



## ICE - Antiderivatives and Change

**Figure 1<sup>1</sup> shows the deviation of average world temperature from the long-term average world temperature.**

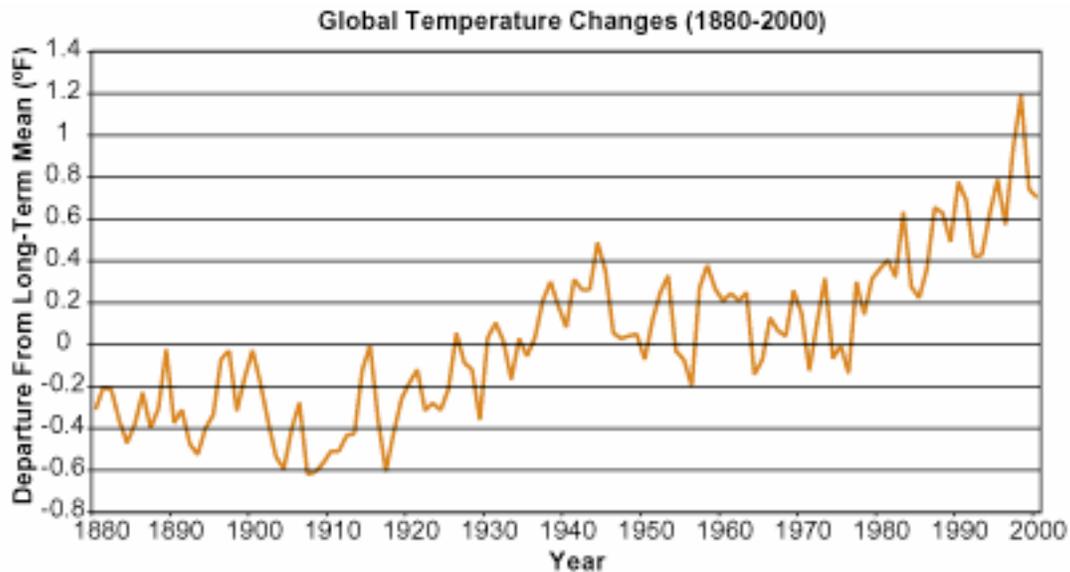


Figure 1: Global temperature changes plotted against time (1880-2000).

**Perhaps the trend most evident from Figure 1 is that since the mid-1970's, the average world temperature has been rising. In a press statement held on December 18, 2001, the World Meteorological Association<sup>2</sup> announced that 9 of the 10 warmest years on record<sup>3</sup> have occurred within the last ten years. According to the National Oceanic and Atmospheric Administration<sup>4</sup>:**

“Global surface temperatures have increased about 0.6°C (plus or minus 0.2°C) since the late-19th century, and about one half degree F (0.2 to 0.3°C) over the past 25 years (the period with the most credible data). The warming has not been globally uniform. Some areas (including parts of the southeastern U.S.) have cooled. The recent warmth has been greatest over North America and Eurasia between 40 and 70°N. Warming, assisted by the record El Niño of 1997-1998, has continued right up to the present.”

<sup>1</sup> Image source: <http://www.epa.gov/globalwarming/climate/index.htm>

<sup>2</sup> For the full text of the press release, see: <http://www.wmo.ch/index-en.html>

<sup>3</sup> The members of the World Meteorological Association have maintained meteorological records since 1860.

<sup>4</sup> <http://wf.ncdc.noaa.gov/oa/climate/globalwarming.html#Q9>

**Published research<sup>5</sup> has suggested that these warming trends are not likely to abate at any time in the near future. Statistical models suggest that in the next 100 years there is a 90% chance that the mean world temperature will rise at least 1.7°C and possibly as much as 4.9°C. (This is equivalent to a temperature rise of between 3.1 and 8.8°F.) The last time that the Earth experienced such a rapid change in average temperature was approximately 2.75 million years ago during the Pliocene epoch<sup>6</sup>**

**Although still somewhat controversial, the emerging consensus among many reputable scientists and scientific organizations is that human activities may play an important role in this global warming phenomenon<sup>7</sup>. The main form of human activity that is usually associated with global climate change is the creation and discharge of so-called<sup>8</sup> “greenhouse gases” into the atmosphere. Figure 2<sup>9</sup> shows a schematic representation of the “greenhouse effect.”**

