

Homework Assignment 12: Due at the beginning of class 3/15/02

In this homework assignment, your ultimate objectives will be to:

- Use data from the EPA to create an equation to represent the marginal cost of reducing the levels of greenhouse gases (in particular, methane CH_4) in the atmosphere.
- Use antiderivatives and your marginal cost function to create a cost function.
- Use your cost function to calculate the actual cost of reducing the levels of methane.
- Estimate the cost of implementing the methane reduction portion of the global climate change plan announced by President Bush¹.

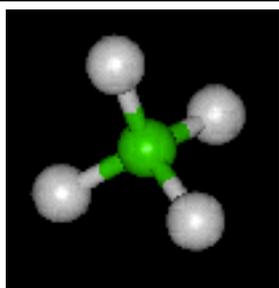


Figure 1: Molecular model of methane. One carbon atom is surrounded by four hydrogen atoms.

In this homework, you will study the costs involved in reducing emissions of the greenhouse gas methane (CH_4 , see Figure 1²).

If you are under a lot of time-pressure this week, skip to page 5 of this assignment.

Over the course of the last few decades, scientists have documented a world-wide rise in average temperatures. According to the National Oceanic and Atmospheric Administration (NOAA)³:

“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.”

Much public (and scientific) opinion suggests that the accumulation of man-made (or anthropogenic) “greenhouse gases” has contributed to this global warming trend in

¹ This refers to the speech given by President Bush at the National Oceanic and Atmospheric Administration on February 14, 2001. The full text of this speech is included as an appendix to this homework assignment.

² Image source: <http://www.nyu.edu/pages/mathmol/library/hydrocarbons/>

³ Source: <http://wf.ncdc.noaa.gov/oa/climate/globalwarming.html#Q9>

significant ways. The argument that is most commonly advanced to support this position⁴ goes like this:

- Certain gases (“greenhouse gases” such as water vapor, carbon dioxide and methane) are known to trap heat in the atmosphere (see Figure 2⁵).
- Since the middle of the 19th century, nations (especially industrial nations) have been releasing large volumes of these gases into the atmosphere.
- The earth is getting warmer.
- Therefore, the “greenhouse gases” must be contributing significantly to the warming of the earth.

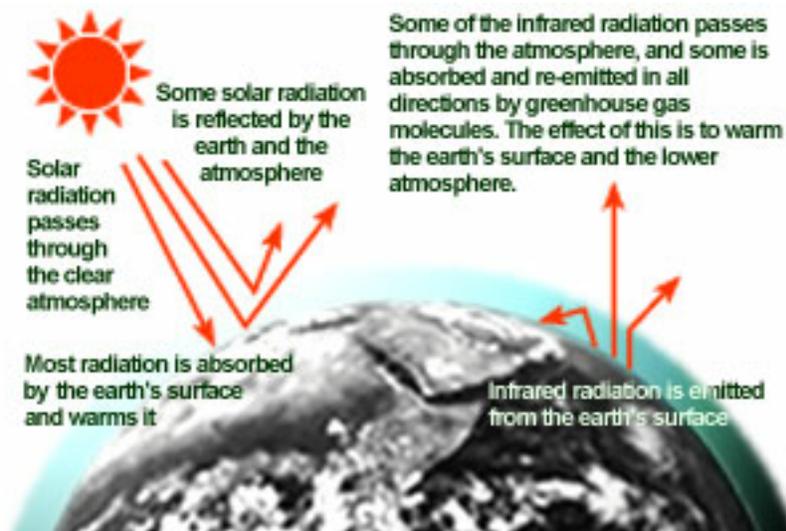


Figure 2: Schematic representation of the “Greenhouse Effect.” That is, the tendency of some atmospheric gases (such as water vapor, carbon dioxide and methane) to trap heat in the atmosphere.

As of the time of writing, however, there is no conclusive scientific evidence that proves that anthropogenic greenhouse gases have contributed significantly to global warming, although large numbers of reputable scientists believe that it is highly improbable that anthropogenic greenhouse gases have not contributed significantly to global warming⁶.

In 1992, the United Nations created the United Nations Framework Convention on Climate Change (UNFCCC)⁷. In the words of one commentary⁸ on the framework:

⁴ See, for example: 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.

⁵ Image source: <http://www.epa.gov/globalwarming/climate/index.html>

⁶ Source: 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.

