of snow cover during the next several decades. Pennsylvania may lose its snowmobiling season by mid-century under either emissions scenario.

FIGURE 11: **Driving Distances to Major Ski Resorts**

Starting Location	Today	2070–2099 (under the higher-emissions scenario)
Philadelphia	80 miles (Blue Mountain, PA)	290 miles (Mt. Snow, VT)
Pittsburgh	60 miles (Seven Springs, PA)	500 miles (Gore Mountain, NY)

the emissions scenarios to become virtually nonexistent in Pennsylvania. The state has 45,000 registered snowmobiles and three distinct regions for snowmobiling: north-central, south-central, and eastern (which includes the Poconos).[118]

- The north-central region (designated the Pennsylvania Wilds) currently averages 18 days with snowmobiling conditions (at least six inches of snow on the ground) each winter.[119] In the short term (2010–2039) under either scenario, these days may be cut to an average of nine days. Mid-century projections (2040–2069) show the season holding at around nine days under the lower-emissions scenario but a complete disappearance of the snowmobile season in the case of higher emissions.
- In south-central Pennsylvania, which already has marginal natural snow and typically just a handful of days with sufficient snowmobiling conditions, this activity is projected to essentially disappear by the middle of the century under either scenario.[120]
- Similarly, in the Poconos and nearby mountains, the snowmobiling season under either scenario may be reduced from its more than one-month historical average to a week or less by mid-century.[121]

The average snowmobile-owning household spends $4,400 annually while snowmobiling in Pennsylvania,

The trails less traveled

When winter conditions are right, snowmobiles—some 45,000 are registered in Pennsylvania—traverse the state's 3,000 miles of public trails. The snow season across the Northeast has already begun to decline in recent years as winters have warmed. Within the next several decades, snowmobiling opportunities are projected to become virtually nonexistent in Pennsylvania under either emissions scenario, as natural snow cover dramatically declines.

and another $750 on snowmobile equipment.[122] With 45,000 registered snowmobiles in the state, resident snowmobilers alone spend about $93 million each year, spread across a variety of sectors in the Pennsylvania economy. However, as good conditions become extremely rare, snowmobiling enthusiasts may become less inclined to plan for and invest in the activity.

Other recreational activities will likely rise in popularity as snowmobiling opportunities decline. Some snowmobiling enthusiasts may switch to all-terrain vehicles (ATVs), for instance, which do not require snow-covered ground. Nationwide, ATV sales have grown while snowmobile sales have declined over the past five years. Still, it remains unclear whether ATVs will enjoy the same broad appeal and generate as much usage and spending as snowmobiles. A broad switch to ATV use would also create concerns for land managers and communities across the state, given that these vehicles tend to have far more damaging impacts on vegetation and trails.

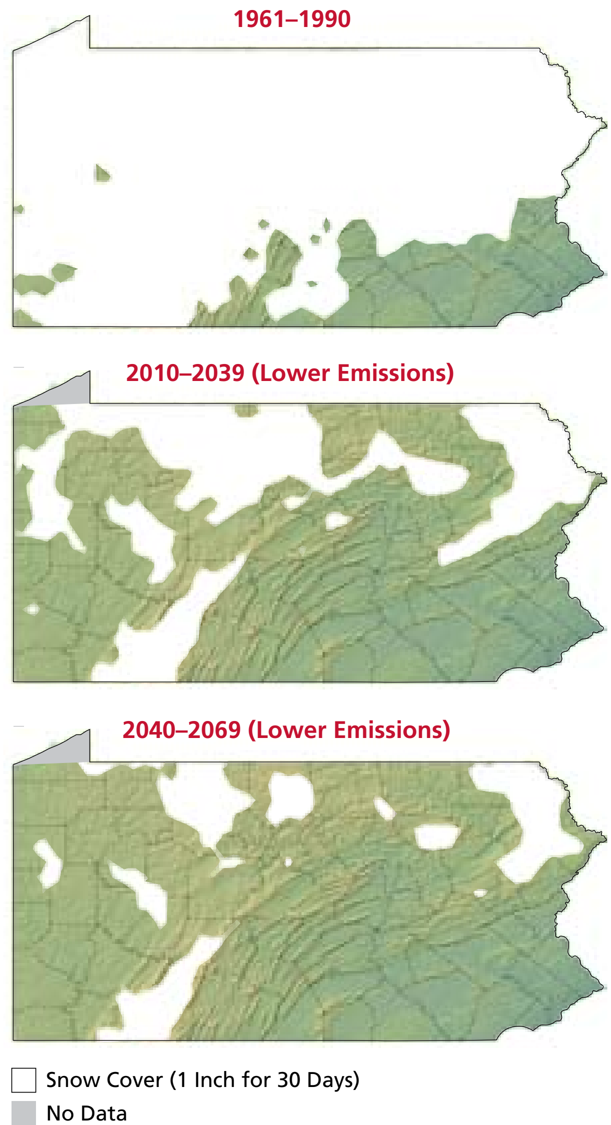
> **While climate models suggest that the loss of winter snow in Pennsylvania will be difficult to avoid, the avoidance of other dangerous impacts is well within reach.**

SKIING

During the 2006–2007 season, 32 ski areas operating in Pennsylvania logged over 2.75 million skier visits, ranking the state sixth nationally in ski visits.[123] Pennsylvania's downhill ski and snowboard resorts are largely clustered in two distinct regions—the Poconos in the northeast and Laurel Highlands in the southwest. This assessment looked at the impact of climate change on the industry by using two indicators that affect the economic sustainability of ski operations throughout a region: 1) a season length of at least 100 days, which is considered necessary for profitability; and 2) the likelihood of being open for the entire Christmas-New Year's holiday period, which is one of the key revenue-generating times for ski areas.

- Under the higher-emissions scenario, eastern Pennsylvania is highly vulnerable in the short term and not expected to meet either of these criteria during the 2010–2039 period.

FIGURE 12: The Changing Face of Winter



A traditional Pennsylvania winter may become increasingly rare as the state's climate changes in the next several decades. White areas on the maps are those that have at least a dusting (one inch or more) of snow cover for 30 days in the average year. Historically, three-quarters of Pennsylvania experienced this type of snow season. Under either emissions scenario, the area with such snow cover shrinks by roughly half in the next several decades and three-quarters by mid-century, and there is essentially no snow cover by late this century. But while climate models suggest that the loss of winter snow in Pennsylvania will be difficult to avoid, the avoidance of other dangerous impacts is well within reach.

Note that "lake-effect" snow in northwest Pennsylvania near Lake Erie was not modeled in these projections; areas without data are shown as gray on the map.

State's ski industry vulnerable

Pennsylvania hosted over 2.75 million skier visits during the 2006–2007 season, but this industry is under growing pressure. Warming winters have increased the amount of snowmaking required in much of the Northeast, at considerable cost both to ski resorts and skiers alike. In Pennsylvania, this trend is projected to progress under either emissions scenario, until many resorts experience conditions that are too warm for snowmaking altogether.

- Western Pennsylvania ski areas remain marginally viable in the near term but fail to meet either criterion by mid-century.
- Thus, under either emissions scenario, by mid-century Pennsylvania is no longer expected to support viable ski operations.

As part of this analysis, the assessment also projected how the need for snowmaking would grow even as ski seasons were shortened by warmer winters. This combination could increase operating costs, leading both to higher prices for consumers and lower profits for ski resorts.

- Under either emissions scenario, western Pennsylvania is projected to lose 15 percent of its season in the next few decades while snowmaking requirements increase by 20 percent.
- The costs of making snow would rise by a greater percentage than the volume of snow made because more energy is required to produce it at higher temperatures.
- By mid-century, warming temperatures may render snowmaking infeasible during much of the winter across Pennsylvania.

Increased use of water and energy for snowmaking could compete with the needs of other water users—especially if droughts occur with increasing frequency—and may drive up operating costs and ticket prices, particularly under the higher-emissions scenario.

Across Pennsylvania there could be a major decline in snow accumulation as more precipitation falls as rain rather than snow, a large drop in the number of days a ski area could be open for operation, and substantial reductions in the number of days when it would be cold enough to make snow.