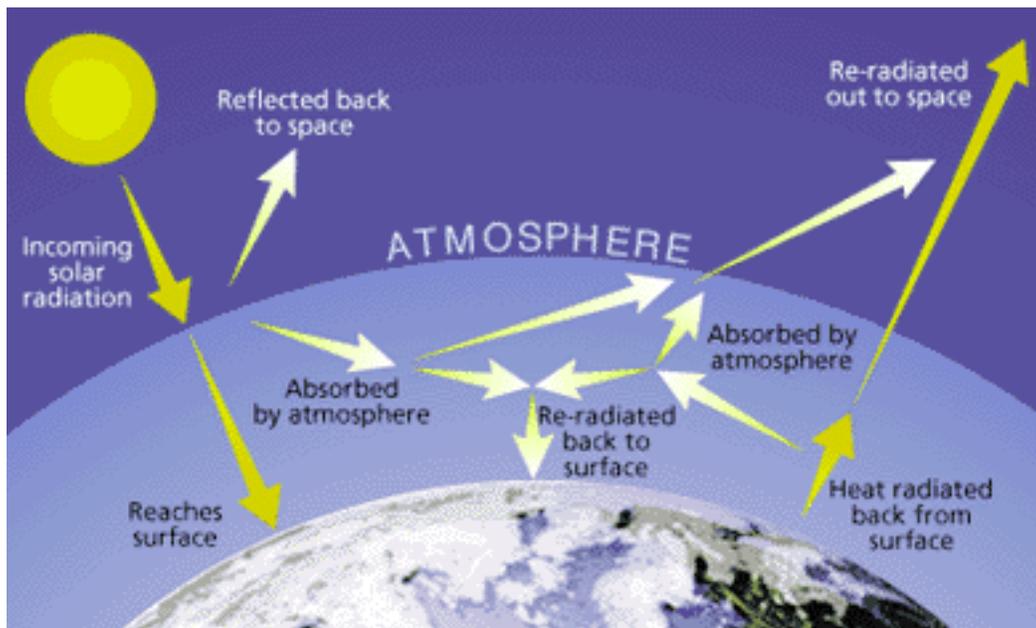


Figure 2: Schematic illustration of the “greenhouse effect.” That is, the tendency of some atmospheric gases to trap heat in the atmosphere, warming the surface of the earth.

<sup>5</sup> T.M.L. Wigley and S.C.B. Raper. (2001) “Interpretation of high predictions for global-mean warming.” *Science*: 293: 451-454.

<sup>6</sup> Source: <http://www.epa.gov/globalwarming/news/>

<sup>7</sup> For example, see: J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell and C.A. Johnson (eds.) *Climate Change 2001: The Scientific Basis*. Cambridge, England: Cambridge University Press, 2002.

<sup>8</sup> The molecular absorption spectra of the gases are just right for absorbing the high energy photons present in solar radiation, re-radiating this energy as photons in the infrared portion of the electromagnetic spectrum.

<sup>9</sup> Image source: <http://www.newscientist.com/hottopics/climate/climatefaq.htm>

**As the National Oceanic and Atmospheric Administration note<sup>10</sup>:**

“The greenhouse effect is unquestionably real, and is essential for life on Earth. It is the result of heat absorption by certain gases in the atmosphere (called greenhouse gases because they trap heat) and re-radiation downward of a part of that heat. Water vapor is the most important greenhouse gas, followed by carbon dioxide and other trace gases. Without a natural greenhouse effect, the temperature of the Earth would be about zero degrees F (-18°C) instead of its present 57°F (14°C). However, the concern is not with the fact that we have a greenhouse effect, but it is with the question regarding whether human activities are leading to an enhancement of the greenhouse effect.”

**The principal greenhouse gases are thought<sup>11</sup> to be:**

- Water vapor,
- Carbon dioxide (CO<sub>2</sub>),
- Methane (CH<sub>4</sub>),
- Ozone (O<sub>3</sub>),
- Nitrous oxide (N<sub>2</sub>O),
- Chlorofluorocarbons (CFCs),
- Hydrofluorocarbons (HFCs),
- Perfluorocarbons (PFCs), and,
- Sulfur hexafluoride (SF<sub>6</sub>).

