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Introduction

This project addresses the need to improve Science Literacy among the public. More specifically, it addresses the need for Climate Change to be taught in school so that students leave the public school system as informed and critical thinking members of society. The Center for Excellence in Science and Mathematics (CESaME) at the California Polytechnic University, San Luis Obispo aims to "improve Science, Technology, Engineering, and Mathematics (STEM) education, teacher education and professional development, and the workforce pipeline in California." In the summer of 2010, the center will be holding a week-long Climate Change Teacher Workshop as a form of professional development for grade 6-12 teachers.

My role in the project was to collect and compile lesson plans relevant to the issue of Climate Change. I submitted the list of lessons to the workshop administrators to evaluate from a scientific perspective, and agreed upon two lessons that could be tried out in classrooms prior to the workshop. By doing the lessons in classrooms, we could gauge how well the lesson met the objective, how well students responded, whether the lesson would be an appropriate difficulty level for the wide age and grade level range of the workshop (grades 6-12), and to discover potential problems and challenges so that teachers can prepare for and avoid such problems.

What is Science Literacy?

The topic of Climate Change falls into many different classes of education and programs being developed. These categories of educational philosophies include science literacy, environmental literacy, Environmental Education (EE), Education for Sustainable Development (ESD), and more. These programs all urge schools to teach about environmental issues as well as prepare students to think critically and make informed decisions about the issues.

The National Science Standards require that all students leave school as science literate adults.

> Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It also includes specific types of abilities. In the National Science Education Standards, the content standards define scientific literacy. Scientific literacy means that a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately (National Science Education Standards, 22).

Science literate students are able to apply the skills and science knowledge learned in science classes to real world situations.

The National Science Teachers Association describes in the Position Statement on Environmental Education,

> [Environmental Education] should be a part of the school curriculum because student knowledge of environmental concepts establishes a foundation for their future understandings and actions as citizens. Central to Environmental Education is the ability of students to master critical-thinking skills that will prepare them to evaluate issues and make informed decisions regarding stewardship of the planet. The environment also offers a relevant context for the learning and integration of core content knowledge, making it an essential component of a comprehensive science education program.

In addition, one declaration states, "All learners are expected to achieve environmental literacy and an appreciation for and knowledge of a range of environmental issues, perspectives, and positions" (NSTA Position Statement).

What is Climate Literacy?

Under the umbrella of science literacy falls the more specific Climate Literacy. The National Oceanic and Atmospheric Administration has created an entire book summarizing the importance of Climate Literacy as well as the "essential principles of climate sciences." The Administration describes that their guide will help communities and individuals understand how they influence climate and how climate influences them and society as a whole. A definition of Climate Science can be found in their guide to Climate,

> People who are climate science literate know that climate science can inform our decisions that improve quality of life. They have a basic understanding of the climate system, including the natural and human-caused factors that affect it. Climate science literate individuals understand how climate observations and records as well as computer modeling contribute to scientific knowledge about climate. They are aware of the fundamental relationship between climate and human life and the many ways in which climate has always played a role in human health. They have the ability to assess the validity of scientific arguments about climate and to use that information to support their decisions (Climate Literacy).

The first step in the public becoming climate literate takes place in the science classroom, where students need to learn basic science principles and how the climate system operates. The next step, often left unaddressed in science classrooms, is the understanding of how science and society interact and how to use critical thinking and analytical skills when dealing with a climate issue.

Current State Standards

Most of the California State Standards for high school that address Climate Change fall under the category of Earth Science. According to the National Center for Education Statistics, only 23.1% of high school students took an Earth Science class in 2005, contrasted with 92.3% of students who took a Biology class (Number of teachers).

Why is it important?

Aside from the specific standards that require that students learn about Climate Change, the introduction to the CA Science Standards reads,

> This content should be taught so that students have the opportunity to build connections that link science to technology and societal impacts. Science, technology, and societal issues are strongly connected to community health, population, natural resources, environmental quality, natural and human-induced hazards, and other global challenges. The standards should be viewed as the foundation for understanding these issues (CA Standards, ix).

Climate Change is an issue that incorporates scientific data, researchers, politicians, special interest groups, etc. and is very much a societal issue. While many science teachers consider the conflict and evaluation of the issue to be a topic for discussion in Social Science or Government classes, many of the teachers in those subjects are not familiar with the science. California values an education in which students can apply scientific facts to past, current, and potential future issues and challenges, to connect the various factors, and make educated and wise choices about issues that are relevant to themselves, their community, and the world.

> Because elementary and high schools are usually not organized to accommodate multidisciplinary studies effectively, environmental topics generally piggyback on established subjects or courses. In practice, environment-related themes and topics appear most frequently in science courses, occasionally in social studies courses, and less frequently elsewhere. This is appropriate because the study of the environment necessarily involves many disciplines—that is, it is based in the

> natural sciences, calls for understanding societal studies, and raises value questions normally associated with the humanities. Thus, environmental studies are applied studies, necessarily based and dependent on the traditional disciplines (Disinger, 6).

Through lessons or units in the classroom on Climate change, students can learn responsibilities as a citizen, to debate or argue about issues in Science, how to gather and interpret data, etc. This subject also is an opportunity for students to gain skills in research, creating action plans and proposing solutions to problems.

A study on public opinions about climate change by George Mason University revealed that “Children express optimism about our ability to respond to global warming,” “many young children believe that new technologies will solve the problem,” and that “most young children actually carry out the environmental actions they think are important” (George Mason University, pg. 15). The children in schools now will still be battling Climate Change in the years to come and should be informed about the problem, the potential solutions, the complex collaboration within society necessary, and the challenges that we face today as well as in the future. In addition, when children express an interest in the subject and a desire to “carry out the environmental actions they think are important,” parents are more likely to talk about the issue and also carry out the environmental actions. By teaching children and youth about the issue, we are also educating parents, stimulating conversation in families, and potentially making positive environmental changes in the home.

Relevance of the Workshop

Most teachers in grades 6-12 are qualified to teach science and hold a single subject teaching credential in one or more areas of science. This credential is renewable every five years with the completion of a written test.

While information, technology, and local and world environmental issues change quickly, science and research are ongoing. Often schools cannot afford to update equipment, textbooks, and additional resources, and teachers are not required to update their lessons and research the most up to date science and environmental news. Because there are few state standards that reflect the need for the issue of Climate Change to be taught, many teachers opt to complete the standards alone, and stay away from an issue about which they do not feel comfortable "taking a side".

Research has shown that teachers, like the public, are not well enough informed on the topic of climate change; however, many teachers are concerned about environmental issues and do positively view pro-environmental laws and actions. Studies have shown that a teacher's decision to teach or not teach an environmental topic in class often revolves around how much personal knowledge about the subject the teacher already has (ESD in the United States, 38). This suggests that teachers trained on the subject of climate change will be more prepared and informed, but will also be more willing to teach a subject. Teachers are more likely to teach what they know, and they will teach what they know better than what they do not know and are not comfortable with. With Climate Change a topic of controversy, confusion, and updated information, it is important to create a satisfactory level of understanding, knowledge, and training for those involved in education.

In an “Environmental Education Needs Assessment of K-12 Teachers in Kentucky” researchers surveyed teachers about current and future needs of K-12 teachers in the process of establishing a regional center for environmental education. The largest percentage of respondents indicated that their preferred method of instruction was in-service trainings during the school year. However, 49% indicated that they preferred summer workshops. In response to the particular needs of teachers implementing environmental education into their curriculum, teachers indicated that funding, field trip opportunities, and curriculum resources (lesson plan and curriculum ideas) were the high-level needs (Meichtry and Harrell, 22).

While Climate Change is only in part included in the California State Standards that guide classroom curriculum, even if the standards are updated to include more about this issue, the standards only guide *what* to teach, not *how* to teach it. The issue is complex and draws from so many fields. The workshop will provide example activities and lesson plans that can be used in classes.

