OHIO CLIMATE ROAD MAP

O·H·I·O ENVIRONMENTAL COUNCIL

KEEP WATCH. TAKE ACTION. MAKE CHANGE

PART ONE

JUNE 2005

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The mission of the Ohio Environmental Council is to inform, unite, and empower Ohio citizens to protect the environment and conserve natural resources. The Ohio Environmental Council works behind the scenes and on the front lines of Ohio's most critical environmental-conservation battles. For more than 35 years citizens across the state have counted on the OEC to be their voice at the Statehouse and state agencies—fighting to protect Ohio's environment through the promotion of sound environmental laws and policies.

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FORWARD

Ohio must prepare to live a world where new technologies are needed to make deep cuts in emissions that are causing global temperatures to rise. If we act sooner rather than later, we can lay the foundation for our energy security and economic health.

When global warming is discussed, common policy debates that come to mind are the Kyoto Protocol or the McCain-Lieberman bill. But limiting the growth of temperatures in order to prevent dangerous interference in our climate will require emission cuts over the next century that are far deeper than the levels prescribed by those policies, and all major emitters–including developing economies such as China and India–will have to participate.

However, if Ohio demonstrates leadership, then key sectors of Ohio's economy, including manufacturing, agriculture, and coal, can be major suppliers of the technologies and processes that will be critical in helping to limit temperature growth.

There are major risks to our climate if we do not limit temperature growth. The last time our planet was close to estimated global temperatures this high was 24,000 years ago when the sea level was 18 feet higher than it is today. The average surface temperature at that time is estimated to be 1°Celcius (or 1.8°Fahrenheit) above our current global temperature. Closer to home, Western states are predicted to face far greater water shortages in the next 50 years than they currently are, because projected temperature increase will result in smaller mountain snow packs and earlier snow melt. This means much greater pressure to divert our largest fresh water source–the Great Lakes–to other parts of the country.

There are also significant risks to Ohio's standard of living that can only be mitigated by preparing to be financial winners rather than losers. It is only a matter of time before a national or international regulatory constraint will affect Ohio. Almost all industrial nations (except the United States and Australia) have agreed to mandatory limits on greenhouse gas emissions. Even some U.S. states are acting on their own to adopt mandatory emission regulations. Whatever form future regulation might take, Ohio's current economic base–manufacturing, agriculture, and even coal–stands to be the supplier of solutions, if enough forethought is applied.

There are past examples of Ohio's government and business interests playing the "just say no" role when acting in regard to environmental challenges–such as the debate over acid rain legislation in the 1970's and 80's. This behavior resulted in those interests not having a seat at the table when the final policy was adopted. By learning from the past, Ohio can engage proactively and move forward with energy policies that prepare us for a better, more prosperous future.

The Ohio Environmental Council has developed this road map to help point the way toward climate solutions for Ohio. By starting down the path today, we can successfully meet the economic, technological, and climate challenges that lie ahead tomorrow.

Vicki L. Deisner
Executive Director
Ohio Environmental Council

REPORT STRUCTURE

The Ohio Climate Road Map is divided into two parts.

Part 1 (presented here) identifies: the scope of the climate stabilization challenge from Ohio's perspective; sectors of Ohio's economy poised to become suppliers of climate technology solutions; how technologies can help us meet the challenge; and a summary of market and policy measures that can set Ohio on the right road.

Part 2 (to be released in the fall of 2005) provides the details of the recommended measures including: the direct impact on climate forcing emissions; the ability to leverage deep reduction technologies down the road; technical issues; legal and regulatory issues; and costs.

Part 1 of the Ohio Climate Road Map is divided into three sections which address the scope of the challenge, technological solutions, and an outline of proactive steps Ohio can take. Many of the technical details and assumptions in the body of the report are explained in detail in the appendices.

Section 1: Road to a Stable Climate. This section provides the framework for understanding the economic and technological challenges that lie ahead in order for Ohio to do "its share" to help stabilize the climate. It is not intended to define precise targets for Ohio, but is meant to demonstrate the magnitude of the challenges, and the reasons why it makes sense to begin addressing the challenges today.

> **What does the road look like?** This subsection describes the scope of challenges in terms of limiting global temperature growth over the next century and emission reduction target levels (from Ohio and other developed economies) that would get the job done.
>
> **Why should Ohio begin to move?** This subsection describes the reasons it makes sense for Ohio to be proactive rather than just reactive to political and economic issues relating to climate change.
>
> **Where are we starting from?** This subsection outlines Ohio's current inventory of greenhouse gases.
>
> **What is our destination?** This subsection details target emission levels needed to reach Ohio's share of a climate stabilization goal.
>
> **Does it matter how we get there?** This subsection highlights how reductions in other greenhouse gases, such as methane and black carbon from diesels, can make the carbon dioxide reduction challenge that much easier to achieve.

Section 2: Technological Solutions and Effectiveness. This section of the report helps describe the climate technology solutions that currently are available or are on the horizon. As technologies and ideas evolve, the mixture of solutions being used may change. However, this section helps envision how technologies that we are familiar with today can help us meet the econonmic and climate stabilization challenges we face.

Section 3: Policy and Market Actions. This section of the report provides a summary of the policy and market measures that can provide Ohio an important start down the road toward climate stabilization.

Appendix I: Explanation of Climate Stabilization Target Levels

Appendix II: Methods for Analyzing Technological Solutions

Appendix III: Potential Climate Impacts from Human Interference

Appendix IV: Common Questions and Answers

Appendix V: Scientific Uncertainties about Climate Change

SECTION 1: ROAD TO A STABLE CLIMATE

What does the road look like?

In order to avoid dangerous interference in our climate, the rise in global temperatures should be limited to no more than 1°Celcius (C) or 1.8°Fahrenheit (F) from current levels. To help meet this temperature growth limit, industrialized countries, such as the U.S., and states, like Ohio, should aim to decrease current CO_2 emissions between 65% and 95% by 2100. The less challenging 65% path is only possible if there are significant reductions in other climate warming gases and/or particles. In Ohio, this could be achieved with a 70% reduction in methane emissions, a 12% reduction in nitrous oxide emissions, and a 90% reduction in diesel black carbon emissions.

These reductions and timeframes were arrived at by considering the following observations from the scientific community:

- The American Meteorological Society, the U.S. National Academy of Sciences, the American Geophysical Union, and many other scientific organizations have concluded that human-generated emissions are adding energy to our climate by trapping heat—which is contributing to a global warming trend.[1]
- Several leading climatologists and some governments (such as the European Union) have concluded that warming more than 1°C above current levels runs the risk of triggering major climactic change. Such change could include an irreversible trend toward sea level rise of several meters resulting from the melting of glaciers and large ice sheets in Greenland and Antarctica over the next millennium. Unless warming is limited, sea level increases of three to six feet could occur in the next few centuries, which would most affect the coastal and low lying areas where much of the world's population resides. Repercussions could include impacts on the global economy and population migrations in the tens or hundreds of millions.
- To meet the temperature target of limiting warming to 1°C, the atmospheric concentration of carbon dioxide (CO_2) must stabilize between 450 and 550 parts per million (ppm). The higher level of 550 ppm is contingent upon significant global reductions of other climate forcing agents, such as methane, ozone, nitrous oxide, diesel black carbon, and others.
- To meet the CO_2 concentration target, industrial nations and states, like Ohio, will have to cut their carbon dioxide emissions 65% to 95% over the next century.

Ohio's economic base is poised to be a leader in innovative climate technology solutions. Investments in emerging ideas can pay off both economically and in terms of climate stabilization.

It is possible to meet this concentration target with innovative private investments and government policies. Delays in taking action will, at best, mean higher economic and societal costs or, at worst, result in failure to avoid dangerous changes in our climate. States, like Ohio, can be leaders in this effort by creating policies that capture economic development opportunities and cost-effective programs that will result in real and immediate reductions in heat-trapping emissions.

Why should Ohio begin to move?

Ohioís economic base can be an important supplier of solutions

Key sectors of Ohio's economy, such as manufacturing, agriculture, and coal, can be major suppliers of the technologies and processes that will be critical in helping to limit temperature growth.

- **Manufacturing**. Ohio has always been one of the country's leading manufacturing states. Some companies are already manufacturing these solutions in Ohio–such as energy efficient insulation by Owens Corning, washers by Whirlpool, and photovoltaic solar panels by First Solar. Ohio is the second largest state for auto manufacturing. Investment in developing advanced engine technologies, such as hybrid electric vehicles and computer controlled combustion, will help Ohio to maintain an industry cluster in the automotive sector. Our state's skilled manufacturing base is positioned to be a major supplier for new technology ventures such as advanced coal gasification (described below).
- **Coal**. While the coal industry was originally perceived as one of the first casualties of cutting CO_2 emissions, coal is actually poised to be a major source of climate solution technology. Integrated Gasification Combined Cycle (IGCC) is a technology that turns coal into a synthetic gas composed of hydrogen and carbon monoxide (which becomes carbon dioxide). More than 90% of the carbon dioxide can be captured from the gasifier and then pumped into deep geologic formations located miles underground. Scientists and engineers who study these formations believe there that is significant data to indicate geologic formations can store carbon dioxide for millions of years. Some types of geologic formations turn the gas into minerals over thousands of years. In addition to carbon dioxide capture and storage, IGCC has several other environmental benefits compared to conventional coal plant technology–including near-zero emissions of other air pollution and waste that contains significantly fewer toxics. IGCC plants that use a mix of coal and biomass could even have **negative** CO_2 emissions because the atmospheric carbon previously absorbed by the biomass (plant material) would be stored geologically, rather than be re-released into the atmosphere.
- **Agriculture and forestry.** Sustainable agriculture and forestry practices can provide immediate reduction in atmospheric carbon and have other economic and environmental benefits as well. "No till" farming can improve water quality as well as allow soils to retain more carbon dioxide than conventional tillage. Selective cutting and practices allowing newer forests to mature before cutting can help keep even more carbon out of the atmosphere.

EMERGING IDEAS WITH PAYOFF POTENTIAL

Charcoal fertilizer

The University of Georgia and others are exploring the potential of charcoal infused with nutrients as an alternative to conventional fertilizer. Charcoal fertilization may have the potential to: improve farm economics; sequester biomass carbon in agricultural soil for very long periods of time (several thousand years); significantly enhance the ability of soil microbes to remove large amounts of carbon from the atmosphere and sequester it for decades; and significantly reduce nitrous oxide emissions from farm fields.

Carbon nano-fibers from gasification

Applied Sciences Inc., in Cedarville, Ohio, has developed a process to use carbon dioxide from a gasifier to produce carbon nano-fibers, a recently developed, advanced material made out of carbon atoms that form molecular "tubes". The material can be used in automobile, aerospace, and shipping construction, and to reinforce building materials, such as concrete. If successful, this process would turn carbon from coal and/or biomass into a marketable product and could be an alternative to geologic sequestration.

Political reality

Whether it is in one year or ten, the U.S. is very likely to address greenhouse gases in a serious manner.

Political offices, from the presidential administration of George W. Bush to the European Union, recognize that climate change is a risk that must be addressed.

- **The Bush Administrationís position**. "The United States is taking prudent steps to address the long-term challenge of global climate change. We are reducing projected greenhouse gas emissions in the near term, while devoting greater resources to improving climate change science and developing advanced energy technologies."–President Bush (2002)

OHIO BUSINESSES PREPARING FOR CLIMATE CHANGE

American Electric Power (AEP)

American Electric Power has been preparing to address the issue of climate change for several years. The company has been offsetting some of their carbon dioxide emissions through soil sequestration (re-foresting) projects. AEP is also participating in the Chicago Climate Exchange, buying off-sets of its greenhouse gas emissions through the market place. More recently, the company announced they have submitted a plan to the Public Utilities Commission of Ohio to build a new Integrated Gasification Combined Cycle plant in Monroe County by 2010. This advanced coal technology would have the potential to use coal as a low/no carbon emitting fuel.

Cinergy

In 2003, Cinergy announced a voluntary plan to reduce its greenhouse gas emissions to an average of 5% below their 2000 level during the period from 2010 through 2012. This step would exceed the mandatory reductions that would be required under the Climate Stewardship Act as it has been proposed U.S. Senators John McCain and Joseph Lieberman. As part of the voluntary program, the company will evaluate its emissions goal in 2010 and determine an appropriate voluntary goal for 2013 through 2015. Cinergy is also working to retrofit one of its old coal plants in Indiana as a new IGCC coal facility. In a recent report to its Board of Directors, Cinergy recommended that the U.S. begin to seriously consider mandatory reductions in carbon dioxide in order to help provide regulatory certainty to the utility sector.