**Reputable data<sup>12</sup> exists to suggest that human activities have changed the atmospheric concentrations of these gases (with the possible exception of water vapor). Although it might be reasonably expected that an increase of the concentration of these “greenhouse gases” in the atmosphere would lead to a rise in world temperature, there is no uncontroversial evidence to establish a link between global warming trends and the accumulation of “greenhouse gases” in the atmosphere as a result of human activity.**

**Despite the lack of a direct connection between global warming trends and human activity, reputable scientists<sup>13</sup> believe that human activities have contributed significantly to these trends – possibly in addition to natural factors such as natural climate variation, changes in the Sun’s energy and the cooling effects of some pollutants<sup>14</sup>.**

**In 1992, the United Nations proposed a Convention for Climate Change (UNFCCC)<sup>15</sup>. In the words of the United Nations, the UNFCCC is one of a**

---

<sup>10</sup> Source: <http://lwf.ncdc.noaa.gov/oa/climate/globalwarming.html#Q9>

<sup>11</sup> Source: Environment Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*. Washington, DC: National Center on Environmental Publications and Information.

<sup>12</sup> See, for example: Environment Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1999*. Washington, DC: National Center on Environmental Publications and Information.

<sup>13</sup> See, for example: A. Kirby. (2001) “Science academies back Kyoto.” *BBC News*, May 17, 2001.

<sup>14</sup> Source: <http://www.epa.gov/globalwarming/uncertainties.html>

<sup>15</sup> To read about this convention (or to read the full text of the convention) visit: <http://unfccc.int>.

***series of documents in which countries around the world are working together to meet ecological challenges. In the words of one introduction to the UNFCCC<sup>16</sup>***

“The 1990s have been a time of international soul-searching about the environment. What are we doing to our planet? More and more, we are realizing that the Industrial Revolution has changed forever the relationship between humanity and nature. There is real concern that by the middle or the end of the next century human activities will have changed the basic conditions that have allowed life to thrive on earth.

The 1992 United Nations Framework Convention on Climate Change is one of a series of recent agreements through which countries around the world are banding together to meet this challenge. Other treaties deal with such matters as pollution of the oceans, expanding deserts, damage to the ozone layer, and the rapid extinction of plant and animal species. The Climate Change Convention focuses on something particularly disturbing: we are changing the way energy from the sun interacts with and escapes from our planet's atmosphere. By doing that, we risk altering the global climate. Among the expected consequences are an increase in the average temperature of the earth's surface and shifts in world-wide weather patterns. Other -- unforeseen -- effects cannot be ruled out.”

***Although the UNFCCC has the signatures of over 200 countries, it was not well-known among the American public until June of 2001 when President Bush announced that the United States would not sign one part of the UNFCCC, which has become known as the Kyoto Protocol. The Kyoto Protocol was first formulated by world leaders in 1997 and called for the reduction in atmospheric concentrations of known greenhouse gases, and lay the financial burden of these reductions on industrialized nations. Among other objections<sup>17</sup>, President Bush specifically addressed this provision of the Kyoto Protocol when speaking at a press conference<sup>18</sup> on June 11, 2001:***

“Our country, the United States is the world's largest emitter of manmade greenhouse gases. We account for almost 20 percent of the world's man-made greenhouse emissions. We also account for about one-quarter of the world's economic output. We recognize the responsibility to reduce our emissions. We also recognize the other part of the story -- that the rest of the world emits 80 percent of all greenhouse gases. And many of those emissions come from developing countries.

This is a challenge that requires a 100 percent effort; ours, and the rest of the world's. The world's second-largest emitter of greenhouse gases is China. Yet, China was entirely exempted from the requirements of the Kyoto Protocol.

India and Germany are among the top emitters. Yet, India was also exempt from Kyoto. These and other developing countries that are experiencing rapid growth face challenges in reducing their emissions without harming their economies. We want to work cooperatively with these countries in their efforts to reduce greenhouse emissions and maintain economic growth.”

***Instead of signing the Kyoto Protocol, President Bush announced that the United States would:***

---

<sup>16</sup> Source: <http://unfccc.int/resource/beginner.html>

<sup>17</sup> President Bush's principal points were that no scientifically verifiable link between global warming and the accumulation of greenhouse gases from human activity existed, many countries would not be able to meet the emission-reduction targets specified in the protocol, and that the Kyoto protocol did not address important atmospheric pollutants such as particulate matter (e.g. black soot).

<sup>18</sup> Source: <http://www.whitehouse.gov/news/releases/2001/06/20010611-2.html>

The full text of President Bush's speech is included as an appendix to this ICE.