Professional development in teaching is as important as development in any field. This workshop is an opportunity for educators to improve their knowledge about Climate Change, to coordinate with other teachers, and to plan and create lessons to use in their own classrooms. This workshop will present educators with all the facts (approved by scientists), as well as effective, tried and accepted lesson plans, demonstrations, activities, and accurate data (and credible sources for updating data in the future).

> Although more teachers are attempting to incorporate [Environmental Education or [Education for Sustainable Development] materials in their teaching, there is little indication that they are well prepared to do such work. It is hard to know whether or not their fragile efforts will survive in a political climate that

> emphasizes high-stakes assessment and traditional disciplinary measures of academic achievement (ESD in the United States, 40).

Beginning teachers and those unfamiliar with Climate Change will build knowledge about the occurrence, while experienced teachers and those familiar with the subject will deepen their content base and knowledge of both the issue itself, but also the challenges and benefits associated with teaching the subject.

Teachers with previous experience teaching Climate Change will contribute stimulating conversation, knowledge and skills. For example, four teachers who plan to attend the workshop allowed me to teach some of the lessons that we accumulated and created for the purpose of distributing to the workshop attendees. Over a period of two weeks I taught two lessons about Climate Change in five different classes from grades 8-12. While I taught the lessons, the teachers remained a large part of the conversations and collaboration involved in the activities and lessons. These teachers will provide invaluable feedback on both the lesson, will help to improve the lesson, and stimulate further lesson development with the other workshop attendees during "teacher time."

Potential Issues of Conflict

Like many topics in science and especially in environmental issues, controversy from students, parents, and community members should be expected. *On the Cutting Edge*, a component of the National Association of Geoscience Teachers, provides professional development for Geoscience teachers and educators, describes,

> Teaching environmental topics can bring out unexpected responses in your students. For example, when you cover the topic of Earth's resources in a physical geology course, you may find previously mild-mannered students become impassioned about the topics, or otherwise attentive and hard-working pupils dig in their heels and resist the information. Doing rock and mineral identification may elicit little emotional response from most students. But when the subject

> matter seems to confront one's personal lifestyle, political leanings or economic situation, then the topic may be perceived in a very different light (Teaching Environmental Issues).

That the issue is controversial is definitely no reason to veer away from teaching the subject in the classroom. It is of course, necessary though, to be prepared for controversy. Teachers should have a plan to notify administrators, and possibly even parents, of the issues they plan to teach, and have relevant data and information to support the cause for teaching Climate Change in the public school. At this point, the workshop administrators do not have a particular strategy to advise, however a guest speaker and teachers at the workshop will contribute important personal experiences and suggestions.

As I was teaching one of the Climate Change lessons in a grade 8 classroom, a student asked why some people think that Climate Change is not due to human actions. At the end of the day, I spoke to the teacher in whose class I was teaching. He then told me that a grade 7 History teacher at the same school teaches students that Climate Change is not real.

Chris Sperber and Ryan Hubbard are two grade 8 Science teachers at Arellanes Junior Hight School in Santa Maria, California, where grade 7 students enter their classes with the understanding that Climate Change is a hoax. Information taught to children by a teacher is most often immediately understood to be the truth. Chris and Ryan plan to attend the workshop. They will be an incredible resource in the area of controversy within a school, but will also be an example of the necessity for teachers to be well prepared to deal with the controversy that will come with teaching the subject.

Journal about the lessons

Lesson #1: The Wedge Game

The wedge game . The Princeton University Carbon Mitigation Initiative program, a partnership between Princeton University, BP, and Ford Motor Company, developed the game as a way to understand and teach the concept of cutting emissions and to become familiar with the tools we have to do so. A copy of the lesson plan, detailed game instructions, and materials required for this game can be found in Appendix A.

TRIAL #1:

The first lesson I taught was in Mrs. Sarah Cameron's Middle School Science class at Fessler Middle School in Santa Maria, California, on Wednesday May 26, 2010. The class was composed of 31 8^{th} grade students. Below is an outline of how my lesson was structured.

Anticipatory Set

- Introduction/About me
- Have any of you been to a farmer's market? What are some things you see there? Farmers! Our central coast communities rely much on farming. This is one industry that will be affected by Climate Change.
- Has anyone heard of it before? What about global warming (many more hands)?
- What do we breath in? and out? CO2! CO2 is a totally natural thing, but humans do lots of things that create more CO2 than is natural to have in the atmosphere. Some of the things are making energy.

Information

- I drew a graph to show the increasing co2 levels (per year), labeled the axis, and put a point at the current level (See **Figure 1** below).

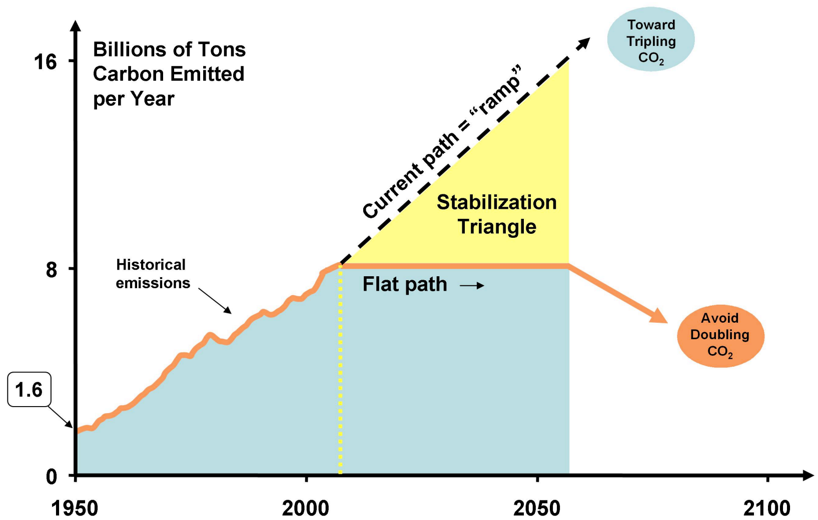

Figure 1: Graph of increasing CO2 Levels used to introduce the concept of wedges

Check for Understanding

- I asked the students to think about how much we emit into the atmosphere per year. They were mostly able to read the graph. I told them that scientists predict that the graph will continue to increase. I drew a dotted line and asked them to predict what the levels would be by 2055. They read the graph.

Information

- I then handed out their wedges. I asked them if they thought the increased co2 would be good or bad (bad). Do you think we could suddenly stop everything we do that emits co2 and get the levels down to zero? Probably not. It might be more reasonable to try to level it out. I drew the horizontal line on the graph and showed them how their "game board" could fit in there.
- Each wedge is something we humans can do to decrease/lower the amount we emit per year by 1 billion tons. If we want to level out the graph, we will have to reduce by 7 billion tons. That means that we will have to do 7 of these things (wedges).
- I reviewed the chart and went over a few of the strategies for lowering emissions

Group Practice

- Students worked in groups of four to six to come up with a triangle of 7 wedges.
- Each group presented— the students explained which wedges they chose and why they chose them, as well as some challenges that might come with the benefits.
- We did not finish all presentations.

Discussion/Improvements to be made

The first observation I made was that the vocabulary associated with Climate Change is unfamiliar to the students. The wedge game requires a basic understanding of

Climate Change as well as a period prior to playing the game to do an in-depth discussion of each of the 15 wedges. After watching the students struggle with some of the terms, I have two suggestions to possibly improve the effectiveness of the game. It might be possible to create a simplified chart for students in lower grades. I discussed with Sarah Cameron, who thought a simplified chart would be simple to create and highly effective. The other option would be to spend more time on the topic and learn the vocabulary in class.

In the presentations, I found that students did not like the idea of being in front of the group and wanted to nominate one person from each group to talk. This would relieve the anxiety from all other non-presenters in the group and therefore reduce the motivation of all but one to understand the concepts and be prepared to discuss the topic. When doing group presentations, the students should each choose which wedge(s) they will talk about and write down some notes. Without having notes during the presentation, students became flustered and silly.

