**Science of Global Warming**

**In Five Steps**

**{ INSTRUCTOR NOTES }**

The lesson before the activity:

Briefly introduce the greenhouse effect. For a concise and relatively clear summary, see:

At the start of the activity:

Assign 5 groups, one for each question. Provide them with the handout “GWin5Steps\_StudentInstructions.doc”

Notes on what they will likely find in their searches appear much farther below. Give students about 30 minutes to work on it. Alternatively, each student can work on one question. In the next class, students who worked on the same question (e.g. question 2) form a group and submit a summary via email to the instructor.

During the activity:

Students will be emailing summaries. You can gather these and finish up in the same class or continue during the subsequent class. Alternatively, the internet search can be done as homework and the group work done at the start of class (i.e. individuals who searched question #2 get together and compose a summary). It is hoped students will appreciate how quickly they can get reliable information from the internet to understand a rather complex issue.

After students have submitted their summaries:

Present summaries. Start with question #1 and *work through to #4 only*. *Do not proceed to #5 without some discussion.* Student groups could present their own summaries, showing the links they used on a video projector. Your class size may dictate how results are presented. The instructor should complement, correct, or supplement as needed. Special instructor notes and supplements are included below under each question.

Discussing an hypothesis as to whether Earth’s surface warm:

The instructor should review the key points from questions 1-4 and/or ask students to review these key points. The “Summary of Findings” page (GWin5Steps\_SummaryFindings.doc) should be distributed to all.

Students are asked to make an hypothesis of what will happen to Earth’s surface temperature considering the answers to questions 1-4.

1. What makes a greenhouse gas a greenhouse gas? Greenhouse gases let in sunlight to warm Earth but absorbs thermal radiation from Earth. The gases get warm and thus, they further warm Earth’s surface.

2. Is carbon dioxide a greenhouse gas? YES.

3. Is the amount of carbon dioxide in the atmosphere increasing? YES.

4. Is CO2 increasing because of human activities? YES.

Therefore… \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

The logical hypothesis is, of course, Earth’s global surface temperature should increase.

Wrap-up:

Once students submit their hypothesis, its time for the final group to present their results showing the temperature is indeed increasing. The instructor should discuss how this same hypothesis was first made by Svante Arrhenius in 1895 based on the physics of questions 1 & 2 only. He suspected but did not know for certain or whether or how much carbon dioxide was increasing in the atmosphere. And, of course, global temperature was not rising at the time. G.S. Callendar later made the same hypothesis in 1938 and it because a well-known and broadly accepted among climate scientists in the 1960s and 1970s. <http://www.aip.org/history/climate/co2.htm>

Only now do we have sufficient temperature data to see a clear rise in temperature. The instructor might want to discuss hypothesis testing at this time. The scientific prediction of global warming is supported by the current warming. The observations are following the physics principles and the hypothesis has not been falsified. In fact, the amount of carbon dioxide in the atmosphere and the amount of warming we see today were predicted with reasonable accuracy in the 1970’s.

So, hopefully students have a much better understanding of how and why climate scientists are so confident the planet will continue to warm unless substantial changes to energy policy are made. Hopefully, students have a better idea of what goes into scientific assessments; the scientific ideas of human-caused global warming goes beyond opinion and is built upon a basis of well-tested physical principles of nature and verifiable observations to support logical conclusions. Hopefully, students see that this information is readily accessible and not so hard to understand.

Expected Results and Instructor Supplements

**Scientists say the planet is warming because of human activities, namely the greenhouse effect from carbon dioxide released to the atmosphere when burning fossil fuels. But, how do we know? How do scientists know?**

1. What makes a greenhouse gas a greenhouse gas?

**ANSWER:** In brief, greenhouse gases are transparent to sunlight but absorb infrared radiation emitted by Earth.

Greenhouse gases are transparent to sunlight, allowing solar radiation through the atmosphere to eventually warm Earth’s surface. These same gases are not transparent to the thermal radiation emitted by Earth. Instead, they absorb and are warmed by the thermal radiation emitted by Earth. Earth’s thermal radiation is restricted from escaping to space. And, the warmed greenhouse gases surrounding Earth act to keep Earth’s surface warmer than it would be without the gases.

Google search using the entire sentence above. Only the links that meet the credible search criteria from the student instructions are listed (i.e. “edu,” “gov,” etc.). Also listed is Cleanet.org (the resource where this activity is found!). Note the American Institute of Physics is aip.org, a scientific society.