“...lead the way by advancing the science on climate change, advancing the technology to monitor and reduce greenhouse gases, and creating partnerships within our hemisphere and beyond to monitor and measure and mitigate emissions.”

***In this ICE, you will analyze some of the data that has been developed as part of President Bush’s plan to better understand the science of climate change.***

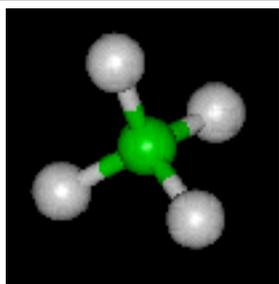


Figure 3: Molecular model of methane. One carbon atom is surrounded by four hydrogen atoms.

***By mass<sup>19</sup>, the second most important greenhouse gas generated by human activity (anthrogenic) is methane (CH<sub>4</sub>). Methane (CH<sub>4</sub>) is a simple hydrocarbon (see Figure 3<sup>20</sup> The capacity<sup>21</sup> of methane to trap heat in the atmosphere is about 21 times as great as carbon dioxide (the most important anthrogenic greenhouse gas by mass). University of Illinois professor of atmospheric sciences Dan Wuebbles estimates<sup>22</sup> that (if there is a link between global warming and anthrogenic greenhouse gases) that methane and other non-carbon dioxide bases may be responsible for as much as 40% of global climate change.***

***In addition, methane is a relatively short-lived greenhouse gas. Methane spends (on average) approximate 12 years in the atmosphere before being converted to some other chemical form (see Figure 4<sup>23</sup>). According to Atul Jain (an atmospheric scientist at the University of Illinois), reductions in methane emissions will result in much quicker reductions in atmospheric concentrations of CH<sub>4</sub>, compared with (say) carbon dioxide which spends anywhere from 50 to 200 years in the atmosphere before being “fixed” in a non-gaseous form.***

***Major source of anthrogenic methane are shown in Figure 5<sup>24</sup>. Most significant are methane emissions<sup>25</sup> from landfills (37%), the natural gas and oil industries (20%), enteric fermentation in the stomachs of***

<sup>19</sup> Source: Environmental Protection Agency. *U.S. Methane Emissions 1990-2020: Inventories, Projections and Opportunities for Reductions*. Washington, DC: National Center on Environmental Publications and Information.

<sup>20</sup> Image source: <http://www.nyu.edu/pages/mathmol/library/hydrocarbons/>

<sup>21</sup> This “capacity” is known as the *global warming potential* in scientific literature.

<sup>22</sup> Source: CNN. “Don’t forget methane, climate experts say.” *CNN*, November 10, 1999.

<sup>23</sup> Image source: [http://adaption.nrcan.gc.ca/posters/images/bc\\_03\\_03\\_e.jpg](http://adaption.nrcan.gc.ca/posters/images/bc_03_03_e.jpg)

<sup>24</sup> Image sources: <http://www.cnn.com> <http://www.epa.gov/> <http://www.hereford.ca> <http://www.utahhistorytogo.org/>

<sup>25</sup> The percentages quoted here were obtained from: Environmental Protection Agency. *U.S. Methane Emissions 1990-2020: Inventories, Projections, and Opportunities for Reductions*. Washington, DC: National Center on Environmental Publications and Information.

**domesticated animals (19%), coal mining (10%) and agricultural applications of natural fertilizer (10%).**

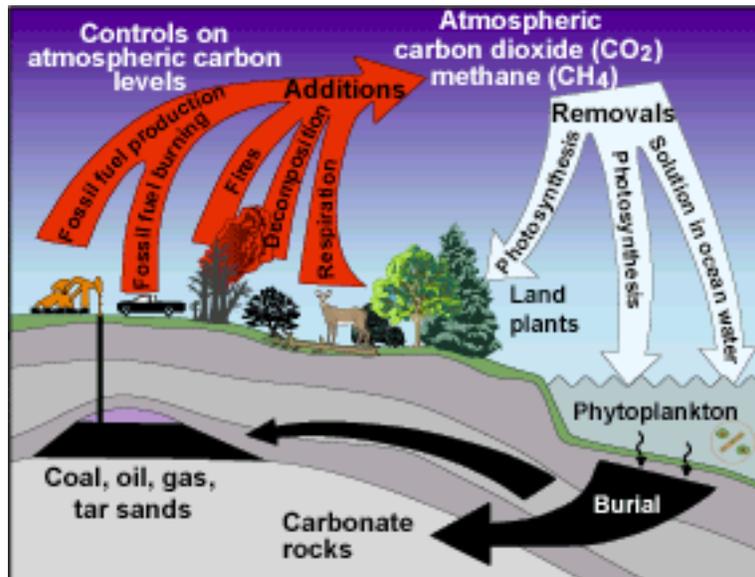


Figure 4: Schematic representation of carbon cycle.