Although all the students completed the activity, I am not convinced that every student fully understood how the triangle “game board” related to the graph that I drew on the board. I suggest that teachers who use this game in the classroom emphasize the relationship between the two to ensure that students understand each wedge represents one billion tons of carbon dioxide. It is important in discussing the relationship between the graph and the triangle board game to also model selecting a wedge from the chart, finding the corresponding wedge color, writing the name of the strategy, and sticking it on the board.

The activity was definitely simple enough for many students to do. There were some ELL in the class who did not talk much. Many could have been shy. Others who had more limited vocabularies may have had a hard time grasping some of the concepts. This activity stimulated conversation among students across all levels of understanding and ability.

TRIAL #2

The second lesson I taught was in the classroom of Mr. Manuel Casillas's High School Chemistry class at Pioneer Valley High School in Santa Maria, California, on Thursday May 27, 2010. The class was composed of 14 students in grades 10-12. Below is an outline of how my lesson was structured.

Anticipatory Set

- Introduction/About me
- Has anyone heard of Climate Change before? What about global warming?
    - Think of some ways that Climate Change/increased temperatures might affect earth. Who, what, etc. Partners.
    - Answers ranged from polar bears to farmers to fish.
    - Our central coast communities rely much on farming. This is one industry that will be affected by Climate Change.

Objective

- Today we are going to talk about Climate Change and some of the potential solutions to the problem.

Purpose

- This is an issue of concern for our generation. It will be something we are dealing with for quite some time and so we need to be informed.

Information

- What do we breath in? and out? CO_2! CO_2 is a totally natural thing, but humans do lots of things that create more CO_2 than is natural to have in the atmosphere…but it is one of the leading causes of Climate Change. Humans do many things to create more carbon dioxide than the atmosphere should naturally contain. One of things that humans do to put off large amounts of co2 is making energy.

  - In partners, discuss and write down: Can you think of some ways we create energy?
  - The students' knowledge of energy creation was much more advanced than the 8th graders, however there were still many students unfamiliar with fossil fuels. Most students think that much energy is created by alternative forms of energy.

- I drew a graph to show the increasing co2 levels (per year), labeled the axis, and put a point at the current level (See **Figure 1** above). I asked the students to think about how much we emit into the atmosphere per year. They were mostly able to read the graph. I told them that scientists predict that the graph will continue to increase. I drew a dotted line and asked them to predict what the levels would be by 2055. They read the graph.
  - Mr. Casillas gave the students some perspective by explaining that with about 7 billion people in the world, we are each essentially responsible for reducing the emissions by one ton. We brainstormed items that could be one ton. We decided that each of us is responsible for reducing emissions by one elephant worth of carbon dioxide.

Check for Understanding

- I then handed out their wedges. I asked them if they thought the increased co2 would be good or bad (bad). Do you think we could suddenly stop everything we do that emits co2 and get the levels down to zero? Probably not. It might be more reasonable to try to level it out. I drew the horizontal line on the graph and showed them how their "game board" could fit in there.

Information

- Each wedge is something we humans can do to decrease/lower the amount we emit per year by 1 billion tons. If we want to level out the graph, we will have to reduce by 7 billion tons. That means that we will have to do 7 of these things (wedges).
- I reviewed the chart and went over a few of the strategies for lowering emissions.

Group Practice

- Students worked in groups of four to come up with a triangle of 7 wedges.
- Each group presented— the students explained which wedges they chose and why they chose them, the total cost of their plan, the mix of colors that they chose and what that means, as well as some challenges that might come with the benefits.
- We finished all presentations.
- Discussion/Improvements to be made
- The vocabulary was very difficult for some students. It might be possible to create a simplified chart for lower grades.

Discussion/Improvements to Be Made

In this lesson, I gave groups the detailed description of each wedge supplied in the Wedge Game materials (Appendix A) because I thought the high school students might be more inclined to refer to the packet. I found, however, that the students preferred to raise their hand and discuss with either myself or with Mr. Casillas. The information provided in the packet was simplified and gave examples, but could be even more simplified to relate more directly to the students.

The students were more inclined to ask questions about vocabulary and concepts that they did not understand than the middle school students were. I found that the younger students had to be prodded to think about terms that they were not familiar with. In either case, I think it is definitely important that the teacher move around the classroom to check on the groups, and bring up important points that should be discussed. Some students did not start out the activity paying much attention to the challenges associated with each strategy. With specific suggestions from Mr. Casilla or myself the students began talking more. It seems that more background knowledge on the subject of Climate Change could enhance the activity, but at the high school level might not be as necessary.

The high school students were able to think about the issues at a higher level. While the middle school presentations consisted of the wedges chosen and why, the high school presentations included the wedges chosen and why, the color represented most on the board and the significance, the total cost, and the potential challenges with the strategies.

One student left the class with the intention of going home to tell his mom about Climate Change. Even without any background knowledge on the subject, the activity succeeded in stimulating interest in the students.

Manuel Casillas brought up an interesting point to consider—simplifying the language does not encourage students to become more science literate or able to discuss important issues like Climate Change at an appropriate level. Manuel says that at some point, the expectations have to be raised and students should begin learning the difficult vocabulary at a young age.

A final suggestion by Mr. Casillas was that by giving each group a presentation board, they could prepare their visual aid appropriately for the presentation and building presentation skills.

Lesson #2: Bias in Science

I created the lesson about bias in science specifically for the workshop because of the focus on communication. I created a worksheet to be filled out pre- and post- test, in which students would read two one paragraph-long excerpts from mainstream newspapers, and answer three questions about each excerpt. The questions related to the credibility of the author, whether a bias exists in the article, and whether the article appears to be truthful. The lesson itself focuses on the idea of bias in two forms. First, reporters can create a bias by presenting one side to an issue and not selecting enough or appropriate sources. On the other hand, the sources themselves can be biased. Students learn the definitions of “bias” and “source.” They then continue to learn about specific sources in the issue of Climate Change, and then how to decide whether a source or a reporter is biased.

TRIAL #1

My first lesson about bias in science was taught in Mr. Ryan Hubbard's 2nd period grade 8 Science class at Arellanes Junior High School in Santa Maria on Wednesday April 3, 2010. A summary of the lesson structure follows below.

- Intro to the workshop
    - Students attempted to fill out the worksheet

Anticipatory Set

- Introduction to sources
    - What kinds of sources do we get information from?
        - Answers range: TV, radio, internet, books, encyclopedia, people, etc.

Objective

Today we are going to learn about these sources and the information that we hear from them as it pertains to the issue of Climate Change.

Purpose

(The students are very familiar with state standards for education) The issue of Climate Change is not required to be taught in schools yet because it is so new and a little bit controversial. This issue is relevant to us now and could become a huge problem in our lifetime. It is important that we are critical of what we hear so that we can be informed and make wise and informed choices for ourselves and in our communities.

Information

- Come up with examples of a conflict
    - They chose *vandalism*
- You are a reporter writing about the subject. Who are the sources that we should interview if we want to get a complete picture?
    - Students shout out the sources and they are listed on the board. See **Figure 2** below.