Credible sites from 1st page of Google search:

<http://cleanet.org/clean/community/activities/c3.html> (includes reviewed activity)

\*\* <http://www.ucar.edu/learn/1_3_1.htm> (best for general education)

<http://epa.gov/climatestudents/basics/today/greenhouse-gases.html>

(better to link to previous topic: the greenhouse effect: <http://epa.gov/climatestudents/basics/today/greenhouse-effect.html>)

<http://www.epa.gov/climatechange/ghgemissions/gases.html>

<http://www.epa.gov/climatechange/ghgemissions/>

2nd page:

<http://www.elmhurst.edu/~chm/vchembook/globalwarmA5.html>

\*\* <http://forecast.uchicago.edu/chapter4.pdf> (best for science majors)

<http://www.un.org/wcm/content/site/climatechange/pages/gateway/the-science/causes-of-climate-change>

2. Is carbon dioxide a greenhouse gas? {Instructor addresses: How do we know?...see below}

**ANSWER:** Yes.

First page of Google search of exact sentence:

<http://www.epa.gov/climatechange/ghgemissions/gases/co2.html> (also contains statements and charts that CO2 emissions are from human activities)

\*\* best <http://www.aip.org/history/climate/co2.htm> (students canget the info by reading the first two paragraphs, not including the italicized summary at the top).

<https://www2.ucar.edu/climate/faq/how-much-carbon-dioxide-and-other-kinds-greenhouse-gas-already-atmosphere>

follow link at bottom to “Earth’s Greenhouse Gases,” which is more relevant for the question of whether CO2 is a greenhouse gas:

<http://www.windows2universe.org/earth/climate/cli_greengas.html> (\*\* very good)

<http://www-das.uwyo.edu/~geerts/cwx/notes/chap01/co2_change.html> (poor, information implicit)

<http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/grnhse.html> (\* good)

2nd page

<http://www.ncdc.noaa.gov/oa/climate/gases.html> (\* good)

{OPTIONAL INSTRUCTOR SUPPLEMENT: How do we know carbon dioxide is a greenhouse gas?}

**ANSWER:** Many sites say CO2 is a greenhouse gas, but how do we know? This has been known since the late 1800’s through theory and experiments, and, can easily be observed in lab experiments. Similar to Tyndall’s experiment in 1959, we can actually show carbon dioxide is a greenhouse gas in a simple classroom demonstration.

Instructor: Start actual experiment at the beginning of class and come back to it now, or show the video from cleanet.org below.

Modern, classroom experiment: <http://cleanet.org/clean/community/activities/c2.html>

<http://www.srh.noaa.gov/jetstream/atmos/ll_gas.htm>

Original theory: 1820s (<http://www.aip.org/history/climate/co2.htm>)

Tyndall experiment 1861 paper: via National Science Digital Library: <http://nsdl.org/sites/classic_articles/Article3.htm>

Original Tyndall paper: <http://nsdl.org/archives/onramp/classic_articles/issue1_global_warming/n3.Tyndall_1861corrected.pdf>

3. Is the amount of carbon dioxide in the atmosphere increasing? How do we know?

**ANSWER**: Yes. The Keeling curve shows the increase, CO2 is rising 🡺

<http://scrippsco2.ucsd.edu/home/index.php>

<http://www.esrl.noaa.gov/gmd/ccgg/trends/>

Keeling, Charles D. (1960). "The Concentration and Isotopic Abundances of Carbon Dioxide in the Atmosphere." Tellus 12: 200-203.

First page of Google search

<http://earth.rice.edu/mtpe/atmo/atmosphere/hot/anom_99/co2_in2.html> (no good)

<http://www.esrl.noaa.gov/gmd/ccgg/trends/> (\*\* best)

…or have students search “carbon dioxide record”

first page

<http://celebrating200years.noaa.gov/datasets/mauna/>

<http://cdiac.ornl.gov/trends/co2/sio-mlo.html> (\*\* best)

<http://keelingcurve.ucsd.edu/>

<http://gcmd.nasa.gov/records/GCMD_CDIAC_CO2_SIO.html> (to extract raw data)

4. Is CO2 increasing because of human activities? {Instructor Supplement: How do we know CO2 is increasing because of human activities? See farther below}.

**ANSWER:** Yes.

First page…

<http://oceanservice.noaa.gov/education/pd/climate/factsheets/howhuman.pdf> (Good, source of info, taken from IPCC)

<http://oceanservice.noaa.gov/education/pd/climate/factsheets/areincrease.pdf> (Good, source of info, taken from IPCC)

<http://www.epa.gov/climatechange/ghgemissions/gases/co2.html> (\*\*best)

{OPTIONAL INSTRUCTOR SUPPLEMENT: How do we know CO2 is increasing because of human activities?}

**ANSWER:** The increase can be attributed to humans by considering the simple combustion equation for methane combined with knowledge that fossil fuels supply most of the world’s energy needs. Of course, they will also need to consider the time taken to create the fossil fuels vs how rapidly the combustion products are released to the atmosphere.