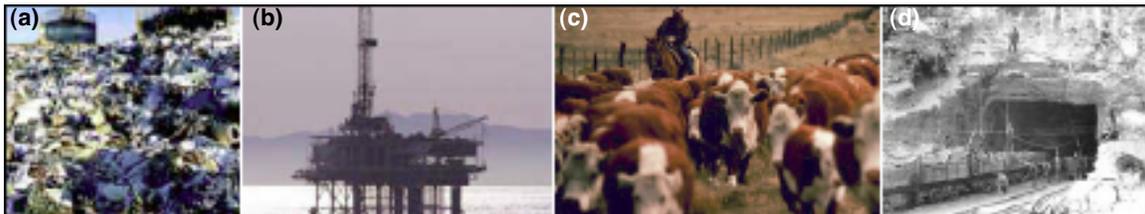


Figure 5: Major sources of anthropogenic methane. (a) Emissions from landfills. (b) Releases of natural gas from oil and gas installations. (c) Enteric fermentation of cellulose in herbivores. (d) Releases of subterranean gases from coal mining.

**The graph given on the next page (Figure 6) and the values given in Table 1 are estimates of the rate at which human activities have been producing methane on a global scale between 1860 and 1994<sup>26</sup>.**

**Guide to Abbreviations:**

MMTCE = millions of metric tons carbon equivalent.

TCE = metric tons carbon equivalent.

These measures of the emissions only take the mass of the carbon in the methane molecule (CH<sub>4</sub>) into account. The mass of the four hydrogen atoms are ignored. The reason for this is to make it easier to compare the emission levels of different carbon-based greenhouse gases.

<sup>26</sup> The data presented here are adapted from: D.I. Stern and R.K. Kaufman. (1998) "Annual estimates of global anthropogenic methane emissions: 1860-1994." In *Trends Outline: A Compendium of Data on Global Change*. Oak Ridge, TN: Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.

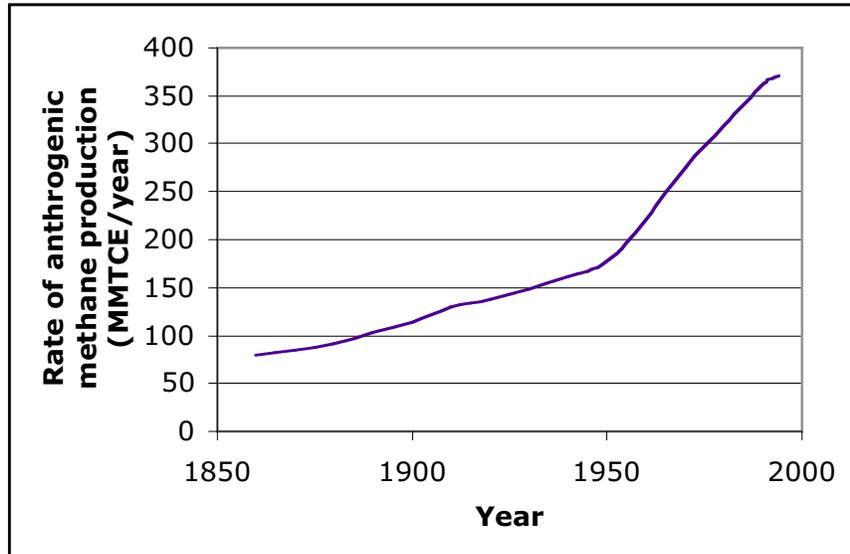


Figure 6: Rate of anthropogenic methane production, 1860-1994.

Year	Rate of anthropogenic Methane production (MMTCE/year)	Year	Rate of anthropogenic Methane production (MMTCE/year)
1860	79.3	1940	161.6
1870	84.6	1950	177.5
1880	92.0	1960	221.1
1890	102.9	1970	275.8
1900	114.2	1980	318.9
1910	129.7	1990	362.3
1920	137.3	1994	371.0
1930	148.9		

Table 1: Rate of anthropogenic methane production, 1860-1994.

