**FIGURE SET HEADER for Set #2**

**Figure Set 2: Methane Emissions from Agriculture**

**Purpose:** To teach students that methane is a powerful greenhouse gas, and to teach the mechanisms by which agriculture contributes a substantial amount of methane to the atmosphere.
**Teaching Approach:** Think Pair - Share
**Cognitive Skills:** (see Bloom's Taxonomy) S Knowledge, Interpretation
**Student Assessment:** Minute Paper

**BACKGROUND for Set #2 (back2.html)**

**Background**

Although methane concentrations are much lower than carbon dioxide, per kilogram, methane is 25 W e.
Methane concentrations have increased by more than 100% since pre-industrial times, indicating that the increased sources due to human activity are much larger than the sinks (reaction with $OH^-$ in atmosphere and oxidation by soil bacteria). Every year, 84 Teragrams (Tg) are in excess W
that agricultural activities contribute about half of all anthropogenic methane emissions, largely from animal digestion, waste, and rice paddies. More information about methane can be found on the U.S. EPA website: http://epa.gov/methane/.

The table in this set (Table 2) was reconstructed from the Intergovernmental Panel on Climate Change (IPCC) reports from 2007, while the figure in this set is taken from Moss et al. (2000). The IPCC 2007 report, which compiled information from various scientific sources, provides W

**FIGURES for Set #2 (figure2.html)**

**Table**

| | Carbon Dioxide ($CO_2$) | Methane ($CH_4$) |
|---|---|---|
| Atmospheric concentration | (ppm)* | (ppm) |
| Pre-industrial | 280 | 0.8 |
| Present (2005) | 379 | 1.77 |
| % Increase | 36% | 121% |
| Atmospheric lifetime (years) | 50-200 | 12 |
| Relative radiative effectiveness | | |
| Per unit mass over 100 years | 1 | 25 |

* ppm: parts per million

**Legend**
**Table 2.** This table was constructed using data from the Intergovernmental Panel on Climate

Change (IPCC) report in 2007. Information is shown regarding two important greenhouse gases, Carbon Dioxide ($CO_2$) and Methane ($CH_4$). Atmospheric concentration data are reported as parts per million (ppm) in the atmosphere, while the % increase indicates the change in ppm for each gas between pre-industrial and present time points.

**Figure**

Figure 2a Methane Sources

**Legend**

**Figure 2a.** This figure shows total global production of methane per year divided into five categories. Units are in teragrams (Tg), which is equivalent to $10^{12}$ grams. A total of 690 Tg of methane are emitted to the atmosphere each year. Agricultural processes (i.e., domestic animal digestion, rice growing, animal waste) produce 210 Tg of methane, which is 30% of total methane emissions and 50% of anthropogenic methane emissions. Natural processes in soil and the atmosphere convert this methane to carbon dioxide by oxidizing the carbon, but 84 Tg of methane do not get oxidized every year and remain in the atmosphere. This imbalance between methane emissions and oxidation has resulted in a 121% increase in atmospheric methane concentrations since pre-industrial times. Figure 2a was drawn from data in Figure 1 in Moss et

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**STUDENT INSTRUCTIONS for Set #2 (students2.html)**

**Student Instructions**

*Part 1*

There are several gases produced by human activities that contribute to climate change. Carbon dioxide ($CO_2$) receives the most attention in the media, but other gases are also very important

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including its relative importance for climate change and why it is increasing in the atmosphere.

Table 2 shows carbon dioxide and methane abundance in the atmosphere, as well as the percent increase for each gas since pre-industrial times. Concentrations of the two gases are reported in parts per million (ppm), which indicates the number of parts of a particular gas relative to one million parts of all gases in the atmosphere. Radiative effectiveness is a term used to describe the ability of a gas to trap radiation energy near the surface of the Earth, and is reported per unit mass.

For the following two questions, come up with an answer on your own. Then, find a partner and discuss this together and write down your answer.

1. Which gas, $CO_2$ or $CH_4$, is more abundant in the atmosphere? Which one has had the highest proportional increase since pre-industrial times?
2. If one kilogram of methane trapped 125 units of radiation energy, how many units of radiation energy would a molecule of $CO_2$ trap?
3. Based on the data in Table 2 (atmospheric concentration and relative radiative effectiveness), which gas, carbon dioxide or methane, is a larger overall contributor to atmospheric warming? Why?