Thus by the middle of the century, under either emissions scenario, the vast majority of ski resorts across the state may become economically unviable, possibly resulting in many closures. On average, each of the 32 ski areas in the state currently brings in revenues of $11.5 million, generating total annual statewide revenues of some $370 million.[124] If three-quarters of Pennsylvania's ski resorts closed, this could result in revenue losses of roughly $270 million in today's dollars. Such losses may be particularly severe for small towns located around Pennsylvania's ski areas, which often rely on resort-generated tourist revenues to help maintain their livelihoods.

Skiers in the region—including those in New York City, Philadelphia, Trenton, and Pittsburgh—who might otherwise favor Pennsylvania hills could expect to drive significantly farther to continue pursuing the sport.

CASE STUDY

Pittsburgh: From Grit to Green

In the late 1860s, as hundreds of factory smokestacks belched thick black smoke over Pittsburgh, author James Parton dubbed it "hell with the lid off." By the 1970s, when the industrial economy irreversibly faltered, Pittsburgh's leaders made "greenification" part of their plan to revitalize the city, and in 2007 it was named the tenth cleanest city in the world.[125] Today Pittsburgh boasts the largest number of "green" buildings east of the Mississippi and has turned its abandoned industrial sites ("brownfields") into assets through extensive redevelopment.

Pittsburgh's David L. Lawrence Convention Center, for example, was built on a former brownfield site and is the world's first convention center certified under the Leadership in Energy and Environmental Design (LEED) standards, a rating system for green buildings. Among its environment-friendly features, three-fourths of the center's exhibition-space lighting comes from natural daylight and half of its "gray" water is recycled, reducing potable water use by three-fourths.

Another former brownfield site in Pittsburgh boasts the largest LEED-certified Silver-level commercial building in the nation: the PNC Firstside Center. When the Children's Museum of Pittsburgh expanded, its green choices allowed it to become the largest Silver LEED-certified museum in the country. And in the fall of 2007, LEED certification reached the residential sector when Summerset at Frick Park, a development of nearly 700 units, was built on a former steel-mill slag dump.

As of April 2008, Pittsburgh had 24 recognized LEED-certified buildings, ranking it fifth among U.S. cities,[126] and many other local institutions and businesses are seeking similar recognition. The Carnegie Library of Pittsburgh, for example, is currently pursuing certification for its Brookline branch.

Pittsburgh's city government is actively encouraging such efforts. In November 2007, the city council passed new incentives that allow green buildings to be 20 percent taller than others in their zoning districts. In May 2008, with the backing of Mayor Luke Ravenstahl, the city's Equipment Leasing Authority approved a policy requiring Pittsburgh to purchase clean vehicles. In June 2008, Ravenstahl created the Mayor's Green Initiative Trust Fund with money saved through bulk purchasing of power. Its mandate includes the setting up of an Office of Sustainable Development and Energy Efficiency and the launch of a Green Council to oversee the city's five-year plan for green initiatives.

Ravenstahl, pledging to reduce CO_2 pollution in Pittsburgh to 7 percent below 1990 levels by the year 2012, joined hundreds of others mayors in signing the U.S. Mayors Climate Protection Agreement.

Pittsburgh has pursued other greening initiatives as well, such as bike and walking trails along its riverfronts and hollows. In 2007 it was named the ninth most walkable American city by a Brookings Institution study.

In the 1950s, when Pittsburgh's future seemed bleak, architect Frank Lloyd Wright was asked how the city could be improved. His answer: "Abandon it!" Yet Pittsburgh has shown that political ingenuity and persistence, along with the backing of private institutions, could revitalize the city's economy, improve civic well-being, and set an example of responsible stewardship for the world.

CHAPTER SIX

Solutions for the Keystone State

This report has highlighted possible consequences of climate change for Pennsylvania. Climate change is already affecting the state's landscape, livelihoods, and traditions, and because some amount of further change is unavoidable, the impacts will grow more substantial over the coming decades. The report has also demonstrated that the extent of warming throughout this century will depend largely on energy and land-use choices—made within the next few decades as well—both in Pennsylvania and around the world.[127]

Analyses project many striking differences in the extent of global warming impacts on Pennsylvania, depending on whether the world follows a higher- or lower-emissions pathway. The lower-emissions scenario implies a future in which atmospheric concentrations of CO_2 rise from approximately 380 parts per million (ppm) today to 550 ppm by the end of the century. Under the higher-emissions scenario, CO_2 reaches 940 ppm in this same time frame.

Yet just as the higher-emissions scenario described in this report does not represent a ceiling on emissions, the lower-emissions scenario does not represent a floor. Indeed, many lines of evidence indicate that reducing emissions even beyond the lower-emissions scenario—and thus keeping CO_2 levels below 550 ppm and generating even fewer severe impacts—is well within our reach.[128]

The latest assessment from the Intergovernmental Panel on Climate Change (IPCC) describes the technical and economic potential for stabilizing atmospheric concentrations of heat-trapping gases at or below the CO_2 equivalent of 450 ppm.[129] Recent analyses[130] indicate that achieving such a target would require the United States and other industrialized nations to reduce emissions some 80 percent below 2000 levels by mid-century, along with substantial reductions by developing countries. These analyses also emphasize the need to set and achieve aggressive near-term reduction goals that will put the world on the right trajectory to hit the mid-century target. In the spring of 2008, several dozen Pennsylvania scientists and economists joined with 1,700 experts from across the United States in calling for these very swift and deep reductions in the heat-trapping emissions that cause global warming.[131]

Even if future emissions can be dramatically curtailed, however, emissions from the recent past guarantee that Pennsylvania and the world will experience at least some additional warming, and significant impacts, over the next several decades. Policy makers and communities across Pennsylvania must therefore begin preparing for and adapting to the consequences of this unavoidable warming.

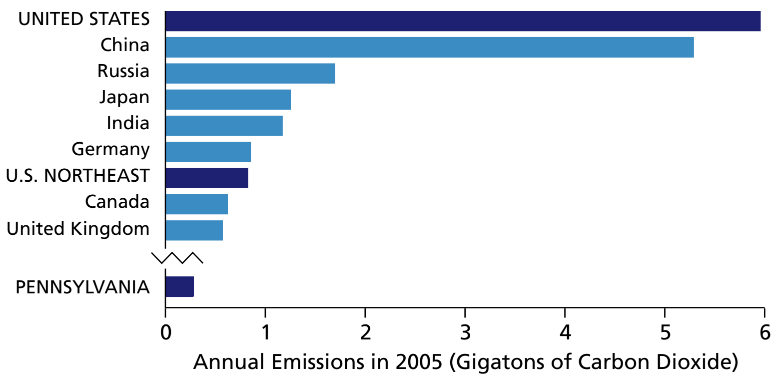
Analyses project many striking differences in the extent of global warming impacts on Pennsylvania, depending on whether the world follows a higher- or lower-emissions pathway.

Mitigation (in the form of emissions reductions) and adaptation are essential and complementary strategies for addressing climate change. Aggressive steps to reduce emissions can limit the scope and costs of regional impacts and thus improve prospects that ecosystems and societies can find effective ways to cope with climate change and take advantage of any potential benefits.

PENNSYLVANIA'S ROLE IN REDUCING EMISSIONS

Pennsylvania—a state that generates 1 percent of global emissions[132]—must play a significant role in responding to this global challenge. Of course, reducing emissions in Pennsylvania alone will not stem global warming. Nevertheless, Pennsylvania's emissions are so high that this single state, when compared

FIGURE 13: **2005 Pennsylvania Emissions: Significant on a Global Scale**



Emissions from fossil fuels in Pennsylvania compared with the major carbon-emitting nations. (U.S. emissions include those from the nine Northeast states, and Northeast emissions include those from Pennsylvania.) On a global scale, Pennsylvania's emissions are half those of the United Kingdom, which has five times the population. Pennsylvania's total emissions are higher than those of New York State and Wyoming combined, while its per capita emissions are more than double those of New York State.