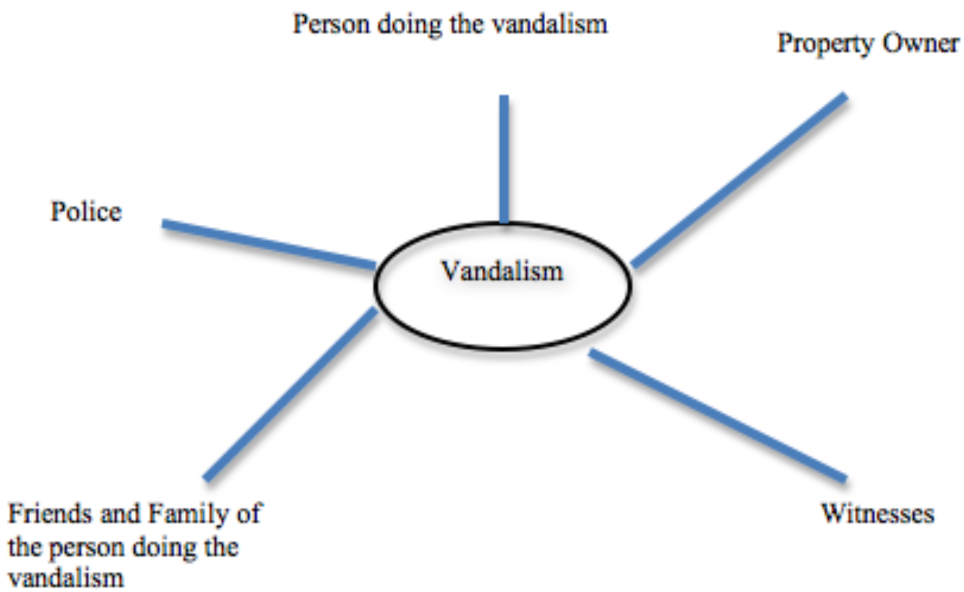

Figure 2: Example web illustrating the sources in an article about vandalism

- Discussion about bias
  - If we interviewed all of these sources, would we get the whole picture?
  - If you could only choose two sources, which would you choose?
  - Do just those two sources give the complete picture?
  - What about if we only chose one source?
- Bias
  - This is called bias
    - I read a dictionary definition and asked them to write it down in their own words.

Check for understanding

- I checked the definitions that the students wrote. Some were right on, but many were confused.
- Clarification: It is when just one side of the story is presented
- Are any of our sources biased?
  - Students responded that the person doing the vandalizing could be biased. They did suggest some others, but most agreed that the person vandalizing would be the most biased in the situation.

Guided Practice

- Now we will talk about the issue of Climate Change
  - List some sources: I wrote them on the board. See **Figure 3** below.

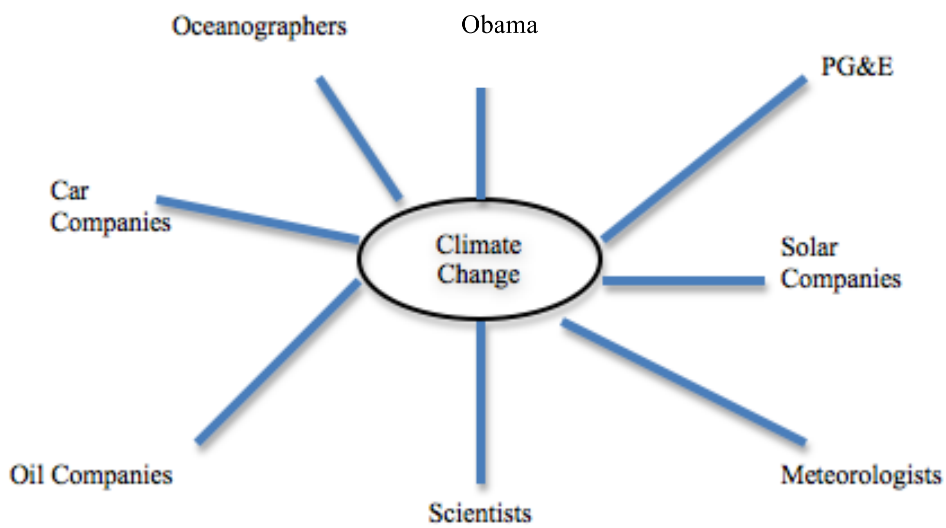

Figure 3: Example web illustrating the sources associated with Climate Change

- When the students were stumped, I did an overview of Climate Change to help brainstorm more people and groups who might be interested in the issue
- Are any of these sources biased?

Group Discussion

- Interest Groups
  - Politicians
  - Businesses
  - Journalists
  - Scientists
- Answer the questions about the interest groups
  - Questions on the worksheet

Discussion/Improvements to be made

The vocabulary in this lesson was difficult for the students. When I read a dictionary definition of the word bias, the students were entirely confused. I should have explained the term in simpler words.

I found that students are not familiar with the term politician, and had trouble describing the roles of some of the categories of people by role. It is interesting that many students said that if they were reporting on the issue of Climate Change, a main source of information would be “Arnold” or Obama, however they had difficulty defining a politician. It seems important to introduce these terms and discuss the roles of each category, the motivation for professionals in each field, and how each might overlap.

With so much focus on the terms and basic concepts, I did not have time to get to the main point that I wanted to make. By doing this activity in the classroom I discovered that the students are definitely able to learn this information, and many are interested in the subject, but it should be a part of a larger unit. The information should be presented in a series of lessons while simultaneously introducing content on Climate Change.

The pre- and post- worksheet was much too difficult for the students, although it can be adjusted to better suit the students. The vocabulary was too difficult, the articles were much too detailed, and the information about the authors seemed entirely irrelevant. The results would not have been accurate because students were copying each other and many wrote “I don’t know” as an answer. Mr. Hubbard suggested using children’s science magazines to extract quotations. When the students understand the quotations, it will be much easier to determine bias, truthfulness, and author and source credibility. I did not administer the students the post-test because it took so long and the results would not have changed from the pre-test.

TRIAL #2

I taught the bias lesson again immediately afterward in Mr. Chris Sperber’s 3rd period Science class at Arellanes Junior High School on Wednesday April 3, 2010. While the lesson was structured mainly the same as the first lesson, I did make some changes based on things that did not go well in the first lesson.

- Structure of the lesson:
  - Chris introduced the subject, asking the students to brainstorm sources
  - Intro to the workshop
    - Students attempted to fill out the worksheet
  - Introduction to sources
    - What kinds of sources do we get information from?
    - Come up with examples of a conflict
      - I used the same example of vandalism
    - You are a reporter writing about the subject. Who are the sources that we should interview if we want to get a complete picture?
      - Students shout out the sources and they are listed on the board. See **Figure 2**.
      - If we interviewed all of these sources, would we get the whole picture?
    - If you could only choose two sources, which would you choose?
      - Do just those two sources give the complete picture?
      - What about if we only chose one source?
  - Bias
    - Bias means only showing one side of the story
      - Write down your own definition of bias
    - Are any of our sources biased?
  - Climate Change
    - Overview of Climate Change to brainstorm more people and groups who might be interested in the issue
      - Humans emit much Carbon Dioxide into the atmosphere, which connects businesses and other groups and organizations to the subject of Climate Change
    - List of potential sources
    - Are any of these sources biased?
  - Discussion
    - Interest Groups
      - Politicians
      - Businesses
      - Journalists
      - Scientists
    - Answer the following questions (Altered from the first lesson):
      - Describe the jobs of each of the groups
      - What motivates each group?
      - What does a person in each group have to do to keep their job?
  - Introduction to different types of organizations, government groups, and mission statements.
    - I read a few mission statements of organizations to introduce the idea that each company is based on specific ideals and is driven by certain motivators. Some are more appropriate for the issue of Climate Change than others.

Discussion/Improvements to be made

I found that telling the students a simple definition of the word bias and then instructing them to write down the definition in their own words was much more effective than asking the students to translate the dictionary definition into their own words.

While I had altered the discussion questions to be easier to comprehend for the students, they still were not clear enough and should be worked on. During "teacher time" at the workshop, teachers should be able to discuss and brainstorm questions appropriate for a variety of grades. The discussion questions need to be very specific and the students need to be held accountable for each question. When I asked students to talk to their neighbor, some would do the work and some would not. When the students were asked to write down their answers, though, their anxiety was increased, and they were much motivated to do the work.

TRIAL #3

The third time I taught the science bias lesson was immediately afterward in Mr. Ryan Heddler's 4th Period Science Class at Arellanes Junior High School on Wednesday April 3, 2010. Below is a summary of the lesson.

- Intro to the workshop
- Introduction to sources
    - What kinds of sources do we get information from?
    - Come up with examples of a conflict →Oil Spill
    - You are a reporter writing about the subject. Who are the sources that we should interview if we want to get a complete picture?
        - Students shout out the sources and they are listed on the board
        - If we interviewed all of these sources, would we get the whole picture?
    - If you could only choose two sources, which would you choose?
        - Do just those two sources give the complete picture?