⁷ You can view all of the official documents connected with UNFCCC at: <http://unfccc.int/>

⁸ Source: <http://unfccc.int/resource/beginner.html>

“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.”

In June, 2001, President Bush announced⁹ that the United States would not sign a major part of the Convention, the so-called Kyoto Protocol on Global Climate Change. Instead, President Bush announced that:

“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.”

⁹ You can find the full text of President Bush's speech at:
<http://www.whitehouse.gov/news/releases/2001/06/20010611-2.html>

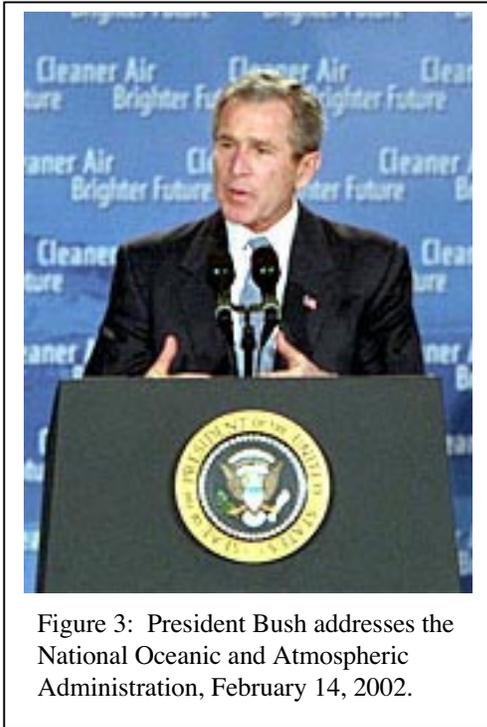


Figure 3: President Bush addresses the National Oceanic and Atmospheric Administration, February 14, 2002.

On February 14, 2002, President Bush addressed the National Oceanic and Atmospheric Administration (see Figure 3¹⁰). Some excerpts from President Bush’s speech are given below.

“America and the world share this common goal: we must foster economic growth in ways that protect our environment. We must encourage growth that will provide a better life for citizens, while protecting the land, the water and the air that sustain life.

In pursuit of this goal, my government has set two priorities: we must clean our air, and we must address the issue of global climate change. We must also act in a serious and responsible way, given the scientific uncertainties ...

... global climate change presents a different set of challenges and requires a different strategy. The science is more complex, the answers are less certain, and the technology is less developed. So we need a flexible approach that can adjust to new

information and new technology.

I reaffirm America’s commitment to the United Nations Framework Convention and it’s central goal, to stabilize atmospheric greenhouse gas concentrations at a level that will prevent dangerous human interference with the climate. Our immediate goal is to reduce America’s greenhouse gas emissions relative to the size of our economy.

My administration is committed to cutting our nation’s greenhouse intensity – how much we emit per unit of economic activity – by 18 percent over the next 10 years...

... Overall, my budget devotes \$4.5 billion to addressing climate change – more than any other nation’s commitment in the entire world. This is an increase of more than \$700 million over the last year’s budget. Our nation will continue to lead the world in basic climate and science research to address gaps in our knowledge that are important to decision makers.”

¹⁰ Image source: <http://www.whitehouse.gov/news/releases/2002/02/20020214-5.html>

Important Terminology and Abbreviations

- MMTCE** stands for Millions of Metric Tons of Carbon Equivalent. Roughly speaking, this is the mass of methane in units of millions of metric tons.
- TCE** stands for Tons of Carbon Equivalent. Roughly speaking, this is the mass of the methane in units of tons.
- The **cost** function is the function whose input is the mass of methane to be removed from the atmosphere (measured in millions of metric tons of carbon equivalent, MMTCE) and whose output is the cost of achieving this removal.
- The **marginal cost** function is the derivative of the cost function with respect to mass of methane.

- Figure 4¹¹ shows the a graph of **marginal cost** plotted against the mass of methane removed/reduced. What kind of function would do a reasonable job of representing the patterns in Figure 4? Use the data given in Table 1¹² (below) to find an equation for the **marginal cost** function.