*Part 2*

Agriculture is one of the most important anthropogenic (human caused) sources of methane to the atmosphere. Rice is cultivated in wetlands, where there is little oxygen available in the soil. Decomposition of organic matter in these anaerobic environments produces methane instead of carbon dioxide. Methane is also produced in the digestive tracts of ruminant animals (e.g., cows, sheep, etc.) during the digestion process, which is then released to the atmosphere. In fact, one cow can release as much as 500 liters of methane per day (Johnson and Johnson 1995). Animal manure is stored in large holding ponds, where anaerobic bacteria decomposing the manure also release methane to the atmosphere. Most of the methane released to the atmosphere is consumed by a reaction with hydroxyl radicals ($OH^-$) or is oxidized by soil bacteria to carbon dioxide

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atmosphere.

Together with a partner, discuss the following:

1. What agriculture activities produce significant amounts of methane?
2. Can you think of other agricultural activities that are not listed on Figure 2a, and therefore do not contribute substantial amounts of methane to the atmosphere?
3. As consumers of food, are there any decisions we could make to reduce the amount of methane emitted to the atmosphere from agriculture?

Write down your answers to these questions and be prepared to share your answers with the rest of the class.

## NOTES TO FACULTY for Set #1 (faculty1.html)

**Faculty Notes**

The suggested student active approach suggested for Figure Set T -Pair- U

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turn to their neighbor to discuss the question, and then share their answer with the class.

Students may need help understanding some of the terms in Table 1. For instance, relative radiative effectiveness may need to be described as the potential for each of the gases to trap heat in the atmosphere, and thus contribute to global warming. Therefore, one kilogram of methane is 25 times more effective at trapping heat compared to carbon dioxide. Two factors influence relative radiative effectiveness, which are physical chemistry (including radiation absorption properties) and lifetime of a molecule in the atmosphere. Physical chemistry of a molecule determines the infrared (IR) wavelength absorbed. Gases with absorption bands in the non-visible portion of the IR spectrum, particularly between 1,000-1,200 wavenumbers, have the highest radiative forcing effect. Carbon dioxide absorption peaks occur at 2350 and 650 wavenumbers while methane absorption peaks occur at 3,000 and 1,300 wavenumbers.

In order to calculate the answer for part 1, question 3, students must consider not only the ppm increase of $CO_2$ and $CH_4$ in the atmosphere, but also the molecular mass of these gases. This is necessary since relative radiative effectiveness is calculated per unit mass (e.g. per kilogram), and not per molecule.

As stated before, methane absorbs frequencies of IR radiation emitted from the E W that would otherwise continue out to space. Even though methane is more effective per molecule than carbon dioxide at radiating heat, carbon dioxide is still the most important greenhouse gas because the quantity of carbon dioxide created by human activities is much greater than the quantity of methane. The students are assigned to discuss this with a partner. Continue this discussion with the entire class, to make sure they know that methane is a substantial contributor to climate change, but is still not as important as carbon dioxide.

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you wish. Figure 2b describes methane sources and sinks. Methane source and sink values in Figure 2b were calculated in individual studies, and were then compiled and scaled to a global level by Moss et al. (2000). There are slight disagreements between the values in the figure, reflecting the error involved when scaling up from multiple scientific studies. Students may be confused regarding why there is methane left over and it does not all get consumed by the reaction with hydroxyl molecules in the atmosphere. They may also notice that there should be much more methane in excess after considering how much methane comes from human activities. However, the methane sinks (oxidation in the atmosphere b-11(e)]TlBT1 0 0d(re)7(a)2( r)-c2(thls orhu

sinks exist; oxidation by hydroxyl ($OH^-$) in the atmosphere and oxidation by methanotrophic bacteria in soil. This figure is taken directly from Figure 1 in Moss et al. (2000), which is
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period to show to the students that the Minute Paper is valuable.

**Post Lesson Assessment – Minute Paper:**
Students take two minutes at the end of the class period to write an answer to the following questions on a piece of paper to be turned in.

- How do agricultural practices produce methane?
- Why is it important to consider methane as a greenhouse gas when there is 350 times more carbon dioxide in the atmosphere than methane?