British Petroleum (BP)

BP, owner of one of Ohio's largest oil refineries (located in Toledo), is adopting several measures to manage its own greenhouse gas emissions. Recently, BP's CEO–Lord John Browne–suggested that policymakers set a global target for climate stabilization of limiting CO_2 concentration to 550 ppm by 2100—the high end of the target stabilization goal suggested in this report.

DuPont

DuPont, which just celebrated the 50th anniversary of its plant in Circleville, has agreed to several goals in order to help mitigate greenhouse gas emissions including: reducing their global carbon-equivalent greenhouse gas emissions by 65% using 1990 as a base year; holding total energy use flat using 1990 as a base year; and obtaining 10% of their global energy use in the year 2010 from renewable resources.

Whirlpool

Whirlpool has committed to decrease its greenhouse gas emissions from global manufacturing and emissions resulting from the use and disposal of its products to 3% below 1998 levels by the year 2008.

- **International pressure.** “There is no bigger long-term question facing the global community than the threat of climate change.” –British Prime Minister Tony Blair (2004)
- **Congressional activity.** Majority party Senators, such as John McCain (R-AZ) and Richard Lugar (R-IN), are working to enact the first mandatory limits on U.S. greenhouse gases.

The recent implementation of the Kyoto Protocol means that all economically developing countries, with the exception of the U.S. and Australia, will be taking steps to reduce their greenhouse gas emissions. This action by Japan, the European Union, Russia, Canada and others puts even more pressure on the U.S. to engage in a serious effort to reduce heat-trapping emissions.

Regardless of what national law or international agreement will be used to address climate change here in the U.S., most political observers and businesses agree that it is coming.

Economic leader or loser

The choices Ohio makes today will affect how it can meet future national policies and treaty agreements that cut greenhouse gases.

- Failure to prepare will likely leave Ohio at an economic disadvantage.
- Showing leadership will allow Ohio to help shape future policies and provide the greatest chance for economic opportunity.
- Ohio’s economic base–coal, agriculture, and manufacturing–can become a large supplier of climate solutions if the state leads rather than follows.

In many ways, the debate over the 1990 acid rain amendments to the Clean Air Act is a lesson for Ohio. Because many Ohio policymakers and industries adopted a “just say no” approach to addressing acid rain and failed to meaningfully engage in the discussions, they did not have any significant influence in the final policy. Ohio business sectors are once again at risk of being left on the sidelines when future climate policy and economy is crafted.

In order for Ohio to address the issue of climate stabilization in ways that make the most sense for our economy and environment, Ohioans must come together to develop common sense policies that move Ohio in the right direction and place our state ahead, rather than behind, the curve.

Where are we starting from (what are the sources of Ohioís emissions)?

Ohio's Inventory of Greenhouse Gases and Particles (Table 1, below)[2] identifies the sources of Ohio's emissions. The energy sector is the single largest source, followed by agriculture and waste management. Industrial processes make up the smallest portion. The largest emissions by type and source are carbon dioxide from the energy sector. Across the U.S., Ohio ranks **third** (behind Texas and California) for greenhouse gas emissions and is responsible for 4.5% of the nation's total emissions.

This clearly underscores why CO_2 from the energy sector must be a major source of emissions cutting efforts. However, deep cuts in other climate forcing agents, such as methane and black carbon can ease the challenge of those efforts.

Ohio's Inventory of Greenhouse Gases and Particles

In million metric tons of carbon equivalent (MMTCE)

Energy Emissions	MMTCE	
Electric Utilities - CO_2	32.00	
Transportation - CO_2	18.68	
Industrial Steam, Coal, and Petroleum Coke Manufacturing - CO_2	11.73	
Diesel Engine Black Carbon - Fine elemental carbon	9.90	
Residential Heating - CO_2	5.95	
Commercial Heating - CO_2	3.11	
Natural Gas and Oil Systems - Methane	1.44	
Mobile Combustion - Methane and Nitrous Oxide	0.62	
Coal Mining - Methane and Nitrous Oxide	0.39	
Stationary Combustion - Methane and Nitrous Oxide	0.13	
Energy Subtotal	83.94	
Industrial Process Emissions	MMTCE	
Ozone Depleting Substitutes (ODS), Electric Transmission and Distribution, Semi Conductor and Aluminum Manufacturing - Hydrofluorocarbons (HFCs), Perfluorochlorocarbons (PFCs), and Sulfur Hexafluoride (SF_6) Emissions	0.83	
Cement Manufacture, Lime Use, Soda Ash - CO_2	0.29	
Industrial Processes Subtotal	1.11	
Agriculture Emissions	MMTCE	
Agricultural Soil Management - Nitrous Oxide	2.71	
Enteric Fermentation - Methane	0.44	
Manure Management - Methane	0.24	
Burning of Agricultural Crop Waste - Methane	0.02	
Agriculture Subtotal	3.40	
Waste Emissions	MMTCE	
Municipal Solid Waste - Methane	2.46	
Wastewater - Methane and Nitrous Oxide	0.33	
Waste Subtotal	2.79	
Gross Emissions (add subtotals)	91.24	
Land Use Change/Forestry Emissions	-7.34	
Net Emissions	**83.90**	**MMTCE**

Table 1

What is our destination (what needs cut and by when)?

There are several emission reduction paths that Ohio could follow to achieve its share of a climate stabilization strategy. Tables 2 and 3 (below) outline two examples that would allow Ohio to meet the target emission levels required to limit global temperature growth to 1°C. (More details on these target levels can be found in Appendix I.)

Each scenario requires deep cuts in carbon dioxide emissions and either maintaining or cutting emissions from other greenhouse gases and aerosols. Example 1 requires a 65% cut in carbon dioxide, a 70% cut in methane emissions, a 12% cut in nitrous oxide emissions, and a 90% cut in diesel black carbon emissions, as well as the maintenance of HFC, PFC, and SF_6 emissions at year 2000 levels.

Example 1 requires less aggressive cuts in carbon dioxide than Example 2, where all non-CO_2 emissions are merely maintained and CO_2 emissions are cut by 95%. In addition to climate stabilization effects, cuts in pollutants such as methane and diesel black carbon provide further environmental and public health benefits.

Example 1: Target levels met with CO_2 and non-CO_2 reductions In million metric tons of carbon equivalent (MMTCE)	
Pollutant	**MMTCE**
Carbon dioxide	
2000 Emissions	71.75
Target level for 2100	26.00
Methane	
2000 Emissions	5.13
Target level for 2030 and beyond	1.54
Nitrous Oxide	
2000 Emissions	3.62
Target maintenance level	3.19
HFC, PFC, and SF6	
2000 Emissions	0.83
Target maintenance level	0.83
Black Carbon (fine soot)	
2000 Emissions	10.00
Target level for 2015 and beyond	1.00

Table 2

Example 2: Target levels met with just CO_2 reductions In million metric tons of carbon equivalent (MMTCE)	
Pollutant	**MMTCE**
Carbon dioxide	
2000 Emissions	71.75
Target level for 2100	8.00
Methane	
2000 Emissions	5.13
Target maintenance level	5.13
Nitrous Oxide	
2000 Emissions	3.62
Target maintenance level	3.62
HFC, PFC, and SF6	
2000 Emissions	0.83
Target maintenance level	0.83
Black Carbon (fine soot)	
2000 Emissions	10.00
Target maintenance level	10.00

Table 3

Does it matter how we get there?

It matters a great deal to Ohioans which emissions reduction path we choose because it directly affects our economy and environment.

Reducing other greenhouse gases (GHGs) means a smoother, steadier, and less challenging CO_2 reduction

While carbon dioxide is the biggest source of heat trapping emissions, other gases and aerosols collectively have a greater warming impact (see Chart 1, below left). If non-carbon dioxide emissions are reduced globally, then CO_2 concentrations can be stabilized at a higher level. For example, a 70% reduction in methane and a 12% reduction in nitrous oxide would allow CO_2 concentrations to be stabilized at 550 ppm while still limiting temperature increase to no more than 1°C. If those pollutants are kept at the same level (i.e. no increases from now on), then CO_2 levels would have to be stabilized at 450 ppm in order to meet the temperature target.

Figure 1 (below right) shows that, for Ohio, reducing its share of CO_2 to reach a 550 ppm global target would require a 65% cut in CO_2 emissions from 2000 levels. However, reducing its share of CO_2 to meet a 450 ppm target would require a 95% cut–a deeper and more difficult path.

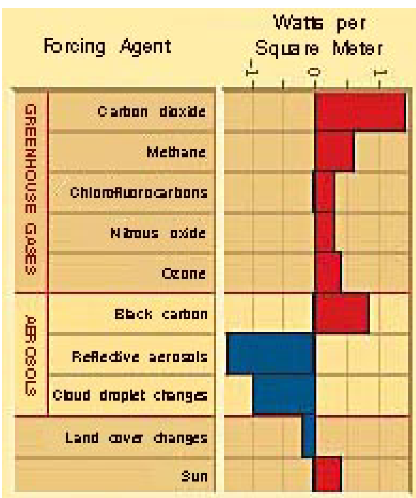


Chart 1. Illustration by Jen Christiansen, from Scientific American (Hansen), March 2004.

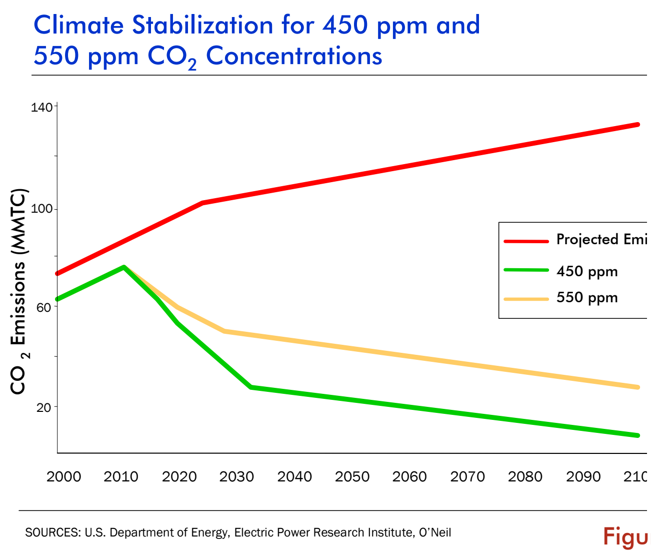


Figure 1

The timing of emission cuts matters (living within our budget)

The prompt reduction of greenhouse gases and aerosols, such as methane, ozone, and black carbon, will create the most rapid cooling effect. This is because the atmospheric concentrations of these pollutants drop within a few years or, in the case of particles, a few weeks after emission cuts occur.

Carbon dioxide, however, has the longest lifetime of all the greenhouse gases. Once CO_2 is emitted into the air, a portion of it will remain in the atmosphere for over a hundred years. Over the course of a century, much of the CO_2 is absorbed by oceans as heat is exchanged between the ocean's surface and the deeper ocean. This build-up makes the task of reducing atmospheric concentrations increasingly difficult as time goes on.

Reducing carbon dioxide emissions sooner rather than later is critical, because there is a finite amount of CO_2 that can be emitted through the end of the century and still allow Ohio to meet a given target concentration rate (such as 550 ppm). Waiting too long to reduce carbon dioxide emissions means the target concentration rate will have to be set even lower and met more rapidly in order to reach climate stabilization. This emissions path is sometimes referred to as a “carbon budget.” Ohio currently is projected to emit an estimated 10,975 million metric tons of carbon equivalent (MMTCE) by the end of the century; however, to do our fair share of emission cuts in that timeframe, Ohio can emit no more than 3,020 MMTCE with a 450 ppm target or 4,540 MMTCE with a 550 ppm target.

In order to live within a 450 ppm carbon budget, Ohio would have to cut its CO_2 emissions 95% by 2100 beginning in 2010. If we were to wait until 2025 to begin cutting back, Ohio would have to reduce its CO_2 emissions 95% by 2036—a drastically shorter time span (see Figure 2 below).

In order to live within a 550 ppm budget, Ohio would have to cut its CO_2 emissions 65% by 2100 beginning in 2010. Waiting until 2025 to begin cutting emissions means that Ohio would have to increase its cut in CO_2 emissions to 92% by 2100 (see Figure 3 below).