Source: Energy Information Administration. 2005. *International energy annual 2005.*

with entire nations, ranks as the world's twenty-second largest emitter of CO_2, emitting almost half that of the United Kingdom, which has five times the population.[133]

Electricity generation accounts for over 40 percent of the state's total CO_2 emissions[134]—not surprising, given Pennsylvania's coal resources and history. What may in fact be surprising, however, is that many of Pennsylvania's coal-fired power plants generate electricity not only for in-state use but also for export to other states on the East Coast. In 2005, Pennsylvania power plants exported fully one-third of all the electricity they generated.[135] If the United States is to achieve the scale of emissions reductions needed, Pennsylvania must figure prominently in a transition to a clean energy future. That transition will need to involve aggressively employing energy efficiency in buildings and industry to reduce demand for electricity while promoting a shift in generation toward an increasingly clean mix of low-carbon and renewable energy sources. To avoid undermining its own and neighboring states' efforts to reduce emissions, the state should permit no new coal-fired plants to be built within its borders until the technology to capture and store carbon emissions is proven effective and is commercially available at the scale needed.[136]

Cars and trucks account for another 26 percent of Pennsylvania's total CO_2 emissions.[137] Pennsylvania's clean energy future can also include vehicles with much better gas mileage, gasoline with lower carbon content, enhanced public transportation systems in and between the state's cities, and smarter development policies that reduce the number of miles traveled.[138]

The good news is that Pennsylvania is a global leader in science, technology, and finance, and a historic innovator in public policy. The new green economy can succeed in Pennsylvania with the right set of public policies and the political will to get the job done.

Recent examples of the state's progress in adopting such policies and practices include the following:

- In 2008 the state legislature created a $650-million funding program to support investment in energy efficiency and renewable energy development.[139]
- The state also enacted requirements in 2008 for in-state production and use of biodiesel and cellulosic ethanol in transportation fuels.[140]
- Other recent legislation requires the establishment of an inventory of the state's emissions and the development of a comprehensive climate change action plan for the Commonwealth.[141]
- Compared with all purchasers of green power in the nation, Pennsylvania now ranks first among states and is the eleventh-largest purchaser overall.[142]
- The Commonwealth's embrace of renewable technology for developing new sources of energy and driving the local economy is paying strong economic development dividends. For example, within months of the state's 2004 adoption of a renewable electricity standard obligating utilities to get increasing portions of their power from renewable energy sources, the Spanish wind-energy company Gamesa announced it was locating its U.S. headquarters in Philadelphia; it subsequently invested $84 million, sited two manufacturing facilities and another office in the state, and created nearly 1,000 jobs. The German company Flabeg chose Allegheny County for its first U.S. solar-mirror production facility, which is expected to create 300 manufacturing jobs.[143]
- Pittsburgh, which has embraced green building technology and related products and expertise as an economic development strategy, boasts the largest number of green buildings of any city of its size east of the Mississippi, and ranks fifth in the country overall.[144]

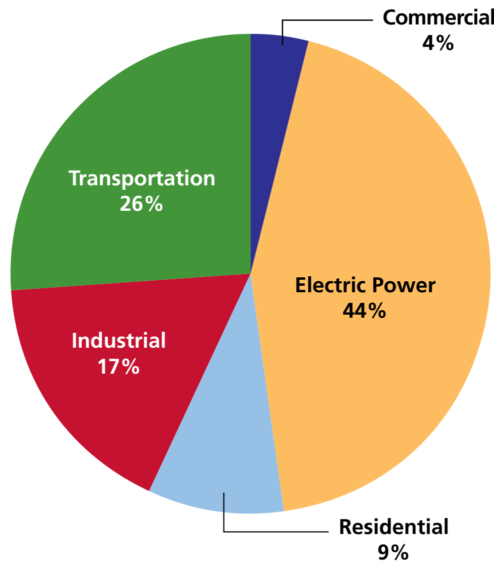
ACHIEVING EMISSIONS REDUCTIONS BY SECTOR

Steps such as those above are an important foundation on which to build Pennsylvania's response to climate change. Starting now and continuing over the next few decades, the state's decision makers at every level—within the business sector, public institutions, and individual households alike—can choose from among many proven or promising strategies to help put Pennsylvania on a path to deep emissions reductions. Some of the specific policies, programs, and practices that could achieve these reductions are outlined below by sector.

Electric power. Perhaps the toughest challenge—and greatest opportunity—for Pennsylvania lies in reducing its dependence on coal for electricity generation. While coal is deeply entrenched in the state's history and culture, Pennsylvania has substantial untapped "reserves" of energy efficiency in its homes, businesses, and industrial processes, as well as ample renewable energy resources.

- Pennsylvania should, for example, emulate other states' programs that successfully help electricity customers reduce their demand through energy efficiency measures.
- Pennsylvania has one of the most abundant, but largely untapped, wind resources in the entire Northeast region.[145]
- The state could strengthen its renewable electricity standard to accelerate the growth of the industry's installed base of wind, solar, and other renewable energy. Consider, for example, that Pennsylvania has more than five times the solar energy potential of neighboring New Jersey yet until very recently had only one-fortieth as much installed solar electric capacity.[146]
- In the near term, the state's coal-fired generators could begin co-firing sustainable biomass (such as timber-processing residues) with coal in their power plants, thus reducing the carbon content of the fuel.
- For the future, some coal-fired power plants may be able to capture the CO_2 emitted from burning coal and place it in permanent storage so that it never reaches the atmosphere. Pennsylvania has promising sites for CO_2 storage in geologic formations underground.[147] The technical viability and cost-effectiveness of carbon capture and storage (CCS), however, are not yet well established. A limited number of pilot projects that combine highly efficient coal-burning technology with CCS might be tested in the state, but federal policies would likely be needed to entice companies to invest in such projects.

FIGURE 14: 2005 Pennsylvania CO_2 Emissions by Sector



Electricity generation—primarily from coal-fired power plants—is the largest source of heat-trapping emissions in Pennsylvania, followed by transportation. Together these two sectors account for over two-thirds of the state's emissions.

Source: Energy Information Administration. 2005. State energy data system. Table 2.

Buildings. The recently enacted investment program contains hundreds of millions of dollars to support energy efficiency upgrades and alternative energy production in and on buildings of all types. Implementation efforts can draw on the experience of successful pioneering initiatives such as the West Penn Power Sustainable Energy Fund and models such as the Keystone Home Energy Loan Program (Keystone HELP).[148] Adopting a requirement that any building substantially funded by the state be built to high-performance standards would be a good way for the Commonwealth to lead by example. Support for additional education and training for architects, engineers, and builders is needed to help disseminate such practices to all parts of the state.

Transportation. The state's plan to reduce emissions from cars and trucks should have three components: (1) higher fuel economy (meaning that less gasoline

"Green" buildings

Reducing energy demand through more efficient building design can provide savings to homes, businesses, and large institutions. Six new dorms on the California University of Pennsylvania campus (in California, PA) are green-design buildings that use one-third less energy than the old dorms. While building "green" costs more up front, the university recouped that expenditure in just 2.5 years and expects to continue to save $750,000 on energy costs each year.

is burned and therefore less CO_2 is emitted per mile traveled); (2) lower carbon content in the fuel that is burned; and (3) fewer vehicle miles traveled. Pennsylvania has adopted California's tailpipe emissions standards for new vehicles—which would require reductions of about 30 percent below 2002 levels by 2016, beginning with the 2009 model year—though implementation has been held up by an adverse decision by the U.S. Environmental Protection Agency. Meanwhile, state and local governments can reduce vehicle emissions through incentives to purchase low-emissions vehicles, sustained investment in public transportation, and incentives and regulations that promote "smart growth" strategies, which reduce urban sprawl and hence the number of miles people drive.[149] The development and use of biodiesel and cellulosic ethanol—plant-based alternatives to fossil fuels—have the potential to significantly reduce heat-trapping emissions. However, in implementing the recently enacted per-gallon content requirements for biofuels produced in the state, the Department of Agriculture must ensure a full accounting of life-cycle emissions per unit of energy delivered and guard against adverse consequences for land use, water resources, and food supply.[150]

Industries and institutions can take advantage of programs and incentives created by recent Pennsylvania legislation to reduce their energy costs and emissions.[151] This can be achieved by improving the energy efficiency of buildings and other facilities and by installing combined-heat-and-power systems[152] and on-site renewable energy systems. More than 50 of the state's academic institutions, both large and small, have already joined together in a consortium to improve and extend greening programs on campus.[153] This innovative effort can be significantly widened, as there are a great many opportunities for reducing energy use in campus buildings and vehicle fleets, securing electricity from renewable energy, educating the student body, and pursuing other emissions-reducing activities.