                - What about if we only chose one source?
- Bias
    - Bias means only showing one side of the story
        - Write down your own definition of bias
        - Would we be biased if we only chose one source from the list?
    - Are any of our sources biased?
- Climate Change
    - Overview of Climate Change to brainstorm more people and groups who might be interested in the issue
        - Humans emit much Carbon Dioxide into the atmosphere, which connects businesses and other groups and organizations to the subject of Climate Change
    - List of potential sources
    - Are any of these sources biased?
- Whole class discussion
    - Interest Groups
        - Politicians
        - Businesses
        - Journalists
        - Scientists
    - In groups, answer the following questions:
        - Describe the jobs of each of the groups
- Attempted to fill out the pre-post worksheet (only post)
- Introduction to different types of organizations, government groups, and mission statements.
    - I read a few mission statements.
- These students only filled out a post lesson worksheet

Discussion/Improvements to be made

Instead of using the worksheet questions or the simplified questions from trial 1, I asked the students in groups to define each of the four job categories because the Discussion questions were still not clear enough and were too difficult for the students.

More background information about Climate Change/global warming is required to fully understand the concept of bias in the context of Climate Change.

The class had a wide range of language abilities, willingness to participate in the class discussion, and critical thinking skills. The activity needs to have enrichment options for students who find it difficult as well as challenging options for students who have completed part of the activity early.

Specific questions to stimulate conversation are necessary for Middle School students. Asking them to discuss is not enough— they definitely want to know the right answer.

I was slow at presenting the information because I am not used to teaching. With appropriate materials and an experienced teacher, the subjects might be discussed more quickly. However, this lesson should be done over a week period while also learning about the Climate Change facts. This would provide the students with much more background information about Climate Change/global warming to apply to the discussions and would relate the science directly to the social, political, and economic components associated with the issue. The important topics to cover should include: bias and sources; How to determine if a news piece is biased; what to look for to determine bias; how to determine specific sources by reading articles.

As previously mentioned in the *relevance of the workshop* section of this paper, a student asked me during this activity about why some people think that Climate Change is not due to anthropogenic causes. We were talking about information sources and bias at the time, so I brought attention to the various groups and individuals that would have a special interest or would be interested in the issue and then asked the students to discuss why some might have strong opinions either way. Although I did respond to the question appropriately, I do not feel that I was fully prepared to do so. Teachers should have a fast understanding on the subject of Climate Change and be prepared to answer these kinds of questions. Rather than tell students what you think, it is important to introduce data and information about sources and bias in a social, political, and economic context.

Conclusion

Climate Change is a subject that appears in the news enough that most students in grades 6-12 can recognize the term “global warming.” Students should be informed about the issue, they should have knowledge of the fundamental scientific processes as well as an understanding of key players in the controversy, the possible solutions, and should have the analytical skills to make wise choices as an individual and a community member.

The first step to a climate science literate public is learning the facts about the climate system. Because such a small percentage of high school students take an Earth Science class, the only subject required to teach most of the climate system science concepts (by the California State Standards), it is important that teachers integrate the subject into other relevant science classes. As the research has shown, teachers who thoroughly understand a subject are more likely to teach that subject to their class. Those well-informed and knowledgeable teachers not only choose to teach the information, but they teach it better and with more enthusiasm.

Students should be able to analyze news stories, the sources, and determine bias. Because science is taught to be an objective topic, with data and right and wrong solutions, youth and adults often can be fooled into believing everything they hear or read. Teachers should encourage group and partner work in Climate Change lessons to stimulate conversation about the subject, and the lessons should be made relevant to the students' personal lives. The issue of Climate Change can be difficult to personalize because it is a global issue. Personal examples, field trips, outdoor observations, online activities, and guest speakers can all make the issue more relevant to an individual student.

The CESaME workshop in summer 2010 is an opportunity for 6-12 grade teachers to work with science professionals, climate scientists, mathematicians, a communication expert, and other interested educators to learn, share, practice activities, and develop personalized Climate Change curriculum for their classroom.

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Appendix A

Lesson Thirteen:
The Stabilization Wedges Game

Subject

Science

Estimated Time

Two-Three class periods

In the first period, the Stabilization Triangle and the concept of wedges are discussed and the technologies introduced. Students can further research the technologies as homework. In the second period, students play the game and present their results. Depending on the number of groups in the class, an additional period may be needed for the presentation of results. Assessment and application questions are included and may be assigned as homework after the game has been played, or discussed as a group as part of an additional class period/assignment.

Grade Level

9-12

Objectives

- The core purpose of this game is to convey the scale of effort needed to address the carbon and climate situation and the necessity of developing a portfolio of options.
- By the end of the exercise, students should understand the magnitude of human-sourced carbon emissions and feel comfortable comparing the effectiveness, benefits, and drawbacks of a variety of carbon-cutting strategies.
- The students should appreciate that **there is no easy or "right" solution to the carbon** and **climate problem.**

Materials

- 1 copy of Instructions and Wedge Table **per student (print single-sided to allow use of gameboard pieces!)**
- 1 Wedge Worksheet and 1 Gameboard with multi-colored wedge pieces **per group**, plus scissors for cutting out game pieces and glue sticks or tape to secure pieces to Gameboard
- Optional - overhead transparencies, posters, or other materials for group presentations

Background

Students will learn about the technologies currently available that can substantially cut carbon emissions, develop critical reasoning skills as they create their own portfolio of strategies to cut emissions, and verbally communicate the rationale for their selections. Working in teams, students will develop the skills to negotiate a solution that is both physically plausible and politically acceptable, and defend their solution to a larger group.

Lessons designed by Roberta Hotinski for The Carbon Mitigation Initiative.

Procedure

I. Introduction (40 minutes)

a. **Motivation.** Review the urgency of the carbon and climate problem and potential ways it may impact the students' futures.

b. **Present the Concepts**. Introduce the ideas of the Stabilization Triangle and its seven "wedges".

c. **Introduce the Technologies.** Briefly describe the 15 wedge strategies identified by CMI, then have students familiarize themselves with the strategies as homework. Participants are free to critique any of the wedge strategies that CMI has identified, and teams should feel free to use strategies not on our list.

d. **Form Teams.** Teams of 3 to 6 players are best, and it is particularly helpful to have each student be an appointed "expert" in a few of the technologies to promote good discussions. You may want to identify a recorder and reporter in each group.

e. **Explain the Rules.** See instructions in **Student Game Materials** at back of packet

II. Playing the Game (40 minutes)

a. **Filling in the Stabilization Triangle**. Teammates should work together to build a team stabilization triangle using 7 color-coded wedges labeled with specific strategies. Many strategies can be used more than once.

b. **Wedge Worksheet.** Each team should fill in one **stabilization wedge worksheet** to make sure players haven't violated the constraints of the game, to tally costs, and to predict judges' ratings of their solution. NOTE: Costs are for guidance only – they are not meant to be used to produce a numerical score that wins or loses the game!

c. **Reviewing the Triangle.** Each team should review the strengths and weaknesses of its strategies in preparation for reporting and defending its solutions to the class.

III. Reports (depending on the number of groups this may require an additional class period)

a. Representatives from each team will defend their solutions to the class in a 5-minute report. The presentation can be a simple verbal discussion by the group or a reporter designated by the group. If additional time is available, the presentations could include visual aids, such as a poster, PowerPoint presentation, etc.

b. Students should address not only the technical viability of their wedges, but also the economic, social, environmental and political implications of implementing their chosen strategies on a massive scale.

IV. Judging

In CMI workshops, the teams' triangles have been judged by experts from various global stakeholder groups, such as an environmental advocacy organization, the auto industry, a developing country, or the U.S. Judging ensures that economic and political impacts are considered and emphasizes the need for consensus among a broad coalition of stakeholders. For a classroom, judges can be recruited from local government, colleges, businesses, and non-profit organizations, or a teacher/facilitator can probe each team about the viability of its strategies.

V. Closure/Assessment of Student Learning

In addition to addressing the game and lessons learned, discussion questions are provided below that give opportunity to develop and assess the students' understanding of the wedges concept and its applications.