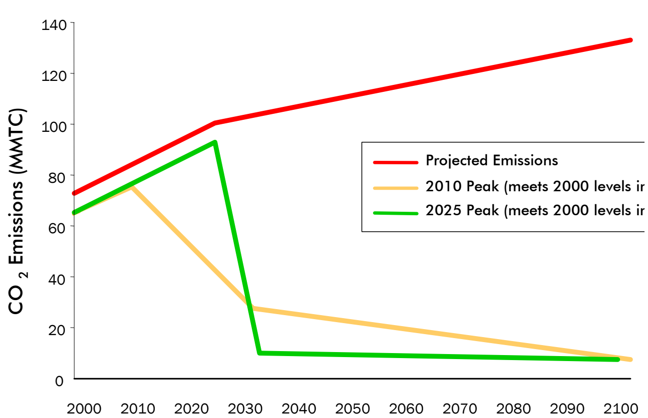
While meeting a 550 ppm target level (a 65% reduction in CO_2 emissions from year 2000 levels by the year 2100) is less challenging than a 450 ppm target level (a 95% reduction in CO_2 emissions from year 2000 levels by the year 2100), the analysis above shows that waiting to begin emission reductions will make meeting either target level extremely challenging, if not virtually impossible.

Heading up or down by 2100?

As shown in Figures 2 and 3, CO_2 emissions are on a downward trajectory. Given that CO_2 emissions have been steadily increasing for hundreds of years, moving into a period of decreasing emissions is a major shift. Further, by the 22nd century, global carbon dioxide emissions are going to have to decrease even more, getting closer to zero, in order to maintain stable CO_2 concentrations.

This means that even if the CO_2 reduction path meets the target budget, it still must lay the groundwork for further reductions past the year 2100. Although advances in conventional technology, such as gains in efficiency, could allow us to live within a carbon budget in the 21st century, we will have to completely transition to no-carbon fuels, such as hydrogen, by the 22nd century.

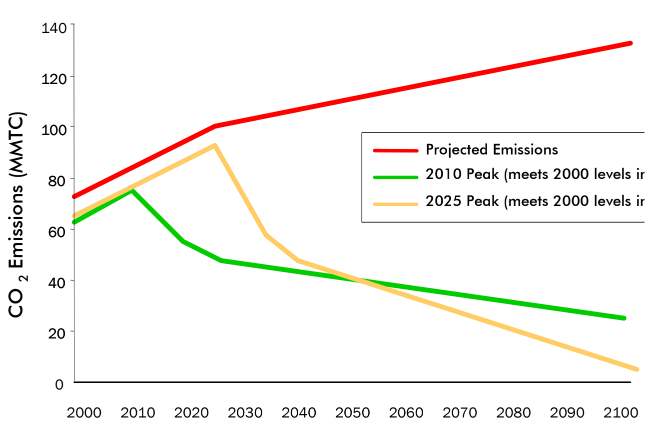
450 ppm Stabilization Path with
Emissions peaking in 2010 and 2025



SOURCES: U.S. Department of Energy, Electric Power Research Institute, O'Neil

Figure 2

550 ppm Stabilization Path with
Emissions peaking in 2010 and 2025



SOURCES: U.S. Department of Energy, Electric Power Research Institute, O'Neil

Figure 3

SECTION 2: TECHNOLOGICAL SOLUTIONS AND EFFECTIVENESS

Non-CO_2 Greenhouse gases and aerosols

In addition to helping stabilize our climate, the reduction of methane, nitrous oxide, hydroflorocarbons, and black carbon (elemental carbon soot) has other environmental, public health, or economic benefits. There are several cost-effective methods for reducing these emissions.

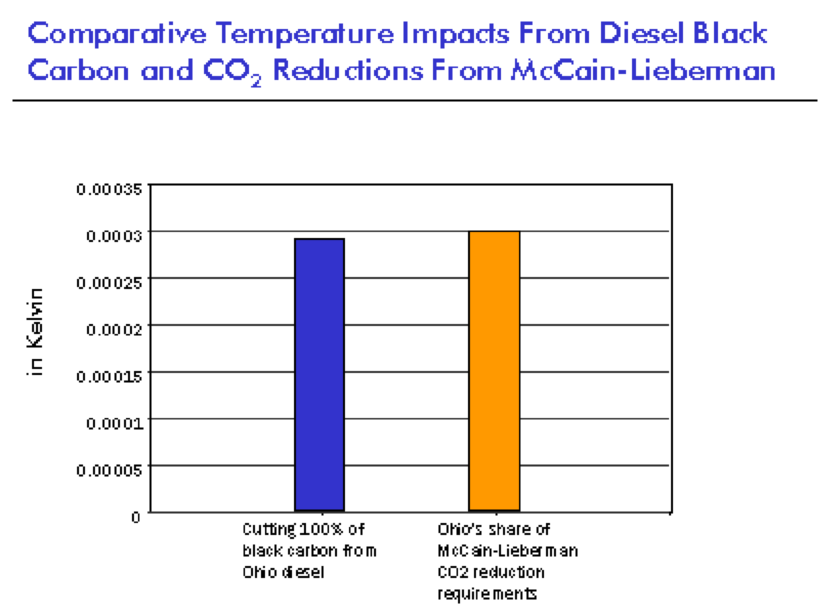
Diesel cleanup

A 90% reduction in diesel emissions is readily achievable with existing technology. Beginning in 2007, all new on-road diesel engines will be required to reduce emissions by 90%. The same will apply to non-road diesels beginning in 2010. However, because diesels are so long-lived, the reductions will not be fully felt until 2035. Cuts in emissions from shipping and rail sources are currently being considered by the U.S. Environmental Protection Agency.

In the meantime, many diesels that are on the road today can replace their muffler with a diesel particulate filter (DPF), reducing black carbon emissions by 90%.[3] The ultra low sulfur diesel fuel needed to use the filters will become the national on-road diesel fuel standard in 2007 and likely will be widely available in 2006. BP's Toledo area refinery is already manufacturing and selling the ultra low sulfur diesel fuel in Ohio.

Older diesels that are not electronically controlled (pre-1994 engines) may not be able to use DPFs. However, biodiesel (which reduces carbon dioxide) or a diesel/water emulsion can reduce black carbon emissions.[4] Simple measures such as idle reduction can also reduce black carbon emissions and save money.

As illustrated in Figure 4, reducing black carbon emissions from on- and non-road diesel engines in Ohio potentially could have cooling impact similar to that resulting from Ohio's share of CO_2 emissions cuts as would be required under the McCain-Lieberman bill. In order to live within our CO_2 budget (as explained on page 12), reducing black carbon emissions does not negate the need to begin reducing CO_2 emissions. However, black carbon emission reductions would provide important, immediate cooling benefits.[5]



SOURCES: Bond, Jacobson, Wigley

Figure 4

Methane reduction

Methane emissions primarily come from landfills, animal feedlots, enteric fermentation (animal flatulence), coal mines, and waste water treatment. Methane from landfills, animal feedlots, coal mines, and waste water treatment can be captured and burned, and in many cases, the fuel can be used to generate electricity. It can also be used to produce liquefied or compressed natural gas for industrial or transportation purposes.

These sources total 85% of Ohio's methane inventory and capturing and burning these fuels would cut the MMTCE of methane from Ohio by more than 70% (see Table 4 below).[6]

Source of Methane	Current Emission Level (MMTCE)	Reduction Technology	Effectiveness	New Emission Level (MMTCE)
Stationary Combustion	0.07	Inspection and maintenance	Not Estimated	0.07
Mobile Combustion	0.04	Inspection and maintenance	Not Estimated	0.04
Coal Mining	0.39	Capture and combustion	90%	0.04
Natural Gas and Oil Production and Transportation	1.44	Inspection and maintenance	Not Estimated	1.44
Enteric Fermentation	0.44	Feed modification	Not Estimated	0.44
Animal Feedlots	0.14	Capture and combustion	90%	0.13
Burning of Agricultural Crop Waste	0.01	Not Estimated	Not Estimated	0.01
Landfills	2.46	Capture and combustion	90%	0.25
Wastewater Treatment	0.15	Capture and combustion	90%	0.02
Total MMTCE	5.13		Total MMTCE	2.42

Table 4

Enteric fermentation from livestock and vaporous emissions from oil and gas production and transportation are also potential sources of reduction. Modification of livestock feed potentially can reduce enteric emissions. Enhanced inspection and maintenance programs are a practical method of reducing vaporous methane emissions—particularly from pipelines.

Nitrous oxide

Nitrous oxide may be the most challenging of the non-CO_2 greenhouse gases to address. Currently, the only available methods to reduce emissions are related to fertilizer management, with which reductions of 12% may be feasible.[7] However, newer fertilization technologies, such as using a charcoal base to create slow-release nitrogen fertilizers, may hold the most promise for long-term methods to reduce the amount of fertilizer needed and, thus, nitrous oxide emissions.

Carbon dioxide

Target reduction levels for carbon dioxide can be reached through a combination of emission cuts and removal of CO_2 from the atmosphere by storing it deep underground or in soils and vegetation. The first can be achieved, in part, by utilizing available sources of alternative energy or moving to advanced low carbon technologies. The second option can be achieved through sustainable agricultural, forestry, and land use practices and geologic storage, and could be greatly enhanced through the development of carbon products and agricultural technology. Whether emissions reductions follow a path to 450 ppm of CO_2 (95% cut from year 2000 levels) or to 550 ppm of CO_2 (65% cut from year 2000 levels), it will take implementation of both options to achieve the goal. The following sections contain graphs which illustrate the magnitude of impacts on carbon emissions from various technologies that can or could be related to Ohio's fundamental business interests. Details of how these estimates were created can be found in Appendix II.

Electric Power Generation Sector

Electricity generation accounts for nearly half of the projected carbon dioxide emissions over the next century. While this source of emissions is the largest, it also may provide the best opportunity for technologies that can provide deep reductions with relative ease. Ohio's power sector is projected to emit 4860 million metric tons of carbon (MMTC) over the next century. If the sector were to reduce its share proportionally to meet a 550 ppm CO_2 concentration target, it would have to limit its total emissions to 2,010 MMTC over the century.

Compared with the transportation and heating/industrial sectors, the power sector offers the most practical opportunities for deep reductions in carbon dioxide emissions based on current technologies. Therefore, it may be advantageous to reduce emissions beyond the sector's proportional share of a climate stabilization goal in order to most effectively meet an overall CO_2 budget goal.

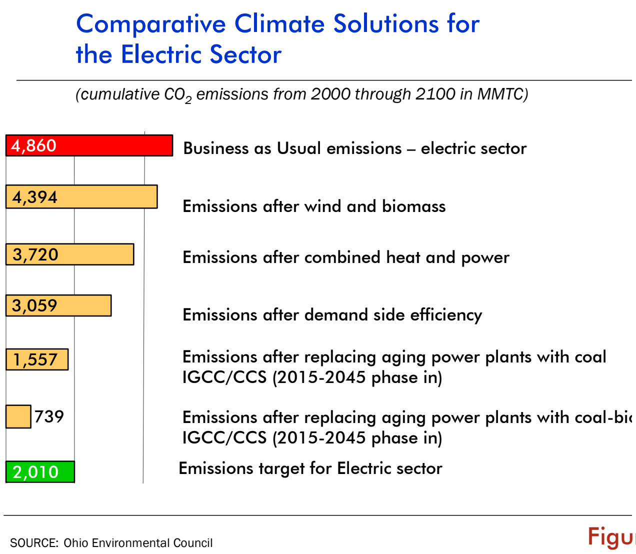


Figure 5

Some conclusions that can be drawn from Figure 5 include that:

- Using industrial steam to generate electricity (combined heat and power), reducing electricity customer demand (demand side efficiency) and increasing small, decentralized power generation (distributed generation such as solar panels and fuel cells) can provide immediate incremental benefits in the short-term and have large cumulative impacts in the long-term.
- Replacing existing plants with IGCC coal with carbon sequestration can provide very deep emissions cuts over the century that could possibly meet this sector's target goal in Ohio. A combined coal and biomass fuel used with IGCC can exceed this sector's target goal.
- Conventional wind turbines and biomass combustion can provide immediate benefits in the short-term, but do not have a large cumulative impact in the long-term.

WHAT ABOUT...

Nuclear Power

Nuclear power is being discussed more frequently by policymakers as a low- or no-carbon option. Current nuclear reactor designs still pose significant questions about operational safety and waste disposal. Next generation reactors are intended to address those issues as well as nuclear proliferation questions. However, it is not yet clear how successful or cost-effective those designs might be. A nuclear power design that could tackle those issues at a reasonable cost would be a clear advantage in addressing carbon constraints and more research is warranted.