- **What are the units of the area under the curve shown in Figure 6? What interpretation does this suggest for the area under the curve in Figure 6?**

**Let  $T$  represent the year, and  $m(T)$  represent the rate at which anthropogenic methane is released into the atmosphere.**

- **Create an expression (using integral notation) that represents the total amount (in MMTCE) of methane released into the atmosphere by human activities between 1860 and the present day.**

- **Based on the appearance of Figure 6, what sort of function would do a reasonable job of representing the rate at which anthropogenic methane is released into the atmosphere?**

- **Use your calculator and the data provided in Table 1 to create an equation for the rate function  $m(T)$ . record your rate function here.**

- **Show that:**

$$F(x) = \frac{A \cdot B^x}{\ln(B)} + C$$

**is an antiderivative of the function:**

$$f(x) = A \cdot B^x.$$

• **Find an antiderivative for the rate function  $m(T)$ . Record your antiderivative here.**

• **The Fundamental Theorem of Calculus provides a method for using antiderivatives to evaluate the area under a curve. Use the antiderivative that you have created to calculate the total amount of anthropogenic methane released into the atmosphere between 1860 and the present day.**

• **One of the points mentioned by University of Illinois researcher Dr. Atul Jain was that gaseous methane only spends about 12 years in the atmosphere before it is “fixed” in some non-gaseous form. Create an expression (using integral notation) for the amount of anthropogenic methane that is currently in the atmosphere, and use antiderivatives to evaluate the expression.**

## ***Appendix A: Full Text<sup>27</sup> of President Bush's Press Conference on Global Warming (June 11, 2001).***

THE PRESIDENT: Good morning. I've just met with senior members of my administration who are working to develop an effective and science-based approach to addressing the important issues of global climate change.

This is an issue that I know is very important to the nations of Europe, which I will be visiting for the first time as President. The earth's well-being is also an issue important to America. And it's an issue that should be important to every nation in every part of our world.

The issue of climate change respects no border. Its effects cannot be reined in by an army nor advanced by any ideology. Climate change, with its potential to impact every corner of the world, is an issue that must be addressed by the world.

The Kyoto Protocol was fatally flawed in fundamental ways. But the process used to bring nations together to discuss our joint response to climate change is an important one. That is why I am today committing the United States of America to work within the United Nations framework and elsewhere to develop with our friends and allies and nations throughout the world an effective and science-based response to the issue of global warming.

My Cabinet-level working group has met regularly for the last 10 weeks to review the most recent, most accurate, and most comprehensive science. They have heard from scientists offering a wide spectrum of views. They have reviewed the facts, and they have listened to many theories and suppositions. The working group asked the highly-respected National Academy of Sciences to provide us the most up-to-date information about what is known and about what is not known on the science of climate change.

First, we know the surface temperature of the earth is warming. It has risen by .6 degrees Celsius over the past 100 years. There was a warming trend from the 1890s to the 1940s. Cooling from the 1940s to the 1970s. And then sharply rising temperatures from the 1970s to today.

There is a natural greenhouse effect that contributes to warming. Greenhouse gases trap heat, and thus warm the earth because they prevent a significant proportion of infrared radiation from escaping into space. Concentration of greenhouse gases, especially CO<sub>2</sub>, have increased substantially since the beginning of the industrial revolution. And the National Academy of Sciences indicate that the increase is due in large part to human activity.

Yet, the Academy's report tells us that we do not know how much effect natural fluctuations in climate may have had on warming. We do not know how much our climate could, or will change in the future. We do not know how fast change will occur, or even how some of our actions could impact it.

For example, our useful efforts to reduce sulfur emissions may have actually increased warming, because sulfate particles reflect sunlight, bouncing it back into space. And, finally, no one can say with any certainty what constitutes a dangerous level of warming, and therefore what level must be avoided.

The policy challenge is to act in a serious and sensible way, given the limits of our knowledge. While scientific uncertainties remain, we can begin now to address the factors that contribute to climate change.

There are only two ways to stabilize concentration of greenhouse gases. One is to avoid emitting them in the first place; the other is to try to capture them after they're created. And there are problems with both approaches. We're making great progress through technology, but have not yet developed cost-effective ways to capture carbon emissions at their source; although there is some promising work that is being done.

---

<sup>27</sup> Source: <http://www.whitehouse.gov/news/releases/2001/06/20010611-2.html>

And a growing population requires more energy to heat and cool our homes, more gas to drive our cars. Even though we're making progress on conservation and energy efficiency and have significantly reduced the amount of carbon emissions per unit of GDP.