What is a fossil fuel?

<http://ecenter.colorado.edu/energy-climate/energy-101/fossil-fuels>

<http://www.energyquest.ca.gov/story/chapter08.html>

fossil fuel chemistry: <http://www.wou.edu/las/physci/GS361/Energy_From_Fossil_Fuels.htm>

<http://telstar.ote.cmu.edu/environ/m3/s3/09fossil.shtml>

Combustion equation (any source, or <http://www.iun.edu/~cpanhd/C101webnotes/chemical%20reactions/combustion.html>

From Chemistry 101 class)

Fossil Fuel energy consumption

See International Energy Outlook from US Energy Information Administration, topic: “Energy-related carbon dioxide emissions” or similar source…lots of sources

<http://www.eia.gov/forecasts/ieo/emissions.cfm>

About half of estimated CO2 releases stays in atm

<http://scrippsco2.ucsd.edu/program_history/keeling_curve_lessons_3.html>

“…57% of fossil-fuel emissions remain airborne.” Confirmed by graph.

Canadell JG, Le Quéré C, Raupach MR, et al. (November 2007). "Contributions to accelerating atmospheric CO2 growth from economic activity, carbon intensity, and efficiency of natural sinks". Proc. Natl. Acad. Sci. U.S.A. 104 (47): 18866–70. Bibcode:2007PNAS..10418866C. doi:10.1073/pnas.0702737104. PMC 2141868. PMID 17962418.

<http://www.pnas.org/content/104/47/18866.long>

see first line of abstract

Aside: Timing and timescales matter. CO2 varies over time by natural processes but comparing the Time it takes to make fossil fuels vs immediate release plus, they remain in atmosphere for hundreds of years leads to accumulation in our lifetime due to burning fossil fuels;

**Discussion**…what will happen? Students to make prediction based on answers to questions 1-4.

See “Discussing an hypothesis as to whether Earth’s surface warm:” from first page.

5. (final student group) Is global average temperature increasing? How do we know?

**ANSWER:** Yes. The National Climate Data Center (NCDC), NASA Goddard Institute for Space Studies (GISS), and the University of East Anglia Climate Research Unit (in the UK) all generate global surface temperatures from raw metrological observations. All show a similar, marked temperature increase over the last 100 years.

GISS compiling thermometer measurements clearly show the increase

<http://data.giss.nasa.gov/gistemp/graphs_v3/> (land & ocean, land only, ocean only, NHEM only, SHEM only, etc. all show warming)

WMO Summary: <http://www.wmo.int/pages/prog/wcp/wcdmp/GCDS_3.php>

<http://www.ncdc.noaa.gov/cmb-faq/anomalies.php>

<http://www.metoffice.gov.uk/research/monitoring/climate/surface-temperature>

First page of exact google search

<https://www2.ucar.edu/climate/faq/how-much-has-global-temperature-risen-last-100-years> (\*\* best, follow links to three main sources: NCDC data are shown on the page plus links to NASA, and UEA)

<http://data.giss.nasa.gov/gistemp/>). (\*\* Very Good, click on graphs icon at top right navigation)

<http://data.giss.nasa.gov/gistemp/graphs_v3/> (land & ocean, land only, ocean only, NHEM only, SHEM only, etc. all show warming)

<http://www.ncdc.noaa.gov/cmb-faq/anomalies.php> (\*\* Very Good)

<http://www.metoffice.gov.uk/research/monitoring/climate/surface-temperature>

<http://www.epa.gov/climatechange/science/indicators/weather-climate/temperature.html>

(US data only at top, global plot at bottom of page)

<http://www.ipcc.ch/publications_and_data/ar4/wg1/en/tssts-3-1-1.html>

<http://www.ncdc.noaa.gov/cmb-faq/globalwarming.html>

Or… search “global average temperature”

<https://www2.ucar.edu/climate/faq/what-average-global-temperature-now> (\*\* best, has links to and explains all three sources of global temperature records)

<http://data.giss.nasa.gov/gistemp/> (\*\* Very Good)

<http://www.epa.gov/climatechange/science/indicators/weather-climate/temperature.html>

(US data only at top, global plot at bottom of page)

<http://www.ncdc.noaa.gov/cmb-faq/anomalies.php> (\*\* Very Good)