Electricity from hydrogen fuel cells

Fuel cells conceivably could replace existing power plants or even be used in a small distributed generation format. However, in order to be low- or no-carbon, the source of the hydrogen must be considered. The least expensive source of carbonless hydrogen is gasified coal or reformed natural gas with carbon capture. Electrolysis (an electric current passed through water) is a more expensive method. Sources for electrolysis include nuclear, wind, solar photovoltaic, hydroelectric, and potentially biomass. Hydrogen also can be generated by coal-fired power plants, but this has virtually no carbon benefits unless the carbon from the plants is captured and sequestered. The difficulty of capturing CO_2 from conventional power plants makes this technology one of the most expensive ways to generate carbonless hydrogen.

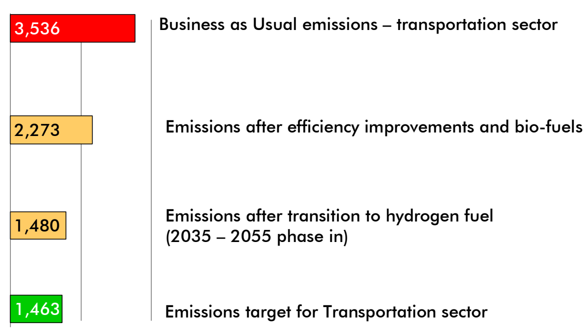
Transportation sector

The transportation sector is the second largest source of CO_2 emissions in Ohio, and accounts for one-third of all the emissions over the next century. Cars, trucks, trains, ships, and planes in Ohio are projected to emit 3,536 MMTC over the next century. If the sector were to reduce its share proportionately in order to meet a 550 ppm CO_2 concentration target (65% cut from year 2000 levels), then it would have to limit its emissions to 1,463 MMTC over the next century.

Unlike the electric sector, the transportation sector may be one of the most challenging sectors in which to achieve deep cuts in carbon dioxide emissions. Fuel efficiency and biofuels offer near-term options to make significant progress. However, the deep cuts that would be required for the sector to meet its proportional share depend on commercialization of electric vehicles (using carbonless electricity) or hydrogen based fuel systems (using fuel cells or combustion of hydrogen). There are several challenges with these technologies, including battery storage capability, the need for an entirely new fuel distribution system, and the on-board fuel storage. While these technological challenges are considerable, they will ultimately have to be addressed in order to meet climate stabilization goals in the long-term.

Comparative Climate Solutions For The Transportation Sector

(cumulative CO_2 emissions from 2000 through 2100 in MMTC)



SOURCE: Ohio Environmental Council

Figure 6

Some conclusions that can be drawn from Figure 6 include that:

- Using more fuel efficient technology (hybrid electric vehicles and computer-aided combustion) in cars and trucks and use of biofuels (cellulosic ethanol and biodiesel) could reduce total projected emissions for the century by 35%.
- In order for this sector to meet its portion of a stabilization goal, the current fleet of conventional vehicles (cars, trucks, trains, plains, and ships) would have to be transitioned to no-carbon, hydrogen-based or electric vehicles (using carbonless electricity) starting in 2035 and ending in 2055–an extraordinarily difficult challenge.

Heating/Industrial sector

The heating/industrial sector is this third largest source of carbon dioxide emissions in Ohio and is projected to emit almost a quarter of the state's CO_2 emissions over the next century. The emissions from this sector come from residential and commercial heating, industrial steam generation, and coal and petroleum coke manufacturing. These sources are expected to emit 2,578 MMTC over the next century. If the sector were to reduce its share proportionately in order to meet a 550 ppm CO_2 concentration target (65% cut from year 2000 levels), then it would have to limit emissions to 1,066 MMTC over the next century.

The thermal sector lies between the electric and transportation sectors in terms of technical challenges. Like the other sectors, efficiency can play an important near-term role in reductions, but ultimately it will require the use of a low- or no- carbon fuel. However, there are some innovative options available to the thermal sector. The industrial steam and coking processes can be transitioned to coal or coal/biomass gasification processes. The use of natural gas for heating and industrial processes can be gradually replaced with a hydrogen-methane mix (known as hy-thene). Initially, the hydrogen content would start out small, only 5% to 10%, but would increase to substantial levels and ultimately transition primary fuel usage from natural gas to hydrogen. The gradual nature of the hy-thene process allows the potential to create a hydrogen fuel distribution system using existing systems–rather than having to switch to an entirely new system from the onset. Finally, commercial and residential heating may be able to address their carbon issues simply by transitioning from gas-powered heat to electrical-powered heat.

Some conclusions that can be drawn from Figure 7 include that:

- Increased efficiency offers the most immediately available technology option, but long-term gains may be modest–with a total reduction of approximately 7%.
- A combination of gradually increasing the use of hy-thene (up to 50% hydrogen) and transitioning coal and coke to gasification could cut total emissions by 32%.
- In order for this sector to meet its portion of a stabilization goal, the heating and industrial sector would have to transition its current technologies to technologies such as gasification, no-carbon hydrogen fuel, or electrification.

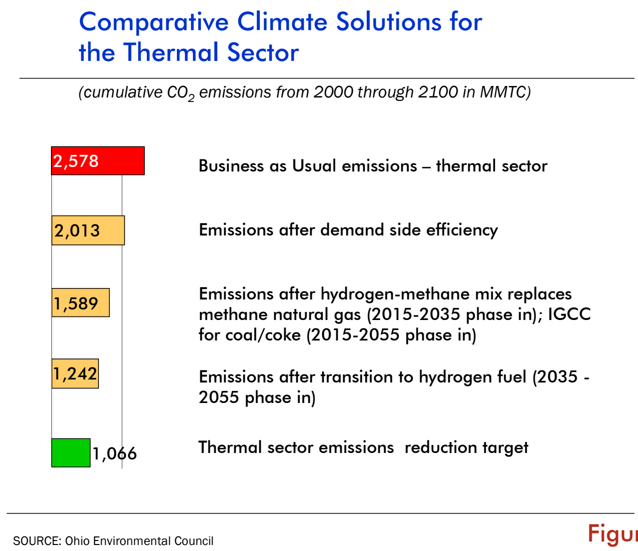


Figure 7

Land use change and taking carbon dioxide out of the atmosphere

Sequestration pulls carbon dioxide from the atmosphere and stores it in soils, vegetation, or geologic formations. In other words, it takes carbon that was released from the Earth's resources (coal, oil, gas, and soil) into the Earth's atmosphere and puts it back into the Earth's crust or the soil and plant life.

Soils and Vegetation

Soil sequestration redirects carbon dioxide from the atmosphere into the soil. Crops, trees, grasses, and other vegetation sequester carbon in the soil naturally. Using conservation tillage methods and sustainable forestry practices can enhance the amount of carbon that is stored by soils or woody biomass, such as trees.

Conversely, when soil is significantly disturbed, such as through conventional tilling or deforestation, carbon is released back into the atmosphere.

The potential for soil and vegetation carbon storage in Ohio is quite significant. For example, a combination of conservation tillage and forestry practices could sequester a total of 246 MMTC.

Geologic formations

Geologic sequestration comes from mechanically trapping CO_2 from emission sources and piping it into geologic formations several miles underground where it will mineralize or, based on what we know about natural carbon dioxide deposits, reside for potentially millions of years. While this technology is primarily considered for use in reducing CO_2 emissions from fossil fuels, it can also be used with biomass fuels because biomass fuels have the potential of being carbon neutral.

There are three types of geologic formations available to sequester carbon in Ohio—coal seams, oil and gas fields, and deep brine or saline aquifers. Unlike sequestration through vegetative growth (where carbon dioxide is pulled directly from the atmosphere), underground storage requires that carbon dioxide be captured before it enters the atmosphere. Following capture, it can be pumped underground.

Initial estimates of Ohio's geologic formations indicate a storage capacity of 1,914 MMTC. However, those estimates include less than half of Ohio's saline aquifers and only a fifth of the coal-seam capacity.

Solution Strategy Examples

There are several combinations utilizing the previously mentioned technologies that can result in emissions reduction meeting a climate stabilization goal.

Example 1 (Figure 8)

This example of technology deployment would reduce Ohio's CO_2 emissions 65% from year 2000 levels by the year 2100 and emit no more than 4,145 MMTC of carbon dioxide over the century–meeting Ohio's share of a global CO_2 reduction goal that aims for a 550 ppm atmospheric concentration by 2100.

The mix of measures would include:

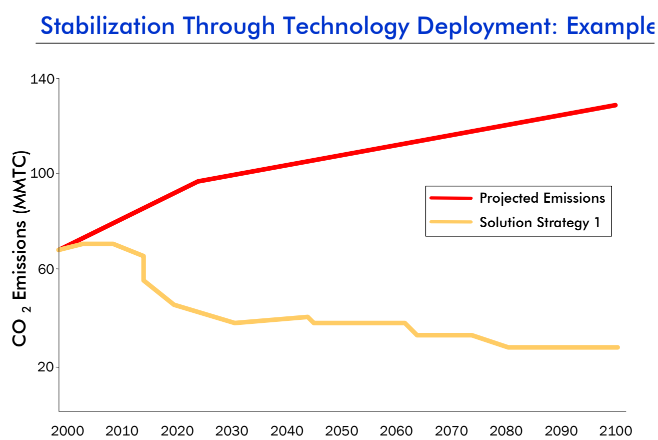
- Soil sequestration through agriculture and forestry. *260 MMTC sequestration through 2100.*
- Greater use of energy efficiency and renewable energy, as well as replacment of Ohio's old coal plants with IGCC coal plants with carbon capture and sequestration. The retrofitting would occur from 2015 through 2045. *659 MMTC emissions through 2100.*
- Increasing efficiency and biofuels use in cars and trucks. *2461 MMTC emissions through 2100.*
- Increasing efficiency in residential, commercial, and industrial natural gas usage, beginning a phase-in of hy-thene starting in 2031, and transitioning to hydrogen fuel starting in 2060. *1,340 MMTC emissions through 2100.*

Example 2 (Figure 9)

In this example, there is less reliance on efficiency and renewable energy because vehicles switch to hydrogen fuel. This scenario reduces Ohio's emissions 85% by 2100 and emits no more than 4,203 MMTC of CO_2 over the century–also meeting Ohio's share of a 550 ppm stabilization goal.

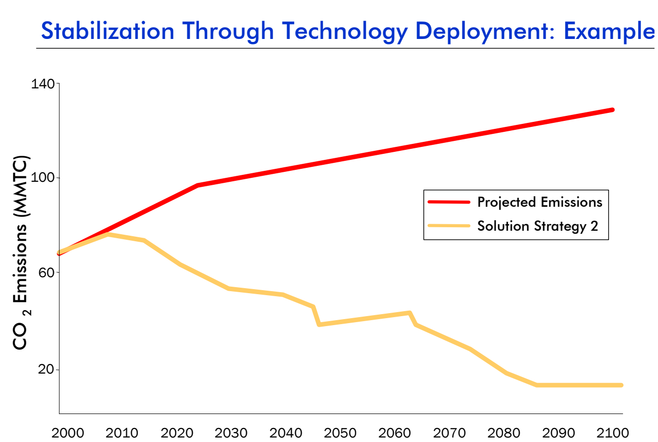
The mix of measures would include:

- Soil sequestration through agriculture and forestry. *260 MMTC sequestration through 2100.*
- Replacement of Ohio's old coal plants with IGCC coal plants with carbon capture and sequestration. The retrofitting would occur from 2015 through 2045. *1557 MMTC emissions through 2100.*
- Increasing efficiency and biofuels use for cars and trucks and transitioning to fuel cell/hydrogen vehicles from 2065 through 2085. *1662 MMTC emissions through 2100.*
- Increasing efficiency for residential, commercial, and industrial natural gas usage, beginning a phase-in of hy-thene starting in 2031, and transitioning to hydrogen fuel starting in 2060. *1,340 MMTC emissions through 2100.*



SOURCES: U.S. Department of Energy, Electric Power Research Institute, Ohio Environmental Council

Figure 8



SOURCES: U.S. Department of Energy, Electric Power Research Institute, Ohio Environmental Council

Figure 9

SECTION 3: POLICY AND MARKET ACTIONS

The Ohio Environmental Council is using several factors to evaluate policy and market measures including:

- direct impact on emissions
- ability to leverage deep reduction technologies down the road
- technical issues
- legal and regulatory issues
- costs

While this section provides an overview, the results of the evaluations and details of the measures are documented in **Part 2**, to be released in fall 2005.