Forestry and agriculture policies in Pennsylvania can be designed to promote cost-effective management practices that reduce emissions. Such practices include increased carbon capture in soils, more efficient use of nitrogen fertilizers, decreased consumption of fossil fuels, and expanded deployment of wind and bioenergy—provided that the latter is produced in a sustainable manner.[154] Capturing and using methane to power farm operations is one such strategy already being implemented successfully on many farms.[155]

ADAPTING TO UNAVOIDABLE CHANGE

Because some additional warming is inevitable, adapting to higher temperatures is now an essential counterpart to reducing emissions. The latter remains paramount: delay in reducing emissions increases the costs—and limits the feasibility—of adaptation, while aggressive steps to reduce emissions improve the likelihood that ecosystems and societies alike will have time to adapt.

Taking action to prepare for the likely consequences of climate change can be less expensive than the damage that would result from doing nothing. Less affluent people and communities, even in relatively wealthy states such as Pennsylvania, will be among the hardest hit by global warming, in part because they can least afford to prepare for or cope with the impacts (such as extreme heat) once they occur. Similarly, small or geographically isolated businesses may have fewer resources and options for coping with climate change. Some highly valued species such as the black cherry, eastern hemlock, or ruffed grouse could

Coal in Pennsylvania: Cleaning Up Our Act

Pennsylvania history is deeply rooted in the coal seams that lace its mountains. Although the state's production has dropped from a historical high of 277 million tons in 1918—the heyday of the Commonwealth's industrial, mining, and manufacturing economy—to 66 million tons in 2006, Pennsylvania still ranks fourth among U.S. states in coal production and it supplies about 6 percent of the nation's output. From the bituminous (relatively soft and high in sulfur) coalfields of the western region to the anthracite (harder and cleaner-burning) coalfields in the east, Pennsylvania's 270 coal mines employ thousands and were at one time vital to the survival of many towns.

Burning coal to generate electricity is the single largest source of global warming emissions both in Pennsylvania and the United States as a whole. In 2004,[156] almost half of Pennsylvania's CO_2 emissions came from burning coal. Coal accounts for over 90 percent of CO_2 emissions in the state's electricity sector.[157]

One of the most important strategies for reducing CO_2 emissions in the state, the nation, and the world is to commit to a transition from fossil fuels such as coal and oil to renewable energy technologies. Yet given the continuing importance of coal to Pennsylvania's economy, it is also essential to make coal a "cleaner" fuel. There are several potential ways to reduce coal's negative environmental impacts and help turn it into a more attractive fuel in an environmentally conscious market.

One such strategy is to use emerging technologies to capture CO_2 emissions as they are expelled from the stacks of coal-fired power plants. The pollution control technologies currently in use at coal-fired plants do not address CO_2 emissions and thus do not reduce them. Instead, these emissions are freely dispersed into the atmosphere, directly adding to the buildup of heat-trapping gases. If CO_2 emissions were captured, however, the gas could potentially be pumped into underground reservoirs for long-term storage. Pennsylvania's numerous unmineable coal seams provide good candidates for CO_2 reservoirs.

Existing coal-fired plants may also substantially reduce their carbon emissions in the near term by replacing some of the coal with biomass such as wood chips or other wood waste. Burning wood creates carbon emissions as well, but it is nevertheless a carbon-neutral fuel: trees absorb carbon as they grow, and when burned emit the same amount they absorbed during their lifetimes. Another potential strategy that has received much publicity lately—coal-to-liquid technology—is not a viable option for reducing heat-trapping emissions because it generates double the emissions of gasoline (the fuel it aims to replace).

How to Prioritize Adaptation Strategies

The various strategies with which the state and local governments, business sectors, and communities in Pennsylvania can prepare for climate change must be considered on a case-by-case basis. Each constituency is unique in the challenges it faces and its ability to adapt. However, the following principles can help set priorities:

1. Monitor the changing environment. Decision makers and resource managers must stay informed about the specific consequences of global warming for the areas they oversee. In particular, improved monitoring both of the climate and the condition of natural systems can give clearer signals about the need for action and more time to formulate appropriate adaptation strategies.

2. Track indicators of vulnerability and adaptation. Monitoring both the progress of specific adaptation strategies and the social factors that limit a community's ability to adapt can enable decision makers to modify strategies and improve outcomes.

3. Take the long view. Decisions with long-term implications (e.g., investments in infrastructure and capital-intensive equipment, irreversible land-use choices) must be considered in the context of climate projections.

4. Consider the most vulnerable first. Climate-sensitive species, ecosystems, economic sectors, communities, and populations that are already heavily stressed for nonclimatic reasons should be given high priority in policy and management decisions.

5. Build on and strengthen social networks. Ties between trusted individuals and organizations are an asset for adaptation at the community level and within business sectors. Strong leaders can inspire organizations in times of difficult change, and well-connected and -informed individuals can disseminate information that may be critical for effective adaptation.

6. Put regional assets to work. Pennsylvania has an enormous wealth of scientific and technological expertise in its universities and businesses that can be harnessed to improve understanding of adaptation opportunities and challenges.

7. Improve public communication. Regular and effective communication with, and engagement of, the public on climate change helps build our regional capacity to adapt.

8. Act swiftly to reduce emissions. Strong and immediate action to reduce emissions, in Pennsylvania and globally, can slow climate change, limit its consequences, and give our society and ecosystems a better chance to successfully adapt to those changes we cannot avoid.[158]

lose critical habitat or other conditions necessary for their continued survival. Therefore it is essential to the economic and ecological sustainability of the region that Pennsylvanians focus attention on the plight of vulnerable communities, sectors, and ecosystems and take steps to increase their resilience in the face of climate change.

Moving swiftly to reduce vulnerability is also smart economics. Governments, businesses, and communities that plan ahead will be positioned to take advantage of the possible benefits of climate change—as with farmers who begin early to replace vulnerable perennial fruit crops with more heat-tolerant varieties, or with ski resort owners who diversify to more year-round attractions. Similarly, communities in Pennsylvania that are modernizing their water and sewer infrastructure could protect their investments by incorporating near-term rainfall projections into their plans.

The adaptation strategies most relevant and feasible for any specific community or economic sector must be assessed on a case-by-case basis (see box, "How to Prioritize Adaptation Strategies.") But this much is clear: a delay in preparing for anticipated changes, or the continued reliance on infrastructure and procedures (e.g., emergency response plans) based on historical experience rather than projected conditions, will increase the state's exposure to climate risks.

A STATE-FEDERAL PARTNERSHIP

Although Pennsylvania and its municipalities can achieve much with their own policies and resources, the scale of emissions reductions required suggests a strong role for the federal government. Federal climate policy, for example, can set a national price on carbon, making power plants that capture and store CO_2 emissions more cost-competitive in the marketplace. Federal carbon-policy options currently being

Coping with a changing climate

The frequency of droughts, particularly short-term droughts of one to three months, is projected to increase over the coming decades under the higher-emissions scenario. Drought and hot summer conditions would increase irrigation needs, particularly for growers of traditionally rain-fed crops. Farmers may be able to cope by investing in and upgrading irrigation systems, assuming the up-front and long-term operational costs are within reach.

debated in Congress might also generate resources to assist with reasonable transitions for coal miners and coal-dependent communities. Complementary federal policies, such as a national renewable electricity standard or increased fuel-economy standards, may help stimulate energy and transportation solutions at the state level. And federal resources devoted to continued climate monitoring and assessments can provide essential information for states and communities to use in devising and implementing adaptation plans. Pennsylvania's U.S. senators and representatives must therefore support strong federal climate and energy policies that will help the state reduce emissions, transition to the promising clean energy economy of the future, and be prepared for the climate change likely to occur in the interim.[159]

CONCLUSION

Climate change represents an enormous challenge, but swift action can put solutions within reach. Because humans are largely responsible for current global warming, changing our actions can limit the severity and extent of impacts. Concerted actions to reduce heat-trapping emissions—on the order of 80 percent below 2000 levels by mid-century and just over 3 percent per year[160] over the next few decades—could keep temperatures and associated impacts from rising even to the level of the lower-emissions scenario used in this study. But the longer we delay, the larger, more aggressive, and costly our ultimate emissions reductions will need to be.