Our country, the United States is the world's largest emitter of manmade greenhouse gases. We account for almost 20 percent of the world's man-made greenhouse emissions. We also account for about one-quarter of the world's economic output. We recognize the responsibility to reduce our emissions. We also recognize the other part of the story -- that the rest of the world emits 80 percent of all greenhouse gases. And many of those emissions come from developing countries.

This is a challenge that requires a 100 percent effort; ours, and the rest of the world's. The world's second-largest emitter of greenhouse gases is China. Yet, China was entirely exempted from the requirements of the Kyoto Protocol.

India and Germany are among the top emitters. Yet, India was also exempt from Kyoto. These and other developing countries that are experiencing rapid growth face challenges in reducing their emissions without harming their economies. We want to work cooperatively with these countries in their efforts to reduce greenhouse emissions and maintain economic growth.

Kyoto also failed to address two major pollutants that have an impact on warming: black soot and tropospheric ozone. Both are proven health hazards. Reducing both would not only address climate change, but also dramatically improve people's health.

Kyoto is, in many ways, unrealistic. Many countries cannot meet their Kyoto targets. The targets themselves were arbitrary and not based upon science. For America, complying with those mandates would have a negative economic impact, with layoffs of workers and price increases for consumers. And when you evaluate all these flaws, most reasonable people will understand that it's not sound public policy.

That's why 95 members of the United States Senate expressed a reluctance to endorse such an approach. Yet, America's unwillingness to embrace a flawed treaty should not be read by our friends and allies as any abdication of responsibility. To the contrary, my administration is committed to a leadership role on the issue of climate change.

We recognize our responsibility and will meet it -- at home, in our hemisphere, and in the world. My Cabinet-level working group on climate change is recommending a number of initial steps, and will continue to work on additional ideas. The working group proposes the United States help lead the way by advancing the science on climate change, advancing the technology to monitor and reduce greenhouse gases, and creating partnerships within our hemisphere and beyond to monitor and measure and mitigate emissions.

I also call on Congress to work with my administration to achieve the significant emission reductions made possible by implementing the clean energy technologies proposed in our energy plan. Our working group study has made it clear that we need to know a lot more.

The U.N. Framework Convention on Climate Change commences to stabilizing concentrations at a level that will prevent dangerous human interference with the climate; but no one knows what that level is. The United States has spent \$18 billion on climate research since 1990 -- three times as much as any other country, and more than Japan and all 15 nations of the EU combined.

Today, I make our investment in science even greater. My administration will establish the U.S. Climate Change Research Initiative to study areas of uncertainty and identify priority areas where investments can make a difference.

I'm directing my Secretary of Commerce, working with other agencies, to set priorities for additional investments in climate change research, review such investments, and to improve coordination amongst

federal agencies. We will fully fund high-priority areas for climate change science over the next five years. We'll also provide resources to build climate observation systems in developing countries and encourage other developed nations to match our American commitment.

And we propose a joint venture with the EU, Japan and others to develop state-of-the-art climate modeling that will help us better understand the causes and impacts of climate change. America's the leader in technology and innovation. We all believe technology offers great promise to significantly reduce emissions – especially carbon capture, storage and sequestration technologies.

So we're creating the National Climate Change Technology Initiative to strengthen research at universities and national labs, to enhance partnerships in applied research, to develop improved technology for measuring and monitoring gross and net greenhouse gas emissions, and to fund demonstration projects for cutting-edge technologies, such as bioreactors and fuel cells.

Even with the best science, even with the best technology, we all know the United States cannot solve this global problem alone. We're building partnerships within the Western Hemisphere and with other like-minded countries. Last week, Secretary Powell signed a new CONCAUSA Declaration with the countries of Central America, calling for cooperative efforts on science research, monitoring and measuring of emissions, technology development, and investment in forest conservation.

We will work with the Inter-American Institute for Global Change Research and other institutions to better understand regional impacts of climate change. We will establish a partnership to monitor and mitigate emissions. And at home, I call on Congress to work with my administration on the initiatives to enhance conservation and energy efficiency outlined in my energy plan, to implement the increased use of renewables, natural gas and hydropower that are outlined in the plan, and to increase the generation of safe and clean nuclear power.

By increasing conservation and energy efficiency and aggressively using these clean energy technologies, we can reduce our greenhouse gas emissions by significant amounts in the coming years. We can make great progress in reducing emissions, and we will. Yet, even that isn't enough.