Policy and Market Opportunities

The OEC is using the following principals to guide the evaluation of measures:

- **Address all emissions.** While climate stabilization cannot occur without deep reductions in CO_2, the CO_2 reduction path will be significantly less challenging if we focus on all greenhouse gases and particles. In addition, reducing non-CO_2 emissions will provide cooling benefits within months or years as well as other environmental and public health benefits.
- **Make near-term reductions in CO_2.** The emissions reduction path for CO_2 over the next century will be the least challenging and most achievable if we begin to make near-term reductions in CO_2 and sequester a greater amount of carbon in soil and biomass as soon as possible.
- **Stay focused on the long-term goal**. Climate stabilization action can and should take advantage of near-term opportunities for emission reductions, but a focus must be maintained on investing in solutions that result in the long-term deep emission cuts.
- **Maximize economic potential.** A focus should always be maintained on minimizing cost and maximizing economic value of climate solutions.
- **Support innovative ìbreak outî technologies.** There are several potential “break out” technologies that might hold promise for revitalizing or developing new industry clusters for Ohio and should be considered for public and private investment.

Priority Areas for Policy and Market Action

Following are general areas of opportunity for policy and market action that Ohio should consider.

I. **Process Initiatives and Industry Incubation**. There are many actions industry and government could take to increase technological and industrial innovation and strengthen research and development efforts.

a. *Expansion and diversification of the Third Frontier Initiative.* While much of the initial impetus for the Third Frontier Initiative has been based on fuel cells, the initiative should broaden its focus and include other climate change solution technologies.

b. *Greenhouse Gas Emissions Registry.* Ohio should develop a statewide registry of Greenhouse Gases. This would not only provide better insight to emissions from Ohio, it would also help Ohio businesses apply voluntary reductions to future federal regulatory programs.

c. *Hydrogen-methane infrastructure research and development.* In order to make hydrogen practical in the long run, Ohio should expand focus on research and development of infrastructure for the use of hythene in Ohio’s existing natural gas distribution system.

d. *Improved coordination of government and industry research and development and investment activities.* Public and private research and development activities in Ohio, including Third Frontier, the Ohio Coal Development Office, the Midwestern Regional Carbon Sequestration Project, and potential private investment efforts should be more efficiently tracked and coordinated by state government.

e. *Initiate and/or participate in credit trading programs.* More companies, governments, and businesses in Ohio should participate in carbon credit trading programs, such as the Chicago Climate Exchange. Ohio should consider establishing a small-scale public greenhouse gas purchase program as an incentive for local near-term carbon reduction innovations.

II. **Clean Air Initiative**. Diesel particulate matter is a major source of air quality problems in Ohio, as well as a significant contributor to climate change. Ohio should launch a diesel cleanup initiative that reduces diesel emissions in general, and ensures that reduction of the elemental carbon portion of those emissions is a priority.

III. **Modernize the Electric System**. Ohio's electrical system is aging, and new investments should be focused on innovative technologies, rather than conventional solutions, that avoid large future emissions.

a. *Develop new low-carbon generation capacity.* Ohio should avoid the siting of new conventional coal-fired power plants and encourage the deployment of IGCC coal plants and renewable energy. Siting preferences, tax advantages, and government procurement initiatives should be considered for IGCC (with a preference for carbon management projects) and renewable energy. Ohio should consider how to cost-effectively phase out existing plants and replace them with newer technologies. Ohio should also consider promoting these innovative technologies by adopting strategies such as Pennsylvania's technology portfolio standard.

b. *Greater investment in cost-effective energy efficiency.* Ohio should address regulatory and market barriers that have held back greater use of combined heat and power (CHP). Small and midsized companies should consider pooling their potential interests to leverage the development of third party services to help develop CHP projects. Ohio should also consider building on existing or creating new efforts to promote efficiency by end-use electricity customers—including demand-side management programs, building code improvement and enforcement, and appliance standards.

IV. **Transition to New Travel and Freight Systems**. New fuels and engine advances will be required for travel and freight systems to meet a future low-carbon goal. While meeting the ultimate goal will be challenging, there are important near-term steps Ohio can take.

a. *Use of biofuels.* The State of Ohio has incentive programs already in place for ethanol, but those incentives should be tailored to more advanced biofuels and bio-products. Ohio should also consider minimum biofuel blending requirements for ethanol and biodiesel.

b. *Use of efficient vehicles.* The State of Ohio should gear government procurement toward purchasing the most fuel efficient vehicles. Ohio should also consider tax incentives and research and development investments to help Ohio's auto industry become manufacturers of newer engine technologies, including hybrid-electric vehicles and computer-aided combustion engines.

V. **Update Heating and Industrial Systems**. To meet stabilization targets, the natural gas sector must also be a focus.

a. *Increase end-use efficiency.* In addition to electric sector efficiency programs, Ohio should engage in similar efforts relating to natural gas use.

b. *Use of hy-thene.* Ohio should encourage the near-term exploration of low percentage hydrogen hy-thene use by creating tax incentives and funding technology development.

c. *Industrial-scale IGCC.* Ohio should encourage the development of industrial scale IGCC in order to help address carbon reduction from industrial coal use.

VI. **Reduce Methane Emissions.** The State of Ohio should develop incentive and technology development programs to reduce emissions from landfills, coal mines, feedlots, and wastewater treatment facilities.

a. *Methane trading program.* Ohio should consider establishing a statewide program for meeting methane reduction goals and trading methane credits. Ohio could also help by encouraging the participation of methane-emitting businesses and industries in U.S. EPA's Methane to Markets (M2M) program.

b. *Reduce emissions from landfills, feedlots, and coal mines.* Ohio should make methane reduction a priority in any technology portfolio program. Ohio should also encourage deployment of landfill gas use technologies and bio-digesters for feedlots and development of wastewater methane capture technologies.

VII. **Use Agricultural and Forestry Practices**

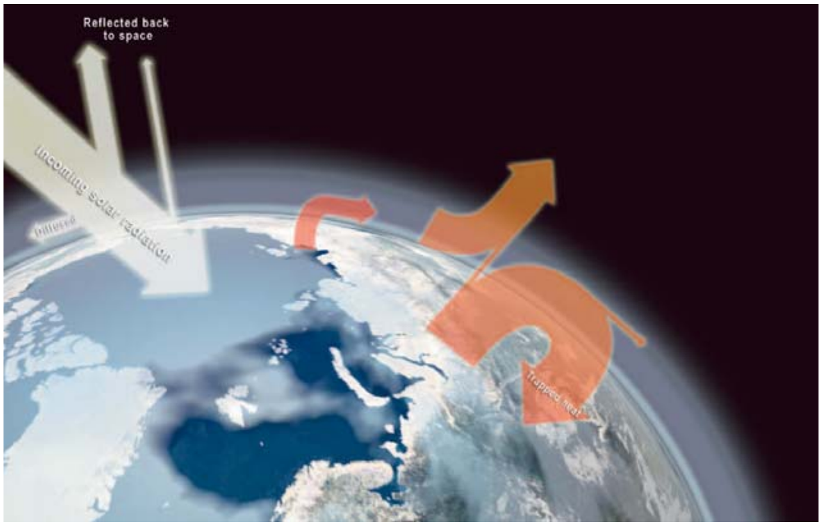
a. *Incentives for no-till farming.* Ohio should adopt tax incentives and crop insurance programs to encourage greater use of conservation tillage.

b. *Develop accounting system standards.* Ohio should work with the agricultural sector, the forestry industry, and non-governmental organizations to develop accounting and monitoring standards for carbon sequestration.

Summary

Ohio can help stabilize the climate by encouraging the development and deployment of innovative technological solutions to climate change dilemmas. Doing so will result in a reduction of greenhouse emissions in the near-term and a manageable goal for the long-term. States that act to address climate change will be the first to modernize their economies, products, and services while cleaning up the environment and improving public health. Taking action now will help lead us to a prosperous future and a stable climate for future generations. Delay or failure to act places both at risk.

APPENDIX I: EXPLANATION OF CLIMATE STABILIZATION TARGET LEVELS



Most of the heat energy emitted from the surface of the Earth is absorbed by greenhouse gases which then radiate the heat back down to warm the lower atmosphere and the planet's surface. Increasing the concentrations of greenhouse gases enhances surface warming, resulting in even less heat energy being released into space.

The climate stabilization goal is aimed at limiting temperature growth over the next century to no more than 1°C from current levels, which means:

- Limiting climate forcing to no more than 1.5 watts per square meter (W/m^2) over the next century.
- Limiting the growth in atmospheric CO_2 to between 450 ppm and 550 ppm over the next century–depending on the extent by which other non-CO_2 global warming agents (such as methane, black carbon, and nitrous oxide) are reduced.
- Developed countries, like the U.S., and states, like Ohio, must reduce CO_2 emissions from 65% to 95% over the next century, again depending on how other non-CO_2 global warming pollution is reduced.

Stabilizing the climate–limiting the increase in global temperature to no more than 1°C from current levels.

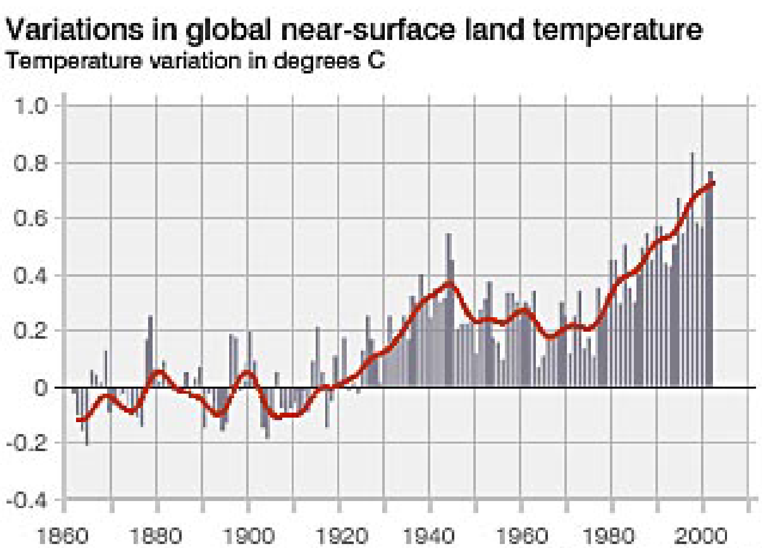


Chart 2.

Stabilizing the climate means reducing emissions of greenhouse gases and aerosols that alter the energy balance of the planet. Human activity is adding energy to our climate system and increasing global temperatures. The Earth's temperature has increased by approximately 0.5°C in the last century and approximately 0.7°C from pre-industrial levels.[8]

Goal: Recommendations from leading climate scientists in the U.S. and elsewhere focus on limiting the global average temperature increase to 1°C over the next century.[9] This is based on avoiding major climate shifts, such as glacial and polar ice sheet melting, as discussed in Appendix III.

Limiting temperature means limiting "climate forcing"

Climate forcing, or radiative forcing, is a natural or man-made variation in the Earth's energy balance with space or, alternately stated, an increase or decrease of energy in the Earth's climate system. There are several sources of radiative forcing, including gases such as methane and carbon dioxide, particles such as elemental (black) carbon and sulfates, and variations in solar radiation. Forcing is measured in watts per meter squared (W/m^2), which quantifies the change in energy caused by a change in the atmosphere, such as increased concentrations in CO_2 or other forcing agents. It is commonly used to compare one climate forcer to another. CO_2 emissions have added 1.46 W/m^2 in positive radiative forcing (warming) to our atmospheric system over the last 150 years.[10]

A Christmas light for every square meter on the Earth describes the energy in 1 watt per meter squared (W/m^2)ñthe unit that climate scientists use to measure the energy changes in the Earthís atmosphere from gases, aerosols, land changes, and solar radiation.

Currently, there is an estimated 0.5 W/m^2 to 1 W/m^2 of climate forcing "in the pipeline".[11] This is because there is a lag between emissions and increased temperatures due to the way that oceans store heat on our planet. Another future climate forcing agent that must be accounted for is sulfur dioxide. Sulfur dioxide is a major component of fine particulate pollution (ammonium sulfate) that contributes to thousands of preventable deaths each year; however, it also exerts a cooling effect on global temperature levels. Sulfur dioxide emissions will be significantly reduced in the U.S. and European Union over the coming decades, but will continue to be emitted from many other regions around the globe. Some estimates suggest that eliminating all sulfur dioxide emissions could increase temperatures by 0.7 °C.[12] If the magnitude of that effect is correct, the targets set in this report would need to be amended.