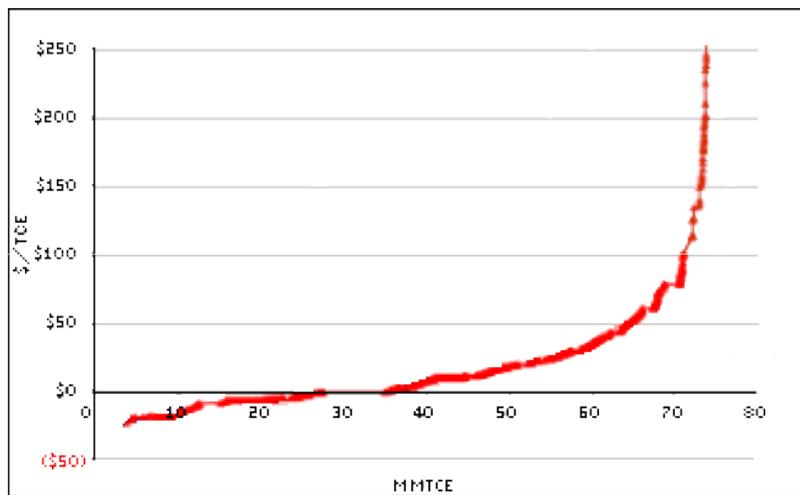


Figure 4: Marginal cost curve for removal/reduction of the greenhouse gas, methane.

Mass of Methane (MMTCE)	10	20	30	40	50	60	70
Marginal Cost (\$/TCE)	-15	-5	0	7.5	20	30	90

Table 1: Marginal cost for removal/reduction of the greenhouse gas methane.

¹¹ Image source: <http://www.epa.gov/>

¹² The graph shown in Figure 4 and the data given in Table 1 are both adapted from: Environmental Protection Agency. **Addendum to U.S. Methane Emissions 1990-2020: Inventories, Projections and Opportunities for Reduction**. Washington, DC: National Center on Environmental Publications and Information, 2001.

2. Marginal cost is the derivative of cost. Use the function that you found in Question 1 to find an equation for the cost function. Your cost function will have an unspecified constant “+C” in it. In order to find the value of this constant C, you will have to decide how much it will cost to bring about no removal/reduction in methane, and use this insight to calculate the value of C. When you write down your answer be sure to include a few sentences that explain how you determined the value of the constant C.
3. The units of the cost function are the same as the units of the area beneath the curve in Figure 4. Use Figure 4 to determine the units of the cost function. Use your cost function to determine the total cost of removing/reducing methane by 30 MMTCE. Be sure that you give the correct units when you quote your answer.
4. If you did the ICE on Global Warming¹³ (3/13/02), then you may have calculated that the mass of anthropogenic methane currently in the atmosphere is about 4256.9 MMTCE. What would be the cost of removing this methane from the atmosphere? For the sake of comparison, the GDP¹⁴ of the United States in 2001 was \$9,969,000,000,000. What percentage of this GDP would have to be devoted to atmospheric cleanup in order to remove all of the anthropogenic methane?
5. The EPA¹⁵ projects that if no measures are undertaken to reduce methane emissions, then in the year 2012 human activity in the United States will result in about 177.25 MMTCE of methane released into the atmosphere. In his speech of February 14, 2002, President Bush pledged to lower the emission of greenhouse gases by 18%. How much will this reduction cost? Also in his speech of February 14, President Bush noted that his budget included \$4,500,000,000 for addressing issues of global climate change. Given this budget constraint, will the United States be able to honor President Bush’s pledge¹⁶?

Epilogue/Reassurance

If you have done your calculations correctly, then your answer to Question 3 should be negative. However, your answer to Question 3 represents a cost, and costs are usually positive. Can you explain this?

¹³ See: http://www.courses.fas.harvard.edu/~mathxb/handouts/xb_ice/warming_ice.pdf

¹⁴ Source: CIA World Fact Book, 2002.

¹⁵ Source: Environmental Protection Agency. Addendum to U.S. Methane Emissions 1990-2020: Inventories, Projections and Opportunities for Reduction. Washington, DC: National Center on Environmental Publications and Information, 2001.

¹⁶ Methane is the second most important anthropogenic greenhouse gas. Carbon dioxide (CO₂) is the most important. President Bush pledged to reduce all greenhouse gas emissions by 18%. If the cost of reducing/removing methane alone is a substantial fraction of the \$4.5 billion budget, then the United States may be hard-pressed to honor this pledge.