The actions highlighted here for meeting the climate challenge are consistent with other widely shared societal goals such as safeguarding and enhancing our nation's energy and economic security, creating jobs, providing affordable transportation, reducing home energy use, ensuring cleaner air, and building a more sustainable economy. Pennsylvania's state and municpal governments, in partnership with businesses, insti-tutions, and an increasingly supportive public, have a rich array of proven strategies and policies at their disposal to meet the climate challenge. The time to act is now.

Untapped renewable energy

Somerset Wind Energy Center in southwest Pennsylvania produces enough electricity annually to supply about 3,400 homes (~25,000 megawatt-hours). The state has tremendous, but largely untapped, renewable energy potential. If aggressively harnessed, wind energy could play a critical role in meeting the demand for clean electricity generation that can grow the economy, create jobs, and reduce air pollution and heat-trapping emissions.

Endnotes

1 Field, C.B., L.D. Mortsch, M. Brlacich, D.L. Forbes, P. Kovacs, J.A. Patz, S.W. Running, M.J. Scott, J. Andrey, D. Cayan, M. Demuth, A. Hamlet, G. Jones, E. Mills, S. Mills, C.K. Minns, D. Sailor, M. Saunders, D. Scott, and W. Solecki. 2007. North America, Chapter 14. In *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson. Cambridge, UK: Cambridge University Press.

2 Siegenthaler, U., T.F. Stocker, E. Monnin, D. Lüthi, J. Schwander, B. Stauffer, D. Raynaud, J.-M. Barnola, H. Fischer, V. Masson-Delmotte, and J. Jouzel. 2005. Stable carbon cycle–climate relationship during the late pleistocene. *Science*, November 25, 310-325.

Lüthi, D., M. Le Floch, B. Bereiter, T. Blunier, J.-M. Barnola, U. Siegenthaler, D. Raynaud, J. Jouzel, H. Fischer, K. Kawamura, and T.F. Stocker. 2008. High-resolution carbon dioxide concentration record 650,000–800,000 years before present. *Nature*, May 15, 453.

3 NOAA Satellite and Information Service. 2008. United States Historical Climatology Network (USHCN). Data from National Climate Data Center. Online at *http://lwf.ncdc.noaa.gov/oa/climate/research/ushcn/ushcn.html*.

Knight, P. 2008. Personal communication, August 27. Paul G. Knight is the Pennsylvania state climatologist. Data available online at *http://climate.psu.edu*.

4 Fisher, A., D. Abler, E. Barron, R.J. Bord, R. Crane, D. De Walle, W. Easterling, C.G. Knight, R. Najjar, E. Nizeyimana, R.E. O'Connor, A. Rose, J. Shortle, and B. Yarnel. 2000. Mid-Atlantic regional assessment. In *U.S. national assessment of the potential consequences of climate variability and change,* edited by National Assessment Synthesis Team Program. Washington, DC: United States Global Change Research Program (USGCRP).

5 Energy Information Administration (EIA). 2007a. *International energy annual 2005*. Online at *www.eia.doe.gov/pub/international/iealf/tableh1co2.xls*, accessed August 2008.

6 EIA. 2007b. State emissions by year 1990-2004. Online at *http://www.eia.doe.gov/oiaf/1605/ggrpt/excel/tbl_statetotal.xls*, accessed August 2008.

7 Nakicenovic, N., J. Alcamo, G. Davis, B. de Vries, J. Fenhann, S. Gaffin, K. Gregory, A. Grübler, T.Y. Jung, T. Kram, E.L. La Rovere, L. Michaelis, S. Mori, T. Morita, W. Pepper, H. Pitcher, L. Price, K. Riahi, A. Roehrl, H. Rogner, A. Sankovski, M. Schlesinger, P. Shukla, S. Smith, R. Swart, S. van Rooijen, N. Victor, and Z. Dadi. 2000. *Special report on emissions scenarios*. An Intergovernmental Panel on Climate Change (IPCC) report. Cambridge, UK: Cambridge University Press.

8 Nakicenovic et al. 2000.

9 Hayhoe, K., C.P. Wake, B. Anderson, J. Bradbury, A. DeGaetano, A. Hertel, X.-Z. Liang, E. Maurer, D. Wuebbles, and J. Zhu. 2006. Quantifying the regional impacts of global climate change: Evaluating AOGCM simulations of past and future trends in temperature, precipitation, and atmospheric circulation in the northeast US. *Journal of Climate,* in review.

Hayhoe, K., C. Wake, T. Huntington, L. Luo, M. Schwartz, J. Sheffield, E. Wood, B. Anderson, J. Bradbury, A. DeGaetano, T. Troy, and D. Wolfe. 2007. Past and future changes in climate and hydrological indicators in the U.S. Northeast. *Climate Dynamics* 28:381-407.

Hayhoe, K., C.P. Wake, B. Anderson, X.-Z. Liang, E. Maurer, J. Zhu, J. Bradbury, A. DeGaetano, A. Hertel, and D. Wuebbles. 2008. Regional climate change projections for the Northeast USA. *Mitigation and Adaptation Strategies for Global Change* 13(5-6).

Northeast Climate Impacts Assessment (NECIA). 2006. *Climate change in the U.S. Northeast*. Cambridge, MA: Union of Concerned Scientists.

10 NOAA Satellite and Information Service 2008.

Knight 2008.

11 NOAA Satellite and Information Service 2008.

Knight 2008.

12 NOAA Satellite and Information Service 2008.

13 NOAA Satellite and Information Service 2008.

Knight 2008.

14 NOAA Satellite and Information Service 2008.

Knight 2008.

15 Knight 2008.

16 NOAA Satellite and Information Service 2008.

17 Intergovernmental Panel on Climate Change (IPCC). 2007a. *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson. Cambridge, UK: Cambridge University Press.

18 Maimone, M. 2008. Personal communication, July 25. Mark Maimone is a consultant on CSO issues and is the vice president of CDM, based in Philadelphia, PA.

19 Hesson, M. 2008. Personal communication, August 27. Molly Hesson is an environmental consultant based in Philadelphia, PA.

Najjar, R. 2008. Personal communication, August 26. Ray Najjar is an associate professor in the Department of Meteorology and Geosciences at Pennsylvania State University.

20 Northeast Climate Impacts Assessment (NECIA). 2007. *Confronting climate change in the U.S. Northeast.* Cambridge, MA: Union of Concerned Scientists.

21 National Oceanic and Atmospheric Administration (NOAA). 2008. Heat wave: A major summer killer. Online at *http://www.noaawatch.gov/themes/heat.php*, accessed on September 1, 2008.

22 Ecanned.com. 2007. Income and poverty in the state of Pennsylvania. January 13. *Online at http://www.ecanned.com/PA/2007/01/income-and-poverty-in-state-of.html.*

23 U.S. Environmental Protection Agency (EPA). 2006. *Excessive heat events guidebook.* EPA 430-B-06-005. Washington, DC, 27. Online at *http://www.epa.gov/heatisld/about/pdf/EHEguide_final.pdf.*

24 EPA. 2007. Heat wave response programs: How is Philadelphia responding to heat waves? Online at *http://www.epa.gov/hiri/about/heatresponseprograms.html.*

25 EPA 2007.

26 EPA 2007.

27 Centers for Disease Control and Prevention (CDC). 1994. Heat-related deaths—Philadelphia and United States, 1993-1994. *MMWR Weekly* July 1, 43(25):453-455.

28 Philadelphia Medical Examiner's Office. 2008. Online at *http://www.phila.gov/health/units/meo/index.html.*

29 The Pittsburgh Channel. 2008. Thousands lose power in Pittsburgh area for hours. June 9. Online at *http://www.thepittsburghchannel.com/news/16548431/detail.html.*

30 American Lung Association. 2006. State of the air: 2006. Online at *http://lungaction.org/reports/stateoftheair2006.html*, accessed on September 1, 2008.

31 Pennsylvania Department of Health, Governor Rendell, and Secretary Calvin Johnson. 2006. *Asthma burden report*. Pennsylvania Health Department, Pennsylvania Asthma Strategic Plan 2006-2009. Online at *http://www.paasthma.org/asthma-resources/burden-report*.