Goal: In order to limit an increase in global temperature to 1 °C, we need to limit additional climate forcing (beyond what is already estimated "in the pipeline") to 1 W/m^2 at most.[13]

Concentrations of pollution create climate forcing

Man-made climate forcing is the result of increasing the concentrations of gases and particles in the atmosphere. For example, in 2003, the concentration of CO_2 in our atmosphere was 379 ppm. If the CO_2 concentration were to increase to 450 ppm, that would add 0.93 W/m^2 of forcing to the atmosphere. If the CO_2 concentration were to increase to 550 ppm, that would add 2 W/m^2 to the atmosphere.[14] Likewise, if methane were to increase from current atmospheric concentrations of 1,755 parts per billion (ppb) to 3,140 ppb, that would add an additional forcing of 0.5 w/m^2. Reducing atmospheric concentrations has a negative climate forcing impact. For example, reducing methane concentrations from today's levels of 1,755 ppb to 1,215 ppb would result in -0.35 W/m^2 of negative forcing.[15]

Goal: In order to meet the climate forcing goal of 1 W/m^2, target levels must be set for greenhouse gases and particles. In this report we describe the two ends of a spectrum of choices:

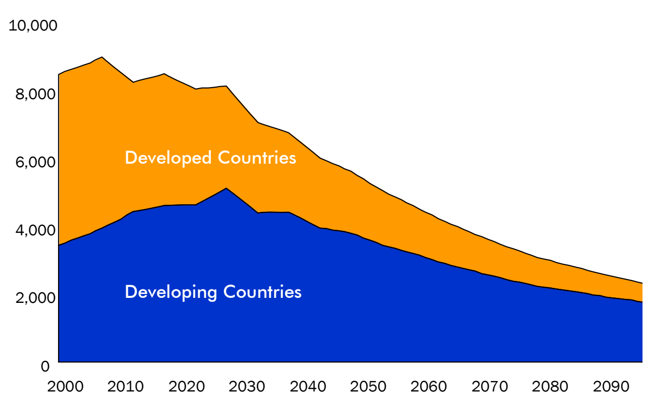
- Case one is the most restrictive for carbon dioxide, limiting its growth to an atmospheric concentration of no greater than 450 ppm and holding other GHG's constant. This would result in a 0.93 w/m^2 increase in forcing over the next hundred years, matching the goal level.

- Case two is the least restrictive on carbon dioxide, limiting CO_2 growth to an atmospheric concentration of no more than 550 ppm, or an increase of 2 W/m^2. In order to counteract the greater CO_2 forcing, concentrations of other greenhouse gases and particles will have to be reduced by 1 w/m^2. The specific reductions needed to hit a 550 ppm target level will be described in the next subsection.

Cutting pollution emissions in order to meet the concentration targets

The concentration of pollution in the atmosphere is determined by annual emissions. Below, we describe the reduction levels needed to achieve the target concentration levels used in this report and the resulting climate forcing and temperature goals.

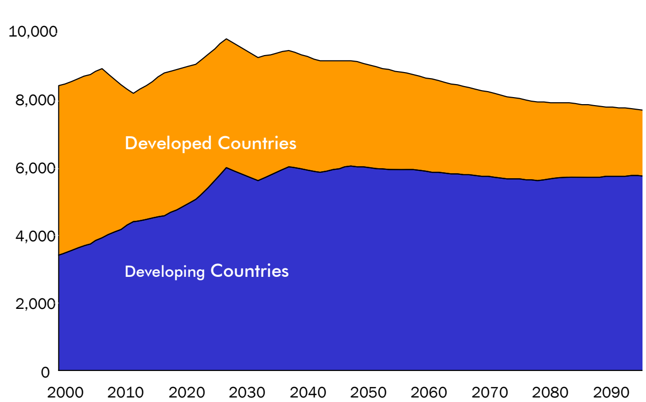
Global CO_2 Reduction Path for Climate Stabiliza with a 450 ppm Concentration Target



SOURCE: O'Neil

Figure 10

Global CO_2 Reduction Path for Climate Stabiliza with a 550 ppm Concentration Target



SOURCE: O'Neil

Figure 11

Carbon dioxide

Once CO_2 is emitted, a portion of it remains in the atmosphere for over a century. This persistence limits the amount of additional CO_2 that can be added to the atmosphere if target concentration levels are to be met.

Goal: In order the meet the CO_2 atmospheric concentration goal of 450 ppm to 550 ppm, economically developed countries, such as the U.S., must reduce CO_2 emissions between 65% (to meet a 550 ppm goal) to 95% (to meet a 450 ppm goal) over the next century.

Figure 10 shows a global reduction pathway that would meet a 450 ppm goal.[16] Under this pathway, global CO_2 emissions are reduced 75% by 2100. It shows two separate pathways for developed and developing countries, with both sets of countries having similar per capita carbon emissions by the end of the century. In this case, developed countries reduce their CO_2 emissions by 95%. Developing countries reduce their level of CO_2 emissions by 50%, based on their year 2000 emissions levels and after a period of growth concluding in 2030.

Figure 11 shows a global reduction pathway that is needed to meet 550 ppm.[17] In this case, global CO_2 emissions are reduced only 10% from 2000 levels by the year 2100. Developed countries reduce their 2000 level CO_2 emissions 65% by 2100. Developing countries are able to increase their 2000 level CO_2 emissions by 168% by 2100. In this case as in the previous one, both sets of countries have similar per capita CO_2 emissions by 2100.

Other Climate Forcers

Goal: In order to allow an increase to 550 ppm, other GHG's must be reduced to a level that produces a -1 w/m^2 climate forcing. For this report, we identified reductions that would meet Ohio's share of this -1 w/m^2 target.

- **Methane.** A 70% reduction in methane emissions from year 2000 levels will result in an estimated 0.54 w/m^2 forcing reduction. In addition, reducing methane emissions creates additional cooling effects (40% more cooling) due to methane's impacts on stratospheric water and ground level ozone. The total cooling effect from this reduction is -0.75 W/m^2. [18]
- **Nitrous oxide.** A 12% reduction of nitrous oxide will produce a - 0.075 w/m^2 climate forcing.[19]
- **Black Carbon.** A 90% reduction in black carbon from diesel will produce a -0.162 w/m^2 climate forcing.[20]
- **Hydroflorocarbons.** Emissions from the most potent climate forcing agents (such as chlorofluorocarbons) have been virtually eliminated due to the Montréal Protocol. However, other related compounds, such as hydroflorocarbons, need to be addressed as well. Current trends indicate a range from +0.25 W/m^2 to -0.25 W/m^2 in climate forcing impacts from these pollutants.[21]

Appendix II: Methods for Analyzing Technological Solutions

The explanations below provide the basis for the graphs and discussions in Section 2: Technological Solutions and Effectiveness.

Electric Sector

- **Renewable energy.** This pathway assumes that 10% of coal-generated electricity would use biomass (2,300 megawatts) and that 2,000 megawatts (MW) of wind power would be built by the year 2020. It also includes much smaller portions of electricity being generated by landfill methane (250 MW), photovoltaic power (81 MW), and hydroelectric power (46 MW). Currently, Ohio's total generation capacity is 30,000 MW. This analysis assumes that all renewable energy sources (including biomass) have zero carbon dioxide emissions. Once the system reaches 4,677 MW in 2020, the analysis assumes that the renewable energy capacity grows at the same rate as the general system. All the renewable energy levels (except wind power) are based on an Environmental Law and Policy Center analysis of renewable energy capacity in the Midwest.[22] The wind power assumptions were modified based on an Ohio Department of Development analysis of potential locations for wind power development.[23]

- **Combined Heat and Power (CHP)**. This pathway assumes that Ohio reaches its technical potential (10,000 MW) for use of combined heat and power technology.[24] Combined heat and power utilizes steam generated for industrial and commercial purposes to generate electricity as well. This analysis assumes that there is no new increase in emissions as a result of switching generation to CHP and, therefore, any megawatt of generation moved from the general power system to CHP results in a 100% reduction in carbon dioxide emissions per megawatt. Once the system reaches the 10,000 MW level in 2020, it assumes that the CHP capacity grows at the same rate as the general system.

- **Energy efficiency.** This pathway assumes that a 1% reduction in the projected growth of electricity demand occurs each year. Recent analyses of efficiency programs in New England states indicate that the most effective state programs can achieve a 1% annual growth reduction by reducing end-use demand.[25] While it is uncertain whether or not this level of effectiveness could continue at the same level throughout the century, the analyses demonstrate the effectiveness of a sustained effort to improve efficiency and the need to draw power from base load generation.

- **Integration Gasification Combined Cycle (IGCC) with geologic sequestration**. This pathway assumes that the electric sector begins retrofitting conventional coal and gas plants to IGCC with geologic carbon sequestration starting in 2015 and lasting until 2045. Unit turnover occurs at a rate of 3.6% per year and is based on the rate of construction of Ohio's current coal power plants. It is assumed, based on estimates by the U.S. Department of Energy and technology vendors, that 90% of the emissions will be sequestered geologically. The process of geologic sequestration is explained more fully on page 31.

- **Coal/biomass IGCC**. This case assumes "co-gasifying" 15% biomass with coal. Once the coal/biomass IGCC power generation system completely replaces the current coal plants (by 2045), emissions from the electric sector are negative, because of the carbon sequestered from gasifying biomass. As in the original renewable energy case, the use of biomass for electric power generation is assumed to have produced zero carbon emissions before capture and sequestration.

Transportation Sector

- **Efficiency and biofuels**. This path assumes that a combination of hybrid electric technology with other vehicle efficiency improvements could result in a 50% reduction of annual projected greenhouse gas emissions from light duty vehicles. Heavy duty diesel vehicles achieve a 35% reduction in greenhouse gas emissions from annual projections by adopting homogenous charge compression ignition (HCCI) and other technology improvements. Both technologies are assumed to be phased in over a 25 year period, starting in 2010. A 10% cellulosic ethanol blend is assumed to be the maximum percentage of biofuels that can displace fossil fuel use by the light duty fleet. Biofuel use begins in 2010.[26]

- **Transitioning to hydrogen/fuel cells**. This path assumes that all vehicles transition to some form of hydrogen fuel–either fuel cells or combustion—and that this takes place over a twenty year period from 2035 to 2055. No assumptions were made concerning the time necessary for infrastructure development. The thirty year turnover period is based on the average useful life of longer lived vehicles, such as heavy duty vehicles or planes. The hydrogen is assumed to come from IGCC coal facilities that capture and sequester carbon (assumes 90% emissions reduction). This case is meant to be purely illustrative and makes no claims about the viability of such a path.

Thermal/Industrial Sector

- **Increased efficiency**. This path assumes that efficiency measures for commercial and residential natural gas can reduce annual growth by 0.43% residentially and 0.48% industrially.[27] As with the electric sector, it is uncertain that this effort could be sustained over a century, but it was projected out to 2100 to evaluate the potential magnitude of reductions.
- **Hy-thene/IGCC**. This path assumes hydrogen is gradually blended with natural gas (up to a 50% mix) from 2015 to 2035. It also assumes that industrial coal boilers, as well as coal and coke technologies transition to advanced gasification technologies with carbon sequestration from 2020 through 2055.[28]
- **Transitioning to fuel cells**. The assumptions of this path are similar to those of vehicle hydrogen. All sources would transition to some form of hydrogen fuel–either fuel cells or combustion—over a twenty year period. Again, no assumptions were made concerning the time necessary for infrastructure development. The hydrogen is assumed to come from IGCC coal facilities that capture and sequester carbon (assumes 90% emissions reduction). As with vehicle, the path here is meant to be purely illustrative and does not reflect any assumptions about the ease or difficulty of this path.

Biologic Sequestration

- **No till farming** *(Potential: 71 MMTC).* No till farming primarily was developed for soil conservation. The practice has several environmental benefits. Because the soil remains covered with vegetation and is not aerated through tillage, soil is conserved, nutrient runoff to rivers and streams is reduced, and the carbon content in the soil is increased and maintained (for the time that the no till method is applied). No till farming can help maintain healthy topsoil, improve water quality, and stabilize global temperatures. According to recent research from the Ohio State University,[29] switching from conventional tillage to no till farming in Ohio could sequester 71 MMTC over a 25-year period, or an average of 2.84 MMTC per year.
- **Grassland development** *(Potential: not yet measured).* Grassland can be used as a buffer between a farm field and a stream in order to reduce nutrient and pesticide runoff. It also has the potential to store high amounts of carbon as well. According to Canada's Resource Efficient Agricultural Production (REAP) organization, willow and switch grass may have greater carbon sequestration potential than conventional crops, such as corn. While a total potential has not yet been calculated for Ohio, this could increase the carbon storage potential from agricultural fields.
- **Forest growth and sustainable forestry practices** *(Potential: 175 MMTC).* Estimates from the U.S. Forest Service show that, between 1987 and 1997, Ohio forests sequestered 70 MMTC—an annual rate of 7 MMTC.[30] This net sequestration activity was the result of new forest growth, often on fallow agricultural lands, and from the maturing of existing forestland. The research indicates that, as

long as the loss of forestlands does not increase relative to new forest growth, maturing forests will be able to maintain a 7 MMTC rate of sequestration for decades. Carbon sequestration levels are particularly high in young forests, namely those growing on agricultural lands. Research from the U.S. Forest Service's lab in Irvine, Pennsylvania also indicates that sustainable management practices aimed at maximizing growth of saw timber over the long-term could increase carbon sequestration activity in forest land.