I've asked my advisors to consider approaches to reduce greenhouse gas emissions, including those that tap the power of markets, help realize the promise of technology and ensure the widest-possible global participation. As we analyze the possibilities, we will be guided by several basic principles. Our approach must be consistent with the long-term goal of stabilizing greenhouse gas concentrations in the atmosphere. Our actions should be measured as we learn more from science and build on it.

Our approach must be flexible to adjust to new information and take advantage of new technology. We must always act to ensure continued economic growth and prosperity for our citizens and for citizens throughout the world. We should pursue market-based incentives and spur technological innovation.

And, finally, our approach must be based on global participation, including that of developing countries whose net greenhouse gas emissions now exceed those in the developed countries.

I've asked Secretary Powell and Administrator Whitman to ensure they actively work with friends and allies to explore common approaches to climate change consistent with these principles. Each step we take will increase our knowledge. We will act, learn, and act again, adjusting our approaches as science advances and technology evolves.

Our administration will be creative. We're committed to protecting our environment and improving our economy, to acting at home and working in concert with the world. This is an administration that will make commitments we can keep, and keep the commitments that we make.

I look forward to continued discussions with our friends and allies about this important issue.

Thank you for coming.

## Appendix B: Collecting Data on Methane Emissions

You might assume that because the United States is one of the world's largest producers of greenhouse gases that the nation is likewise one of the greatest per-capita producers of greenhouse gases (that is, the quantity of greenhouse gas produced by every person in the country). However, reputable statistics exist<sup>28</sup> to suggest otherwise. The graph shown in Figure 7<sup>29</sup> shows that the per-capita greenhouse gas production of the United States has not risen appreciably since 1990.

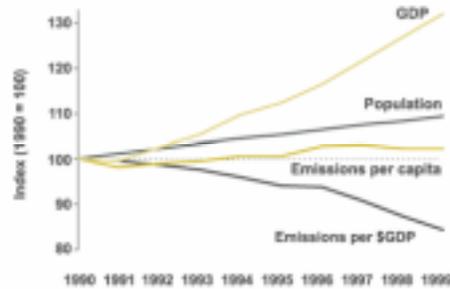


Figure 7: Per-capita greenhouse gas production for United States, 1990-2000.

According to *New Scientist* magazine<sup>30</sup>, the country with the highest per-capita production of greenhouse gases is Australia. The country with the highest per-capita production of the important greenhouse gas methane is the neighboring country of New Zealand<sup>31</sup> (see Figure 8<sup>32</sup>).

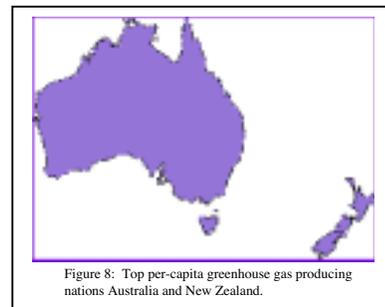


Figure 8: Top per-capita greenhouse gas producing nations Australia and New Zealand.



Figure 9: A sheep equipped with various monitoring devices to determine the amount of methane produced.

In the case of New Zealand, the most significant source of methane emissions is enteric fermentation of cellulose in the stomachs of domesticated herbivores such as sheep and cattle. (New Zealand has approximately 21 sheep and cattle for every person<sup>33</sup>.) Figure 9<sup>34</sup> shows part of the New Zealand Government's program of research to study the amount of methane produced due to fermentation of cellulose by herbivores.

<sup>28</sup> Source: Bureau of the Census, *Statistical Abstract of the United States*, 2000.

<sup>29</sup> Image source: <http://www.epa.gov/globalwarming/emissions/individual/index.html>

<sup>30</sup> See: N. Jones. (2001) "2001 set to be second warmest year on record." *New Scientist*, December 1, 2001. and D. Carrington. (2002) "Predicted global sea level rise swells." *New Scientist*, February 19, 2002.

<sup>31</sup> Source: <http://www.landcare.cri.nz/science/climate/climatechange/index.shtml?methane>

<sup>32</sup> Image source: <http://www.ti.com/australia/>

<sup>33</sup> Source: New Zealand High Commission, Ottawa, Canada. <http://www.nzhcottawa.org/>

<sup>34</sup> Image source: <http://www.landcare.cri.nz/science/climate/climatechange/index.shtml?methane>