32 Pennsylvania Department of Health, Governor Rendell, and Secretary Calvin Johnson 2006.

33 Pennsylvania Department of Health, Governor Rendell, and Secretary Calvin Johnson 2006.

34 Asthma and Allergy Foundation of America. 2008a. *Asthma capitals*. Online at *www.asthmacapitals.com*, accessed July 2008.

35 Kunkel, K.E., H.-C. Huang, X.-Z. Liang, J.-T. Lin, D. Wuebbles, Z. Tao, A. Williams, M. Caughey, J. Zhu, and K. Hayhoe. 2008. Sensitivity of future ozone concentrations in the northeast USA to regional climate change. *Mitigation and Adaptation Strategies for Global Change* 13(5-6).

36 CDC. 2002. Asthma prevalence and control characteristics by race/ethnicity—United States. *Morbidity and Mortality Weekly Report* 53:145-148.

37 CDC 2002.

American Academy of Allergy, Asthma and Immunology. 2000. *The allergy report.* Milwaukee, WI.

38 LaDeau, S.L., and J.S. Clark. 2006. Pollen productions by Pinus taeda growing in elevated atmospheric CO_2. *Functional Ecology* 10:1365-1371.

39 Ziska, L.H., D.E. Gebhard, D.A. Frenz, S.S. Faulkner, B.D. Singer, and J.G. Straka. 2003. Cities as harbingers of climate change: Common ragweed, urbanization and public health. *Journal of Allergy and Clinical Immunology* 111(2):290-295.

40 Asthma and Allergy Foundation of America. 2008b. *Spring allergy capitals*. Online at *www.allergycapitals.com*, accessed July 2008.

41 Maimone 2008.

42 Maimone 2008.

43 Maimone 2008.

44 Maimone 2008.

45 EPA. 1999. *Combined sewer overflow management fact sheet: Sewer separation*. 832-F-99-041. Washington DC. Online at *http://www.epa.gov/owmitnet/mtb/sepa.pdf.*

46 Water conservation measures in response to drought can include encouraging use of more efficient plumbing fixtures and appliances, switching to porous paving materials to increase infiltration of storm water, and moving toward non-potable water reuse, rain barrels, and cisterns. In some cases, additional reservoirs may need to be constructed. Relevant storm-water management recommendations are available through the Pennsylvania Department of Environmental Protection at *www.depweb.state.pa.us* and the Philadelphia Water Department at *www.PhillyRiverInfo.org*.

47 Additional information and guidance on source-water protection is available from the U.S. Environmental Protection Agency at *http://cfpub.epa.gov/safewater/sourcewater*.

48 Delaware River Basin Commission (DRBC). 2008. The Delaware River Basin. Online at *http://www.state.nj.us/drbc/thedrb.htm*, accessed on September 1, 2008.

49 DRBC 2008.

50 DRBC 2008.

51 Hesson 2008.

Najjar 2008.

52 IPCC 2007a. These projections are seen as conservative in that they do not account for the rapid rate of ice breakup and melting currently being observed in the polar ice sheets (particularly those of Greenland), nor do they assess the potential for further acceleration of this melting. For the Delaware Estuary, these projections need to be adjusted to account for local impacts on the relative position of the land and the sea, including land subsidence due to geological processes, which is estimated at four inches over 100 years.

53 Hesson 2008.

Najjar 2008.

54 The location of the salt line depends on the discharge of fresh water from the Delaware River, the elevation of the ocean, and the volume of tidal waters moving northward from the Delaware Bay toward Trenton, NJ. Depending on seasonality and rainfall, the salt line can migrate over 30 miles per year, vacillating between the Chesapeake and Delaware Canal and Philadelphia.

55 Hesson 2008.

Najjar 2008.

56 Although the salinity in the Delaware Estuary has been studied and modeled since the inception of the Delaware River Basin Commission in the mid-twentieth century, additional research is needed to understand how sea-level rise, other facets of climate change, and upstream water quality may alter the dynamic relationship between drought, human water needs, and salinity in southeastern Pennsylvania.

57 Pennsylvania Historical and Museum Commission. 2008. Agriculture in Pennsylvania. Online at *http://www.phmc.state.pa.us/ppet/agriculture/page4.asp?secid=31,* accessed on September 1, 2008.

58 National Agriculture Statistics Service (NASS). 2002. Statistics by state. Washington, DC: U.S. Department of Agriculture. Online at *http://www.nass.usda.gov/Statistics_by_State/*, accessed on June 6, 2007.

59 IPCC 2007a.

60 Glick, P. 2007. *The gardener's guide to global warming.* Reston, VA: National Wildlife Federation.

61 Klinedinst, P.L., D.A. Wilhite, G.L. Hahn, and K.G. Hubbard. 1993. The potential effects of climate change on summer season dairy cattle milk production and reproduction. *Climatic Change* 23:21-36.

62 St. Pierre, N.R., B. Cobanov, and G. Schnitkey. 2003. Economic losses from heat stress by U.S. livestock industries. *Journal of Dairy Science* 86(Suppl. E):E52-E77.

63 Wolfe, D.W., L. Ziska, C. Petzoldt, L. Chase, and K. Hayhoe. 2008. Projected change in climate thresholds in the Northeastern U.S.: Implications for crops, pests, livestock, and farmers. *Mitigation and Adaptation Strategies for Global Change* 13(5-6).

64 Lake Erie Concord Grape Belt Heritage Association, Inc. 2008. Lake Erie concord grape belt. Online at *www.concordgrapebelt.org*, accessed on September 1, 2008.

65 Welch's. 2008. History. Online at *http://www.welchs.com/about-welchs/history.aspx*, accessed on September 1, 2008.

66 Lake Erie Concord Grape Belt Heritage Association, Inc. 2007. *The economic impact of the grape juice and winery sectors of the Lake Erie concord grape belt.* Conducted with assistance from Cornell University and Pennsylvania State University. Online at *http://www.concordgrapebelt.org/cgbnews/images/uploads/Grape_Ec_Impact_Study.pdf.*

67 Westwood, M.N. 1993. *Temperate zone pomology.* Portland, OR: Timber Press.

68 Westwood 1993.

69 Wolfe et al. 2008.

70 Wolfe et al. 2008.

71 Wolfe et al. 2008.

72 Tobin, P.C., S. Nagarkatti, G. Loeb, and M.C. Saunders. 2008. Historical and projected interactions between climate change and voltinism in a multivoltine insect species. *Global Change Biology* 14(5):951-957.

73 Tobin et al. 2008.

74 Saunders, M. 2008. Personal communication, July 15. Michael Saunders is a professor of entomology at Pennsylvania State University.

75 Saunders 2008.

76 NASS. 2008. *Fruit crops*. Washington, DC: U.S. Department of Agriculture. Online at *http://www.nass.usda.gov/Statistics_by_State/Pennsylvania/Charts_and_Maps/specialty.ppt*, accessed June 30, 2008.

77 Westwood 1993.

78 Crassweller, R. 2008. Personal communication, July 2. Robert Crassweller is a professor of horticulture at Pennsylvania State University.

79 Wolfe et al. 2008.

80 Wolfe et al. 2008.

81 Wolfe et al. 2008.

82 Hoffman, L. 2004. Crop profile for field corn in Pennsylvania. Online at *http://www.ipmcenters.org/cropprofiles/docs/pacornfield.pdf*, accessed on September 1, 2008.

83 Wolfe et al. 2008.

84 Fleischer, S. 2008. Personal communication, August 19. Shelby Fleischer is a professor of entomology at Pennsylvania State University.

85 Sato, S., M.M. Peet, and R.G. Gardener. 2001. Formation of parthenocarpic fruit and aborted flowers in tomato under moderately elevated temperatures. *Scientia Horticulturae* 90:243-254.

86 Wolfe et al. 2008.

87 Lauten, G., B. Rock, S. Spencer, T. Perkins, and L. Ireland. 2001. Climate impacts on regional forests, Chapter 5. In *Preparing for a changing climate: The potential consequences of climate variability and change. The New England Regional Overview*, edited by the New England Regional Assessment Group. U.S. Global Change Research Program, University of New Hampshire.