Geologic Sequestration

- **Coal formations** *(Potential: 942+ MMTC).* Coal seams contain pockets of methane that can be displaced by carbon dioxide–which adsorbs twice as strongly to coal as methane. The Ohio Geologic Survey has estimated the sequestration potential for five of Ohio's 20 coal beds. The portion of these beds that cannot be mined could sequester 942 MMTC.
- **Oil and gas fields** *(Potential: 484 MMTC).* Currently, production from an oil or gas field can be enhanced by pumping carbon dioxide into the oil or gas reservoir. Once in the reservoir, the integrity of the carbon dioxide can be maintained, as long as the pressure in the reservoir remains the same. Typically, the carbon dioxide used in this technique is pumped and piped from natural geologic carbon dioxide reservoirs, but could easily come from captured carbon dioxide in conjunction with gasified coal or reformed natural gas. The Ohio Geologic Survey has estimated oil and gas reservoirs in Ohio could sequester 484 MMTC of carbon dioxide.
- **Saline aquifers** *(Potential: 488+ MMTC).* Saline aquifers, or deep saltwater aquifers, represent the largest potential for geologic sequestration. The carbon dioxide is pumped under several layers of bedrock or "cap rock" and, over centuries, transforms from a gas to a mineral (calcium carbonate). The Ohio Geologic Survey has analyzed three of Ohio's seven saline aquifers and estimated that the aquifers could sequester 488 MMTC.
- **Mineralization** *(Potential: unknown, possibly unlimited).* While currently expensive and technically difficult, CO2 can be turned into an inert mineral and stored as rock. However, innovative companies, such as Applied Sciences, Inc., are developing processes to turn the carbon dioxide created during fossil fuel gasification into useable products, such as the carbon nano-fibers used in the ship building, automotive, and aerospace industries.

APPENDIX III: POTENTIAL CLIMATE IMPACTS FROM HUMAN INTERFERENCE

The United Nations Framework Convention on Climate Change (UNFCCC), of which the U.S. is a signatory, contains the concept of preventing "dangerous anthropogenic interference" or DAI. Many climate stabilization target levels are anchored by this concept.

While DAI has not been explicitly defined, there are three broad impacts that climate researchers describe to cover the meaning of the phrase. These are:

- Large climate system disruptions which are non-linear and potentially catastrophic and where changes may not be reversible, such as ice sheet disintegration and changes in ocean circulation.
- Loss of ecosystems, such as the widespread bleaching of coral reefs.
- Direct effects on human society, such as loss of water resources and severely diminished agricultural productivity.

Thus, there are no single DAI or a consensus as to unacceptable climate impacts *that can be avoided.* Should a consensus emerge, it will more likely occur in the political rather than the scientific arena.

The European Union has adopted a non-binding temperature target of 2 °C above pre-industrial temperatures–or slightly more than 1 ° C from current temperatures. "The (European) Council…acknowledges that to meet the ultimate objective of the UNFCCC to prevent dangerous anthropogenic interference with the climate system, overall global temperature increase should not exceed 2ºC above pre-industrial levels (*emphasis added*);…"[31] This target limit on temperature increase was chosen because the highest estimated temperature range in the last several hundred thousand years was 1.5 °C above the pre-industrial global mean temperature. Therefore, intolerable changes in the composition and functioning of today's ecosystems could not be ruled out if the global mean temperature exceeded 2 °C.

The Quori Kalis glacier, Peruvian Andes. Top, a 1978 view. Bottom, the same location as seen in 2000. Ohio State University image.

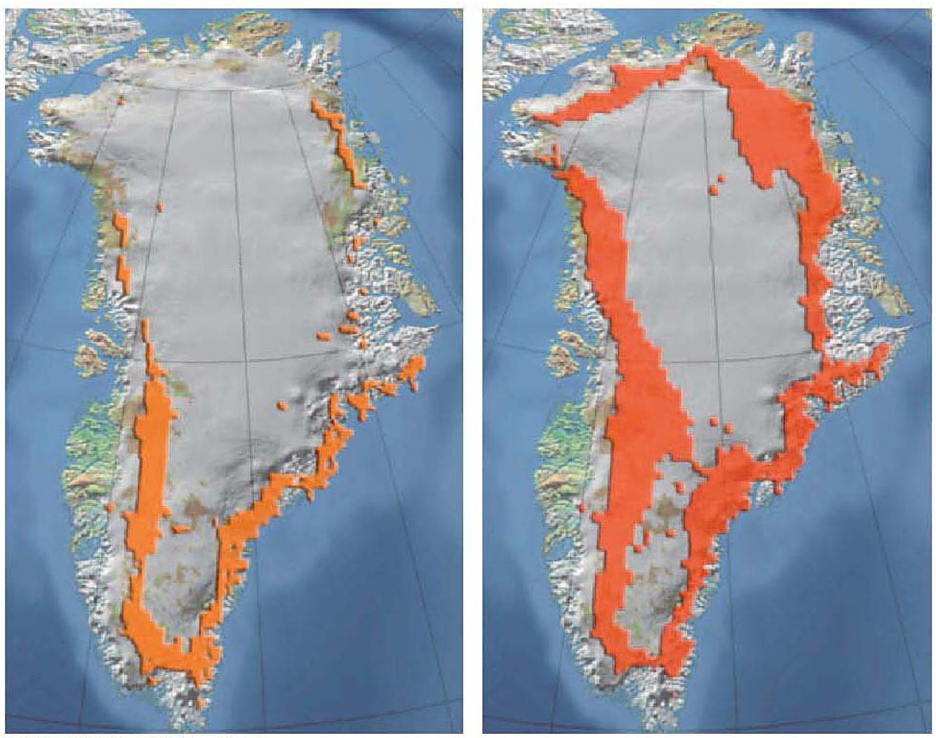
James Hansen of NASA's Goddard Institute for Space Studies (GISS), one of the United States' leading climatologists, asserts that the "level of dangerous anthropogenic influence is likely to be set by the global temperature and planetary radiation imbalance at which substantial deglaciation becomes practically impossible to avoid." The consequence of deglaciation is significant sea level rise which will inundate global coastlines, perhaps beginning over the next several decades.[32] This deglaciation could be initiated at 1 °C above current temperatures.

Sea level rise is one of many issues resulting from warming temperatures. The following outlines just three of the impacts from warming that could directly or indirectly affect Ohioans.

Sea Level Rise

Historical data indicate that during an increase of 1°C from current temperatures would match the maximum climate forcing during the Eemian period (24,000 to 36,000 years ago) when sea level was 6 meters above current levels. Recent studies indicate a complete melting of the Greenland ice sheet could increase sea level 7 meters (about 23 feet). Additional studies using climate models predict that, if our global temperature increased 3°C over the next century and stayed at that level for the next thousand years, the ice sheets would melt completely.[33] In this case, the current climate models indicate less temperature sensitivity than historical estimates indicate. Part of this discrepancy may be due to recent studies which indicate that the ice melt process may have previously unknown feedback mechanisms which can increase melt rate and are not included in current climate models.

This concern is underscored by the recent Arctic Climate Impact Assessment issued by 30 governments, including the United States. The report found that seasonal surface melt on the Greenland ice sheet increased 16% between 1979 and 2002.[34]



©2004, ACIA/ Map ©Clifford Grabhorn

The melt zone, where summer warmth turns snow and ice around the edges of the ice sheet into slush and ponds of melt water, has been expanding inland and upland to record high elevations in recent years. In addition to contributing to global sea level rise, this process adds freshwater to the ocean, potentially impacting ocean circulation and thus regional climate.

It is uncertain how ice melt of this magnitude would affect the Great Lakes and waterways in Ohio. However, there are likely to be considerable national costs associated with adapting to impacts on coastal areas. The international costs are likely to be far greater given that the greatest impacts from sea level rise will be on the coastal and low lying areas where much of the world's population resides. A major disruption of international economy and interregional migration are possible consequences that would affect all regions of the globe–including Ohio.

Pressure on the Great Lakes Fresh Water Supply

While the direct impacts on the Great Lakes are less certain, fresh water supply in other regions of North America may be significantly affected–creating pressure for increased water use from the lakes. A recent study exploring the potential warming impacts to the Western U.S. found that additional warming of 1 to 2°C by mid-century would result in a large reduction of mountain snow pack and a commensurate reduction in natural water storage.[35] Under this scenario, the Colorado River Reservoir System will not be able to meet all the demands placed on it as reservoir levels will be reduced by over one-third and releases will be reduced by as much as 17%. The resulting hydropower generation reductions could be as high as 40%. All users of Colorado River hydroelectric power will be affected by lower reservoir levels and flows, with the greatest effects felt in the lower Basin states.

Past proposals have already been made to divert water from the Great Lakes to the Western U.S. or other areas.

- **North American Water and Power Alliance (NAWPA).** In 1964, a group of engineers from California developed a plan to move water from Alaska and the Pacific Northwest to the southwest. Under that plan, a massive lake— 500 miles long and 10 miles wide—would have been created in British Columbia and filled by diverting water from nearby rivers, as well as from a canal that would have started in Lake Michigan and crossed the Continental Divide.
- **Ogallala Aquifer.** In the 1980s, at the direction of the U.S. Congress, the U.S. Army Corps of Engineers suggested the diversion of water from the Great Lakes via the Mississippi River in order to compensate for the rapid depletion of the Ogallala aquifer in the high plains states.
- **Trading Coal Slurry for Fresh Great Lakes Water.** Also in the 1980's, a proposal was made by mining companies to build a pipeline from the Montana/Wyoming area to the Great Lakes region to pipe out coal slurry and bring in freshwater.

While these proposals were rejected, due to both cost and opposition from the Great Lakes governors, it is highly probable that these (and other) ideas could re-emerge as more pressure is placed on scarce western water resources.

Ecological Impacts

Ecosystems are the earliest indicators of climate change. A recent study by the Union of Concerned Scientists and the Ecological Society of America[36] outlined several potential ecological impacts that could occur as a result of increased warming. For example:

Great Lakes

- Declines in the duration of winter ice are expected to continue.
- The distribution of many fish and other organisms in lakes and streams will change. Cold-water species such as lake trout, brook trout, and whitefish and cool-water species such as northern pike and walleye are likely to decline in the southern parts of the region, while warm-water species such as smallmouth bass and bluegill are likely to expand northward.
- In all lakes, the duration of summer stratification will increase, adding to the risk of oxygen depletion and formation of deep-water "dead zones" for fish and other organisms.

Wetlands

- Changes in the timing and severity of flood pulses are likely to reduce safe breeding sites, especially for amphibians, migratory shorebirds, and waterfowl and may cause many northern migratory species such as Canada geese to winter further north.

Forests

- The distribution of forests is likely to change as warmer temperatures cause the extent of boreal forests to shrink and many forest species to move northward. The new forest composition will depend on the ability of individual species to colonize new sites and the presence of both geographic and human barriers to migration. Also, the geographic range of forest pest species such as the gypsy moth is likely to expand as temperatures warm and the distribution of food plants changes.

Bird Populations

- Long-distance migratory birds such as scarlet tanagers, warblers, thrushes, and flycatchers depend on trees and caterpillars for food. Especially for those migrants who time their migration by day length rather than by weather, food sources may be severely reduced when they arrive in the Great Lakes region.
- Resident birds such as northern cardinals, chickadees, and titmice might be able to begin breeding earlier and raise more broods each season. However, increasing populations of resident species could further reduce the food available for migratory songbirds that breed in the Great Lakes, ultimately reducing forest bird diversity in the region.

APPENDIX IV: COMMON QUESTIONS AND ANSWERS

How realistic is the movie *The Day After Tomorrow*, or the book *State of Fear*?

The Day After Tomorrow is a disaster film, and like all films of that genre, it mixes fact and fiction to tell a suspenseful story. For example, the sea level rise depicted in the movie is projected under certain temperature warming scenarios–but over a thousand years, not seven days. *State of Fear* attempts to stick closer to climate science, but includes many misunderstandings or misrepresentations of the science–many of which are addressed in the questions below.