1) Given physical challenges and risks, how many wedges do you think each wedge strategy can each realistically provide?

2) In choosing wedge strategies, it's important to avoid double counting – removing the same emissions with two different strategies. For example, there are 6 strategies for cutting emissions from electricity, but we project only 5 wedges worth of carbon produced from the electric sector 50 years from now. Can you think of reasons, other than the adoption of alternative or nuclear energy, that emissions from electricity would be lower or higher than we predict? Examples: increased use of carbon-intensive coal versus natural gas (higher), slower population growth (lower), substitution of electricity for fuel, as via plug-in electric cars (higher).

3) Industrialized countries and developing countries now each contribute about half the world's emissions, although the poorer countries have about 85% of the world's population. (The U.S. alone emits one fourth of the world's CO_2.) If we agree to freeze global emissions at current levels, that means if **emissions in one region of the world go up as a result of economic/industrial development, then emissions must be cut elsewhere**. Should the richer countries reduce their emissions 50 years from now so that extra carbon emissions can be available to developing countries? If so, by how much?

4) Nuclear energy is already providing one-half wedge of emissions savings – what do you think the future of these plants should be?

5) Automobile emissions are a popular target for greenhouse gas cuts. What percent of greenhouse gases do you think come from the world's passenger vehicles? (answer: about 18%)

Resources & Feedback

More stabilization wedge resources, including background articles and slides, and a form for feedback are available at http://www.princeton.edu/~cmi/resources/stabwedge.htm.

National Standards Alignment:

National Science Education Standards

Unifying Concepts and Processes (K-12): Systems, Order and Organization

Science as Inquiry, Content Standard (9-12): Abilities necessary to do scientific inquiry; Understandings about scientific inquiry

Science in Personal and Social Perspectives, Content Standard (9-12): Natural and Human Induced Hazards; Environmental Quality

Stabilization Wedges: A Concept & Game

The **Carbon Mitigation Initiative** is a joint project of Princeton University, BP, and Ford Motor Company to find solutions to the greenhouse gas problem. To emphasize the need for early action, Co-Directors Robert Socolow and Stephen Pacala created the concept of stabilization wedges – 25 billion ton "wedges" that need to be cut out of predicted future carbon emissions in the next 50 years to avoid a doubling of atmospheric carbon dioxide over pre-industrial levels.

The following pages contain:

- An introduction to the carbon and climate problem and the stabilization wedge concept (pp. 1-3)
- Descriptions of currently available mitigation tools that have the capacity to reduce future emissions by at least one wedge (pp. 4-8)
- Materials and instructions for carrying out the "Stabilization Wedges Game," an activity that drives home the scale of the carbon mitigation challenge and the tradeoffs involved in planning climate policy (pp. 9-16)

You can download a free up-to-date copy of this guide and view additional resources at our wedge website:

http://www.princeton.edu/~cmi/resources/stabwedge.htm

We hope to revise these materials with your input! If you have questions or feedback, please contact Dr. Roberta Hotinski, Consultant to CMI, at **hotinski@hotmail.com**.

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The Carbon and Climate Problem

Evidence continues to accumulate that carbon dioxide, or CO_2, from fossil fuel burning is causing dangerous interference in the climate. Including 2006, six of the seven warmest years on record have occurred since 2001 and the ten warmest years have occurred since 1995. Tropical glaciers with ice thousands and tens of thousands years old are disappearing, offering graphic rebuttal to claims that the recent warming is part of a natural cycle. Models predict that, without action to curb the growth of greenhouse gases in the atmosphere, we risk triggering catastrophe -- cessation of the dominant pattern of ocean circulation, loss of the West Antarctic ice sheet, or a several-fold increase in category-five hurricanes.

CO_2 and some other gases in the atmosphere change the climate by letting sunlight pass through the atmosphere and warm the planet, but hindering the escape of heat to outer space (a phenomenon popularly known as "the greenhouse effect"). By burning fossil fuels, which are composed mainly of hydrogen and carbon, we add CO_2 to the atmosphere.

The Earth's atmosphere currently contains about **800 billion tons** of carbon as CO_2, and combustion of fossil fuels currently adds about **7 billion tons of carbon** every year. If we think of the atmosphere as a bathtub, these carbon emissions are like water coming out of the tap to fill the tub (Figure 1). The ocean and land biosphere act as two drains for this bathtub – carbon can be taken out of the atmosphere by being dissolved in the surface ocean or being taken up by growing forests. However, these two "drains" only take out about half the carbon we emit to the atmosphere every year. The remainder accumulates in the atmosphere – currently at a rate of roughly 4 billion tons per year – so the level of carbon in the tub is rising.

The fossil fuel tap was "opened" with the Industrial Revolution. In pre-industrial times, the atmosphere contained only about 600 billion tons of carbon, 200 billion tons less than today (Figure 2). As an illustration of the importance of CO_2 to the Earth's climate, ice core records show that past atmospheric carbon changes of a similar order have meant the difference between Ice Ages and the warmer conditions of the past 10,000 years.

Observations indicate that the carbon already added to the atmosphere has raised the global average temperature by around 1º Fahrenheit since the 19th century, and almost every year the fossil fuel tap is opened wider. An average of many forecasts predicts that we'll be adding **14 billion tons** of carbon per year to the "bathtub" in 50 years, twice today's rate, unless action is taken to control carbon emissions. If we follow this path, the amount of carbon in the atmosphere will reach 1200 billion tons -- **double its pre-industrial value** – well before the end of this century, **and will continue to increase** into the future. As a result, the Earth's temperature is expected to rise at a rate unprecedented in the last 10,000 years. **How can we get off this path?**

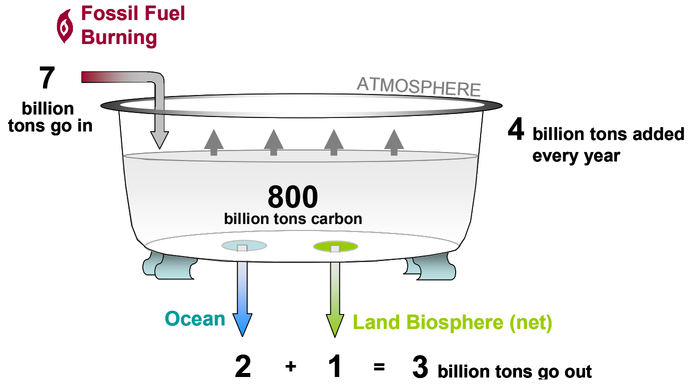


Figure 1. *The atmosphere as a bathtub, with current annual inputs and outputs of carbon. The level in the tub is rising by about 4 billion tons per year.*

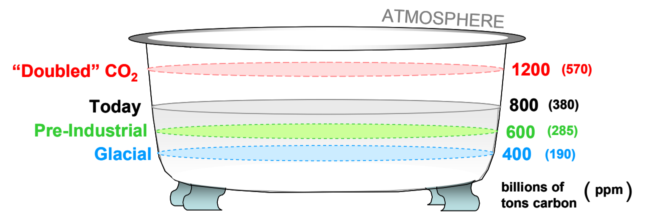


Figure 2. *Past, present, and potential future levels of carbon in the atmosphere in two units. 2.1 billions of tons of carbon = 1 part per million (ppm).*

An Introduction to Stabilization Wedges

The "stabilization wedges" concept is a simple tool for conveying the emissions cuts that can be made to avoid dramatic climate change.

We consider two futures - **allowing emissions to double versus keeping emissions at current levels** for the next 50 years (Figure 3). The emissions-doubling path (black dotted line) falls in the middle of the field of most estimates of future carbon emissions. The climb approxi-mately extends the climb for the past 50 years, during which the world's economy grew much faster than its car-bon emissions. Emissions could be higher or lower in 50 years, but this path is a reasonable reference scenario.