88 Iverson, L., A. Prasad, and S. Matthews. 2008. Modeling potential climate change impacts on the trees of northeastern United States. *Mitigation and Adaptation Strategies for Global Change* 13(5-6).

89 Stefanou, S.E. 2008. Economic impact of the mushroom industry in Chester County, PA. *Mushroom News*, May 1. Online at *http://www.highbeam.com/doc/1G1-179404449.html.*

90 Stefanou 2008.

91 Collom, J. 2005. *Mushrooms summary*. In *Pennsylvania agricultural statistics 2004-2005*. U.S. Department of Agriculture, National Agriculture Statistics Service, 48.

92 Stefanou 2008.

93 Sasek, T.W., and B.R. Strain. 1990. Implications of atmospheric CO_2 enrichment and climatic change for the geographical distribution of two introduced vines in the USA. *Climatic Change* 16:31-51.

94 U.S. Forest Service. 2004. Northeastern forest inventory & analysis. Online at *http://www.fs.fed.us/ne/fia/states/pa/*, accessed September 1, 2008.

95 U.S. Forest Service 2004.

96 Pennsylvania Forest Products Assocation. 2005. Quick facts. Online at *http://paforestproducts.org/quickfacts.cfm*, accessed September 2, 2008.

97 Iverson et al. 2008.

98 Stout, S., L. Iverson, A. Prasad, and M. Peters. 2008. Potential changes of tree species habitats in the Pennsylvania wilds. In review. Online at *www.northeastclimateimpacts.org.*

99 Stout et al. 2008.

100 Stout et al. 2008.

101 Stout et al. 2008.

102 Stout et al. 2008.

103 Stout et al. 2008.

104 Stout et al. 2008.

105 Iverson et al. 2008.

106 Paradis, A., J. Elkinton, K. Hayhoe, and J. Buonaccorsi. 2008. Role of winter temperature and climate change on the survival and future range expansion of the hemlock woolly adelgid (Adelges tsugae) in eastern North America. *Mitigation and Adaptation Strategies for Global Change* 13(5-6).

107 Matthews, S., L. Iverson, and S. Stoleson. 2008. Pennsylvania bird habitat and climate change. In review. Online at *www.northeastclimateimpacts.org.*

108 Pennsylvania Department of Agriculture. 2007. Data & statistics: PA's forest product industry. Online at *http://www.agriculture.state.pa.us/agriculture/cwp/view.asp?q=128901*, accessed September 1, 2008.

109 Pennsylvania Forest Products Association. 2004. PA forests and you. Online at *http://paforestproducts.org/downloads/paforestsandyou.pdf*, accessed September 2008.

110 McWilliams, W.H., C.A. Alerich, D.A. Devlin, A.J. Lister, T.W. Lister, S.L. Sterner, and J.A. Westfall. 2004. *Annual inventory report for Pennsylvania's forests: Results from the first three years*. Resource bulletin NE-159. Newton Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station.

111 Luppold, W.G., and M.S. Bumgardner. 2006. Influence of markets and forest composition on lumber production in Pennsylvania. *Northern Journal of Applied Forestry* 23(2):87-93.

Strauss, C.H., B.E. Lord, and M.J. Powell. 2007. *Economic impact and timber requirements of the wood industry in Pennsylvania*. Report prepared for Pennsylvania Hardwoods Development Council, Pennsylvania Department of Agriculture (Harrisburg, PA).

112 McWilliams et al. 2004.

113 Stout et al. 2008.

114 Stout et al. 2008.

115 Lord, B., W.F. Elmendorf, and C.H. Strauss. 2006. Pennsylvania's snowmobile riders and their needs. Online at *http://www.dcnr.state.pa.us/councils/saac/Snowmobile%20report.pdf*, accessed July 11, 2008.

116 Snow-covered days refers to the number of days with at least a dusting of snow on the ground.

117 Raffield, B., and C. Guerrisi. 2000. *Snowmobiling in Pennsylvania*: *An economic impact study and snowmobile user survey*. Report prepared for the Pennsylvania State Snowmobile Association.

118 International Snowmobile Manufacturers Association. 2008. Snowmobile statistics: 2007-2008 United States snowmobile registrations. Online at *http://www.snowmobile.org/stats_registrations_us.asp*.

119 Scott, D., J. Dawson, and B. Jones. 2007. Climate change vulnerability of the US Northeast winter recreation-tourism sector. *Mitigation and Adaptation Strategies for Global Change* 13(5-6):577-596.

120 Scott et al. 2007.

121 Scott et al. 2007.

122 Lord et al. 2006.

123 Hawks, T. 2008. Personal communication, July 25. Troy Hawks is managing editor of the *National Ski Areas Association Journal*.

124 RRC Associates. 2002. *Pennsylvania Ski Areas Association economic impact study 2000-2001*. Report prepared for Pennsylvania Ski Areas Association.

125 Malone, R. 2007. Which are the world's cleanest cities? *Forbes*, April 16.

126 U.S. Green Building Council and Green Building Alliance. 2008. LEED benchmarking data: April 2008. Online at *http://www.gbapgh.org/Files/LEED%20Benchmark%20Handout%20April%202008.pdf.*

127 For a thoughtful analysis of how deeply the state should cut its emissions and how it might effectively and economically do so, see: Pennsylvania Environmental Council. 2007. *Climate change roadmap for Pennsylvania.* Online at *http://www.pecpa.org/roadmap*, accessed September 2008.

128 Meinshausen, M. 2006. What does a 2°C target mean for greenhouse gas concentrations? A brief analysis based on multi-gas emissions pathways and several climate sensitivity uncertainty estimates. In *Avoiding dangerous climate change,* edited by H.-J. Schellnhuber, W. Cramer, N. Nakicenovic, G.W. Yohe, and T.B. Wigley. Cambridge, UK: Cambridge University Press.

129 IPCC. 2007b. *Climate change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer. Cambridge, UK: Cambridge University Press.

130 Luers, A., M. Mastrandrea, K. Hayhoe, and P. Frumhoff. 2007. *How to avoid dangerous climate change: A target for U.S. emissions reductions.* Cambridge, MA: Union of Concerned Scientists.

131 Union of Concerned Scientists. 2008. *U.S. scientists and economists' call for swift and deep cuts in greenhouse gas emissions.* Cambridge, MA. Online at *http://www.ucsusa.org/global_warming/solutions/big_picture_solutions/scientists-and-economists.html*, accessed September 2008.

132 Data sources: EIA. 2004a. State emissions by year. Online at *http://www.eia.doe.gov/oiaf/1605/ggrpt/excel/tbl_statetotal.xls.* And: EIA. 2005. *International energy annual 2005*. Online at *www.eia.doe.gov/pub/international/iealf/tableh1co2.xls*, accessed August 2008.

133 Ibid.

134 EIA 2004a.

135 EIA 2008. Pennsylvania electricity profile. Online at *http://www.eia.doe.gov/cneaf/electricity/st_profiles/pennsylvania.html*, accessed September 2008.

136 The 10 states to Pennsylvania's east and north (from Maryland to Maine) have joined together in a groundbreaking effort to reduce emissions from electric power plants. Known as the Regional Greenhouse Gas Initiative, this program takes effect in 2009. The resulting reductions could be negated, however, by an increase in electricity exports from Pennsylvania to those states and/or by the construction of additional coal-fired generation in Pennsylvania. See: Regional Greenhouse Gas Initiative, Inc. 2008. *Staff Working Group final report evaluating potential emissions leakage*. April 1. Online at *http://www.rggi.org*.

137 EIA. 2004b. State emissions by sector. Online at *http://www.eia.doe.gov/oiaf/1605/ggrpt/excel/tbl_statesector.xls.*

138 Pennsylvania Transportation Funding and Reform Commission. 2006. Investing in our future: Addressing Pennsylvania's transportation funding crisis. Online at *http://www.dot.state.pa.us/Internet/pdCommissCommitt.nsf/HomePageTransFundReformComm?OpenForm*, accessed September 2008.