How can there be global warming when there is cooling in the middle of the Antarctic?

Temperature change in the Earth's climate is observed by looking at global mean temperature changes over time. There certainly are examples of temperatures decreasing over time in various locations around the globe–however, the term "global warming" refers to the fact that the average global temperature is increasing. It should be noted that while there are examples of temperature dropping in the Antarctic, there are more places in the Antarctic where temperature is shown to be increasing.

Why do satellite measurements show that temperatures in the air above the Earthís surface are not rising as high or as fast as would be expected if warming was really occurring?

New light has been shed on the difference between surface and satellite temperatures, a discrepancy that has confounded climatologists and supported skeptics' views about climate. Scientists at the University of Washington, by solving the measurement puzzle, have corrected this long-standing problem. Measurements now show consistent and increasing temperature trends at the earth's surface and in the troposphere.[37]

Have there not been warmer periods in human history than we have experienced in recent decades?

The use of proxy indicators (tree rings, corals, ice cores, and lake sediments) to reconstruct climate supports the conclusion that the temperatures of the past 25 years have been higher than any time in the past 1,000 years and likely for the past 2,000 years.[38]

Can natural causes can be responsible for the warming we currently are experiencing?

There are several natural source of climate forcing:

- Variations in the Earth's rotation, or wobbling of the Earth's axis that occurs in roughly 20,000-year cycles, are associated with waxing and waning of ice sheets.
- Solar activity can have a powerful impact on temperature variability. The little ice age in 16th and 17th century Europe correlated with a period of low sunspot activity.
- Water vapor is probably the most important greenhouse gas, absorbing energy that would otherwise escape to space.
- Volcanoes release aerosols into the air that cool the planet for a year or more. In 1991, Mt. Pinatubo emitted 20 million tons of SO_2 and other aerosols, resulting in a temporary cooling during the early 1990s.
- Clouds reflect and shade the surface from solar radiation.

However, simulations of past and current climates show that the warmth of the past 25 years cannot be explained without factoring in human-generated emissions and other human activities (i.e. land use changes).[39]

Last winter was so cold—how can there be any global warming?

Global warming is ubiquitous, but day-to-day weather fluctuations can still be significant. Warming to date makes the probability of a warmer than "normal" season about 60%, rather than the 30% that prevailed from 1950 to 1980.[40]

Is the warming of the past century not just a natural rebound from the little ice age?

Any rebound from the European little ice age, which peaked between 1650 and 1750, would have been largely complete by the 20th century, and, were it not for human activities, we would now be heading toward a colder climate.[41]

Is human-made global warming not saving us from the next expected ice age?

Yes, but the gases that we have added to the atmosphere are already far more than needed for that purpose.[42]

Are there not some advantages to a little warming?

There could be localized benefits. For instance, some regions of the world could experience increased crop yields if adequate precipitation and water supply accompany higher temperatures, but there is no opportunity to fiddle with dials and controls—many more regions and ecosystems are projected to suffer at the hands of climate change than might benefit from it.

Is surface warming mainly not urban "heat island" effects near weather stations?

The greatest warming is found not in urban areas, but in remote regions such as central Asia and Alaska. The largest areas of surface warming are over the ocean, far from urban locations. [43]

Appendix V: Scientific Uncertainties About Climate Change

There are still many uncertainties in our understanding of our climate system. Three key areas are: the relative sensitivity of surface temperature change to climate forcing; the role that oceans play in "storing" heat that can later affect surface temperatures; and how our lack of knowledge affects the accuracy of climate modeling.

Climate Sensitivity: Will concentration targets equal temperature targets?

Climate sensitivity is the global mean surface temperature change that occurs in response to a doubling of CO_2 concentrations. Because climatologists are uncertain about how atmospheric concentrations (and climate forcing) affect temperature, they refer to possible future temperature growth in terms of ranges. The Intergovernmental Panel on Climate Change has estimated a range of 1.4 to 5.8°C increase due doubling of CO_2 concentrations, although others calculate a more likely range of 2.1 to 3.6°C, with a one in twenty chance of being above or below that level.[44]

The chart below indicates the risk of "overshooting" a temperature target based on a concentration target. It indicates that with a 450 ppm target, there is still a 65% chance the 2.0°C increase above pre-industrial levels will be exceeded.[45]

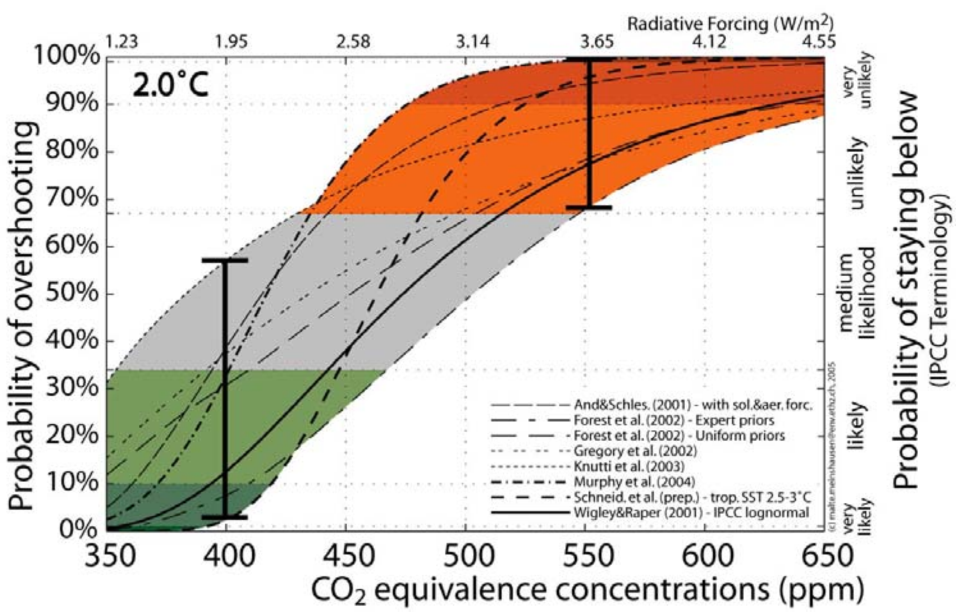


Chart 3. Meinshausen, 2005.

Ocean Temperature Lag

Since the late 1800s, there has been a total forcing of approximately 1.8 W/m^2. Nearly 1.0 W/m^2 can be accounted for by the 0.6 to 0.7°C observed temperature increase since 1880, but it is not enough to account for the total energy reaching the earth's surface. This means that surface temperatures have not fully responded to the forcing that has taken place to date; thus, there is an energy imbalance.

What has happened to the remaining 0.8 W/m^2? Some of the excess heat has melted snow and ice; however, most of this unrealized forcing has gone into heating the oceans as they have a much larger capacity for absorbing heat than land surfaces. Heat stored in the ocean is described as "warming in the pipeline", or heat that will make its presence felt at a future time as warmer oceans transfer their heat into the air. Based on the current imbalance, a surface temperature increase of 0.6 °C will still take place, even if current atmospheric conditions were held constant.[46] This imbalance means that the global temperature responds slowly to forcing agents, with much of the response lagging several decades behind the initial forcing.

There is uncertainty in understanding ocean temperature lag due to the fact that oceanic measurements do not have a long history. However, oceans have an advantage over land when predicting future temperatures since they are less affected by weather variations.

Climate modeling

Climate models, or General Circulation Models (GCMs), provide the "best-guess" picture of future climate impacts. Global climate models are computer simulations–in other words, they are represented by mathematical equations that are solved using a three-dimensional grid over the globe. These models include the major climate system components (such as atmosphere, oceans, land surface, snow, ice, and living things) and the processes that go on within and between them (such as water circulation, sea ice, and cloud formation). Because assumptions about these components differ among models, their use can yield different results.

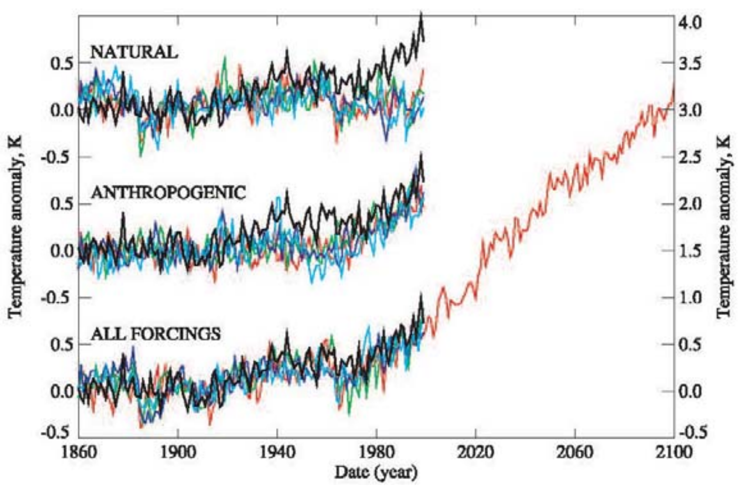


Chart 4. Stott et al., 2000.

The resolution (grid size) of global models is fairly coarse, meaning that there is generally higher confidence in larger scale (broad area) projections and greater uncertainty at smaller scales. For example, climate models are neither designed nor capable of predicting local weather.

Uncertainties in modeling include that we have only a short history of direct and reliable observations regarding the earth–about 150 years. In addition, there is much uncertainty about how other forcing affects climate, including the physics of water vapor and clouds and the distribution and role of aerosols.

However, there are several examples of how climate models have some predictive power. Early climate models accurately predicted the temperature impact (around 0.5 °C) of the Mount Pinatubo volcanic eruption prior to it being measured.[47]

The mid-Holocene age (6000 years ago) and Last Glacial Maximum (approximately 20,000 years ago) also appear consistent with the modeling understanding of climate. However, the current GCMs cannot reconstruct winters of the Eocene age, 55 to 36 million years ago. This was the last time in Earth's history when atmospheric CO_2 was above 500 ppm. There were palm trees and crocodiles in Wyoming, deep ocean temperature was 12.8 °C (today it is approximately 1.7 °C), and sea level was at least 300 feet higher than the current level.

The 20th century provides the best example of the predictive power of GCM models. If human generated effects are left out, the models fail to match the observed record. When they are included, the temperature changes match with the observed record.

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5. From Jacobson, [M.Z. Jacobson, *Control of fossil-fuel particulate black carbon and organic matter, possibly the most effective method of slowing global warming*, J. Geophys. Res., Vol. 107, No. D19, 4410, 2002, doi:10.1029/2001JD001376.] the North American black carbon effect on temperature is 0.0245°K. Assuming U.S. black carbon represents 90% of North America, then the U.S. black carbon temperature effect is 0.021°K. From Bond, [Bond et al., *A technology-based global inventory of black and organic carbon emissions from combustion*, J. Geophys. Res., Vol. 109, No. D14, 203, 2004, doi:10.1029/2003JD00369.] assuming diesel is 50% of U.S. black carbon, then temperature change from cutting all U.S. black carbon-diesel emissions is 0.0105°K. Assuming just a one-time Kyoto reduction for Annex I countries (2670 teragrams (Tg) CO_2 per year by 2010), Wigley [T.M.L. *Wigley, The Kyoto Protocol: CO_2, CH_4 and Climate implications*, GRL, Vol. 25 No. 13, 1998, pp. 2285-2288] calculates a 0.08°K cooling by 2100. Cutting all the black carbon from U.S. diesel would have 13% of the temperature value of all Kyoto reductions or the value of cutting 347 Tg of CO_2 by 2010. A cut of 7% of 1990 levels of U.S. CO_2 is 349 Tg. Note the temperature impact from black carbon reductions would be felt faster (one decade, not multiple decades) than the CO_2 reduction. In January 2004, Ohio's sales volumes of distillate fuel oil was 2.8% of the U.S. total (U.S.: 170,765.7 thousand gallons/day; Ohio: 4931.4 thousand gallons/day). Therefore, cutting all Ohio black carbon emissions from diesel would have a temperature impact of 0.00029°K. With Ohio's CO_2 emissions at 4.7% of total U.S. emissions, Ohio's contribution to the Kyoto Protocol would have been 16.4 Tg and would have achieved temperature improvement of 0.00048°K. A further calculation for McCain-Lieberman uses the projected, annual difference between 2005 and 2010 emissions in Ohio at 5.392 Tg CO_2. This would mean a temperature reduction of 0.00015626°K by 2100 and a 0.0000044°K improvement by 2010.

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