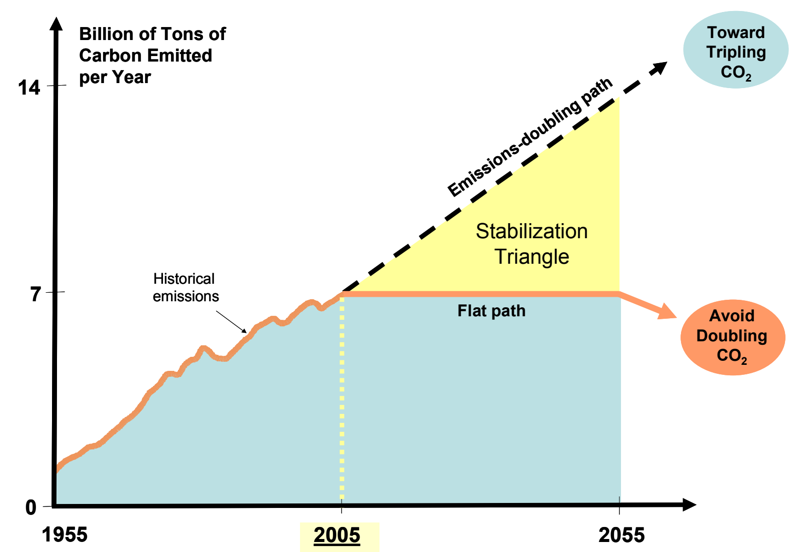


Figure 3. *Two possible emissions scenarios define the "stabilization triangle."*

The emissions-doubling path is predicted to lead to significant global warming by the end of this century. This warming is expected be accompanied by decreased crop yields, increased threats to human health, and more frequent extreme weather events. The planet could also face rising sea-level from melting of the West Antarctic Ice Sheet and Greenland glaciers and destabilization of the ocean's thermohaline circulation that helps redistribute the planet's heat and warm Western Europe.

In contrast, we can prevent a doubling of CO_2 if we can keep emissions flat for the next 50 years, then work to reduce emissions in the second half of the century (Figure 3, orange line). This path is predicted to keep atmospheric carbon under 1200 billion tons (which corresponds to about 570 parts per million (ppm)), allowing us to skirt the worst predicted consequences of climate change.

Keeping emissions flat will require cutting projected carbon output by about 7 billion tons per year by 2055, keeping a total of ~175 billion tons of carbon from entering the atmosphere (see yellow triangle in Figure 3). This carbon savings is what we call the **"stabilization triangle."**

The conventional wisdom has been that only revolutionary new technologies like nuclear fusion could enable such large emissions cuts. There is no reason, however, why one tool should have to solve the whole problem. CMI set out to quantify the impact that could be made by **a portfolio of existing technologies** deployed on a massive scale.

To make the problem more tractable, we divided the stabilization triangle into **seven "wedges."** (Figure 4) A wedge represents a carbon-cutting strategy that has the potential to grow from zero today to avoiding 1 billion tons of carbon emissions per year by 2055, or one-seventh of the stabilization triangle. The wedges can represent ways of either making energy with no or reduced carbon emissions (like nuclear or wind-produced electricity), or storing carbon dioxide to prevent it from building up as rapidly in the atmosphere (either through underground storage or biostorage).

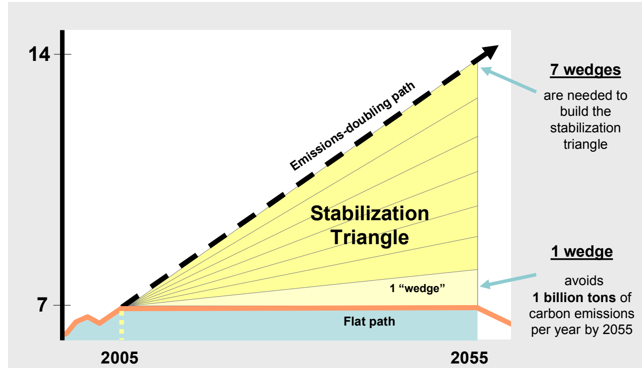


Figure 4. The seven "wedges" of the stabilization triangle.

Keeping emissions flat will require the world's societies to "fill in" the seven wedges of the stabilization triangle. In CMI's analysis, **at least 15 strategies are available <u>now</u>** that, with scaling up, could each take care of at least one wedge of emissions reduction. No one strategy can take care of the whole triangle -- new strategies will be needed to address both fuel and electricity needs, and some wedge strategies compete with others to replace emissions from the same source -- but there is already a more than adequate portfolio of tools available to control carbon emissions for the next 50 years.

Wedge Strategies Currently Available

The following pages contain descriptions of 15 strategies already available that could be scaled up over the next 50 years to reduce global carbon emissions by 1 billion tons per year, or **one wedge.** They are grouped into four major color-coded categories:

Efficiency & Conservation

- Increased transport efficiency
- Reducing miles traveled
- Increased heating efficiency
- Increased efficiency of electricity production

Fossil-Fuel-Based Strategies

- Fuel switching (coal to gas)
- Fossil-based electricity with carbon capture & storage (CCS)
- Coal synfuels with CCS
- Fossil-based hydrogen fuel with CCS

Nuclear Energy

- Nuclear electricity

Renewables and Biostorage

- Wind-generated electricity
- Solar electricity
- Wind-generated hydrogen fuel
- Biofuels
- Forest storage
- Soil storage

Each strategy can be applied to one or more sectors, indicated by the following symbols:

= Electricity Production, = Heating and Direct Fuel Use, = Transportation, = Biostorage

Increased Efficiency & Conservation

1. Transport Efficiency

A typical 30 miles-per-gallon (30 mpg) car driving 10,000 miles per year emits a ton of carbon into the air annually. Today there are about 600 million cars in the world, and it's predicted that there will be about 2 billion passenger vehicles on the road in 50 years. **A wedge of emissions savings would be achieved if the fuel efficiency of all the cars projected for 2055 were doubled from 30 mpg to 60 mpg**. Efficiency improvements could come from using hybrid and diesel engine technologies, as well as making vehicles out of strong but lighter materials.

Cutting carbon emissions from trucks and planes by making these engines more efficient can also help with this wedge. Aviation is the fastest growing component of transportation.

2. Transport Conservation

A wedge would be achieved if the number of miles traveled by the world's cars were cut in half. Such a reduction in driving could be achieved if urban planning leads to more use of mass transit and if telecommuting becomes a good substitute for face-to-face communication.

3. Building Efficiency

Today carbon emissions arise about equally from providing electricity, transportation, and heat for industry and buildings. The largest potential savings in the buildings sector are in space heating and cooling, water heating, lighting, and electric appliances.

It's been projected that the buildings sector as a whole has the technological and economic potential to cut emissions in half. **Cutting emissions by 25% in all new and existing residential and commercial buildings would achieve a wedge worth of emissions reduction.** Carbon savings from space and water heating will come from both end-use efficiency strategies, like wall and roof insulation, and renewable energy strategies, like solar water heating and passive solar design.

4. Efficiency in Electricity Production

Today's coal-burning power plants produce about one-fourth of the world's carbon emissions, so increases in efficiency at these plants offer an important opportunity to reduce emissions. **Producing the world's current coal-based electricity with doubled efficiency would save a wedge worth of carbon emissions.**

More efficient conversion results at the plant level from better turbines, from using high-temperature fuel cells, and from combining fuel cells and turbines. At the system level, more efficient conversion results from more even distribution of electricity demand, from cogeneration (the co-production of electricity and useful heat), and from polygeneration (the co-production of chemicals and electricity).

Due to large contributions by hydropower and nuclear energy, the electricity sector already gets about 35% of its energy from non-carbon sources. Wedges can only come from the remaining 65%.

Suggested Link: **2007 IPCC Mitigation Report, pre-copy edit version**
http://www.mnp.nl/ipcc/pages_media/AR4-chapters.html

Carbon Capture & Storage (CCS)

If the CO_2 emissions from fossil fuels can be captured and stored, rather than vented to the atmosphere, then coal, oil, and natural gas could continue to be used to meet world energy demands without harmful climate consequences. The most economical way to pursue this is to capture CO_2 at large electricity or fuels plants, then store it underground. This strategy, called carbon capture and storage, or **CCS**, is already being tested in pilot projects around the world.