139 The legislation was 2007–2008 H.B. 1 ("An Act providing for alternative sources of energy; establishing the Alternative Energy Development Program, the Consumer Energy Program, the Home Energy Efficiency Loan Program, the Home Energy Efficiency Loan Fund and the Alternative Energy Production Tax Credit Program; and providing for the powers and duties of the Department of Environmental Protection"). Online at *http://www.legis.state.pa.us/cfdocs/legis/home/session.cfm,* accessed September 2008. Also see: Office of Governor Ed Rendell. 2008a. Gov. Rendell signs bill establishing $650-million energy fund to support conservation, spur renewable energy development. Press release. July 9. Online at *http://www.portal.state.pa.us/portal/server.pt?open=512&objID=2999&PageID=434874&level=2&css=L2&mode=2&cached=true&month=6.*

140 There were two pieces of legislation: 2007-2008 S.B. 22 ("An Act amending the act of November 29, 2004 [P.L. 1376, No. 178], known as 'The Alternative Fuels Incentive Act,' further

providing for definitions and for the Alternative Fuels Incentive Fund; and providing for biomass-based diesel production incentives") and 2007-2008 S.B. 36 ("An Act providing for the study and mandated content of biodiesel fuel"). Online at *http://www.legis.state.pa.us/cfdocs/legis/home/session.cfm,* accessed September 2008.

141 This legislation is 2007-2008 S.B. 266 ("An Act providing for a report on potential climate change impacts and economic opportunities for this Commonwealth, for duties of the Department of Environmental Protection, for an inventory of greenhouse gases, for establishment of Climate Change Advisory Committee, for a voluntary registry of greenhouse gas emissions and for a climate change action plan"). Online at *http://www.legis.state.pa.us/cfdocs/legis/home/session.cfm*, accessed September 2008.

142 U.S. Environmental Protection Agency Green Power Partnership Program. 2008. National top 25 (as of July 8, 2008). Online at *http://www.epa.gov/greenpower/,* accessed September 2008.

143 Office of Governor Ed Rendell. 2008b. Governor Rendell says solar mirror manufacturing facility will create 300 manufacturing jobs. Press release. August 20. Online at *http://www.portal.state.pa.us/portal/server.pt?open=512&objID=2999&PageID=434874&level=2&css=L2&mode=2&cached=true&month=7*.

144 Green Building Alliance. 2008. LEED benchmarking data: July 2008. Online at *http://www.gbapgh.org/PA_Green_Building_Stats.asp,* accessed September 2008.

145 Deyette, J., S. Clemmer, and D. Donovan. 2003. *Plugging in renewable energy: Grading the states*. Cambridge, MA: Union of Concerned Scientists.

146 Ibid. Also see: L. Sherwood. 2008. *U.S. solar market trends 2007*. Latham, NY: Interstate Renewable Energy Council.

147 Commonwealth of Pennsylvania Department of Conservation and Natural Resources. 2008. Report of the carbon management advisory group. Online at *http://www.dcnr.state.pa.us/info/carbon/final-report-0508.aspx,* accessed September 2008.

148 Also see: *http://www.keystonehelp.com*.

149 Pennsylvania Transportation Funding and Reform Commission 2006.

150 Union of Concerned Scientists Clean Vehicles Program. 2007. *Biofuels: An important part of a low-carbon diet*. Cambridge, MA.

151 See legislation described in endnote 141.

152 EPA. 2008a. Combined heat and power partnership program. Online at *http://www.epa.gov/chp*, accessed September 2008.

153 The Pennsylvania Environmental Resource Consortium. 2008. About PERC. Online at *http://www.paconsortium.state.pa.us/about.htm*, accessed September 2008.

154 Commonwealth of Pennsylvania Department of Conservation and Natural Resources 2008.

155 EPA. 2008b. The AgStar program. Online at *http://www.epa.gov/agstar/,* accessed September 2008.

156 EIA 2004b.

157 EIA 2004b.

158 NECIA 2007.

159 For information on recent federal climate policy efforts, see: Union of Concerned Scientists. 2008. Lieberman-Warner Climate Security Act: S. 3036. Online at *http://www.ucsusa.org/global_warming/solutions/big_picture_solutions/climate-security-act.html*.

160 Moomaw, W., and L. Johnston. 2008. Emissions mitigation opportunities and practice in northeastern United States. *Mitigation and Adaptation Strategies for Global Change* 13(5-6).

Photo Credits

Front cover
Apple orchard: iStockphoto.com/Delmas Lehman
Solar installation: Craig Miller Productions and DOE, NREL
Sledding: iStockphoto.com/Geoff Kuchera
Wind turbines: Community Energy, Inc.
Girl in fountain: AP Photo/George Widman

Chapter One: Introduction
Page 4 © Brian A. Morganti/www.stormeffects.com

Chapter Two: Impacts on Cities and Towns
Page 12 AP Photo/George Widman
Page 15 Jupiter Images
Page 17 3 Rivers Wet Weather Inc.
Page 19 Creative Commons

Chapter Three: Impacts on Agriculture
Page 20 iStockphoto.com/Aimin Tang
Page 22 USDA NRCS
Page 23 iStockphoto.com/Bronwyn8
Page 24 iStockphoto.com/lissart
Page 26 (mushrooms) iStockphoto.com/whitemay
(farmer) iStockphoto.com/Kalulu
Page 27 USDA/Scott Bauer

Chapter Four: Impacts on Forests
Page 28 iStockphoto.com/ooyoo
Page 31 (white-throated sparrow) iStockphoto.com/Flatcoater
(American goldfinch) iStockphoto.com/BirdImages
(ruffed grouse) Jupiter Images
Page 32 © Brian A. Morganti/www.stormeffects.com
Page 33 PennFuture

Chapter Five: Impacts on Winter Recreation
Page 34 iStockphoto.com/MentalArt
Page 36 iStockphoto.com/N8K
Page 38 AP Photo/Gene J. Puskar
Page 39 Brad Feinkopf

Chapter Six: Solutions for the Keystone State
Page 40 Craig Miller Productions and DOE, NREL
Page 44 Scott Beveridge/Observer-Reporter
Page 45 Picturequest
Page 46 iStockphoto.com/Eric Michaud
Page 47 Jupiter Images
Page 48 Community Energy, Inc.

Back cover
USDA/Scott Bauer

CLIMATE CHANGE IN PENNSYLVANIA

IMPACTS AND SOLUTIONS FOR THE KEYSTONE STATE

Global warming is already making a mark on Pennsylvania's landscapes, livelihoods, and traditions, and over the coming decades the impacts are expected to grow more substantial. Research presented in this report shows many striking differences in the scale of these impacts, determined by whether the world follows a higher- or lower-emissions pathway. The higher-emissions scenario assumes continued heavy reliance on fossil fuels, causing heat-trapping emissions to rise rapidly over the course of the century. The lower-emissions scenario assumes a shift away from fossil fuels in favor of clean energy technologies, causing emissions to decline by mid-century.

As this report outlines, emissions choices we make today—in Pennsylvania and worldwide—can help shape many aspects of Pennsylvania's economy, quality of life, and very character.

For more information on the changing climate in Pennsylvania visit

www.climatechoices.org/pa

This report represents a collaborative effort between the Union of Concerned Scientists (UCS) and a team of independent experts to analyze climate change and the related impacts on key sectors in the state of Pennsylvania. The goal of this work is to combine state-of-the-art analyses with effective outreach to provide opinion leaders, policy makers, and the public with the best available science upon which to base informed choices about climate change mitigation and adaptation. For more information on the science underpinning this work visit *www.northeastclimateimpacts.org/pa*.

The **Union of Concerned Scientists** (UCS) is the leading science-based nonprofit working for a healthy environment and a safer world. UCS combines independent scientific research and citizen action to develop innovative practical solutions and to secure responsible changes in government policy, corporate practices, and consumer choices.

PRINTED ON RECYCLED PAPER USING SOY-BASED INKS

National Headquarters
Two Brattle Square
Cambridge, MA 02238-9105
Phone: (617) 547-5552
Fax: (617) 864-9405

Washington, DC, Office
1825 K Street NW, Suite 800
Washington, DC 20006-1232
Phone: (202) 223-6133
Fax: (202) 223-6162

West Coast Office
2397 Shattuck Ave., Ste. 203
Berkeley, CA 94704-1567
Phone: (510) 843-1872
Fax: (510) 843-3785

Website www.ucsusa.org **Email** ucs@usa.org

Union of Concerned Scientists

Citizens and Scientists for Environmental Solutions