5. CCS Electricity

Today's coal-burning power plants produce about one fourth of the world's carbon emissions and are large point-sources of CO2 to the atmosphere. **A wedge would be achieved by applying CCS to 800 large (1 billion watt) baseload coal power plants or 1600 large baseload natural gas power plants in 50 years. As with all CCS strategies, to provide low-carbon energy the captured CO2 would need to be stored for centuries.**

There are currently 3 pilot storage projects in the world, which each store about 1 million tons of carbon underground per year. Storing a wedge worth of emissions will require 3,500 times the capacity of one of these projects.

6. CCS Hydrogen

Hydrogen is a desirable fuel for a low-carbon society because when it's burned the only emission product is water vapor. Because fossil fuels are composed mainly of carbon and hydrogen they are potential sources of hydrogen fuel, but to have a climate benefit the excess carbon must be captured and stored.

Pure hydrogen is now produced mainly in two industries: ammonia fertilizer production and petroleum refining. Today these hydrogen production plants generate about 100 million tons of capturable carbon. Now this CO2 is vented, but only small changes would be needed to implement carbon capture. **The scale of hydrogen production today is only ten times smaller than the scale of a wedge of carbon capture.**

Distributing hydrogen fuel, however, requires building a hydrogen infrastructure connecting large plants with smaller-scale users.

7. CCS Synfuels

In 50 years a significant fraction of the fuels used in vehicles and buildings may not come from conventional oil, but from coal. When coal is heated and combined with steam and air or oxygen, carbon monoxide and hydrogen are released and can be processed to make a liquid fuel called a "synfuel."

Coal-based synfuels result in nearly twice the carbon emissions of petroleum-derived fuels, since large amounts of excess carbon are released during the conversion of coal into liquid fuel. The world's largest synfuels facility, located in South Africa, is the largest point source of atmospheric CO2 emissions in the world. **A wedge is an activity that, over 50 years, can capture the CO2 emissions from 180 such coal-to-synfuels facilities.**

Suggested link: **U.S. National Energy Technology Laboratory: Sequestration FAQ's**
http://www.netl.doe.gov/technologies/carbon_seq/faqs.html

Fuel Switching

8. Fuel-Switching for Electricity

Because of the lower carbon content of natural gas and higher efficiencies of natural gas plants, producing electricity with natural gas results in only about half the emissions of coal. **A wedge would require 1,400 large (1 billion watt) natural gas plants displacing similar coal-electric plants.**

This wedge would require generating approximately four times the Year 2000 global production of electricity from natural gas. In 2055, 1 billion tons of carbon per year would be emitted from natural gas power plants instead of 2 billion tons per year from coal-based power plants.

Materials flows equivalent to one billion tons of carbon per year are huge: a wedge of flowing natural gas is equivalent to 50 large liquefied natural gas (LNG) tankers docking and discharging every day. Current LNG shipments world-wide are about one-tenth as large.

Suggested link: **U.S. Environmental Protection Agency: Electricity from Natural Gas**
http://www.epa.gov/cleanenergy/natgas.htm

Nuclear Energy

9. Nuclear Electricity

Nuclear fission currently provides about 17% of the world's electricity, and produces no CO_2. **Adding new nuclear electric plants to triple the world's current nuclear capacity would cut emissions by one wedge if coal plants were displaced.**

In the 1960s, when nuclear power's promise as a substitute for coal was most highly regarded, a global installed nuclear capacity of about 2000 billion watts was projected for the year 2000. The world now has about one-sixth of that envisioned capacity. If the remainder were to be built over the next 50 years to displace coal-based electricity, roughly two wedges could be achieved.

In contrast, phasing out the worlds' current capacity of nuclear power would require adding an additional half wedge of emissions cuts to keep emissions at today's levels.

Suggested link: **Climate Change 2001: Mitigation, "Nuclear Power"**
http://www.grida.no/climate/ipcc_tar/wg3/128.htm

Renewable Energy & Biostorage

10. Wind Electricity

Wind currently produces less than 1% of total global electricity, but wind electricity is growing at a rate of about 30% per year. **To gain a wedge of emissions savings from wind displacing coal-based electricity, current wind capacity would need to be scaled up by a factor of 30.**

Based on current turbine spacing on wind farms, a wedge of wind power would require a combined area roughly the size of Germany. However, land from which wind is harvested can be used for many other purposes, notably for crops or pasture.

11. Solar Electricity

Photovoltaic (PV) cells convert sunlight to electricity, providing a source of CO2-free and renewable energy. The land demand for solar is less than with other renewables, but **installing a wedge worth of PV would still require arrays with an area of two million hectares, or 20,000 km^2.** The arrays could be located on either dedicated land or on multiple-use surfaces such as the roofs and walls of buildings. The combined area of the arrays would cover an area the size of the U.S. state of New Jersey, or about 12 times the size of the London metropolitan area.

Since PV currently provides less than a tenth of one percent of global electricity, achieving a wedge of emissions reduction would require increasing the deployment of PV by a factor of 700 in 50 years, or installing PV at 60 times the current rate for 50 years.

A current drawback for PV electricity is its price, which is declining but is still 2-5 times higher than fossil-fuel-based electricity. Also, PV can not be collected at night and, like wind, is an intermittent energy source.

12. Wind Hydrogen

Hydrogen is a desirable fuel for a low-carbon society because when it's burned the only emission product is water vapor. To make hydrogen fuel from wind energy, electricity generated by wind turbines is used in electrolysis, a process that liberates hydrogen from water. **Wind hydrogen displacing vehicle fuel is only about half as efficient at reducing carbon emissions as wind electricity displacing coal electricity, and 4 million (rather than 2 million) windmills would be needed for one wedge of emissions reduction.** That increase would require scaling up current wind capacity by about 80 times, requiring a land area roughly the size of France.

Unlike hydrogen produced from fossil fuels with CCS, wind hydrogen could be produced at small scales where it is needed. Wind hydrogen thus would require less investment in infrastructure for fuel distribution to homes and vehicles.

Renewables & Biostorage (cont'd)

13. Biofuels

Because plants take up carbon dioxide from the atmosphere, combustion of "biofuels" made from plants like corn and sugar cane simply returns borrowed carbon to the atmosphere. Thus burning biofuels for transportation and heating will not raise the atmosphere's net CO2 concentration.

The land constraints for biofuels, however, are more severe than for wind and solar electricity - just one wedge worth of carbon-neutral biofuels would require 1/6th of the world's cropland and an area roughly the size of India. Bioengineering to increase the efficiency of plant photosynthesis and use of crop residues could reduce that land demand, but large-scale production of plant-based biofuels will always be a land-intensive proposition.

Ethanol programs in the U.S. and Brazil currently produce over 35 billion liters of biofuel per year from corn and sugarcane, respectively. **One wedge of biofuels savings would require increasing today's ethanol production by about 30 times, and making it sustainable.**

14. Forest Storage

Land plants and soils contain large amounts of carbon. Today, there is a net *removal* of carbon from the atmosphere by these "natural sinks," in spite of deliberate deforestation by people that *adds* between 1 and 2 billion tons of carbon to the atmosphere. Evidently, the carbon in forests is increasing elsewhere on the planet.

Land plant biomass can be increased by both reducing deforestation and planting new forests. **Halting global deforestation in 50 years would provide one wedge of emissions savings.** To achieve a wedge through forest planting alone, new forests would have to be established over an area the size of the contiguous United States.

15. Soil Storage

Conversion of natural vegetation to cropland reduces soil carbon content by one-half to one-third. However, soil carbon loss can be reversed by agricultural practices that build up the carbon in soils, such as reducing the period of bare fallow, planting cover crops, and reducing aeration of the soil (such as by no till, ridge till, or chisel plow planting). **A wedge of emissions savings could be achieved by applying carbon management strategies to all of the world's existing agricultural soils.**

Suggested links:
U.S. DOE, Energy Efficiency & Renewable Energy
http://www.eere.energy.gov/

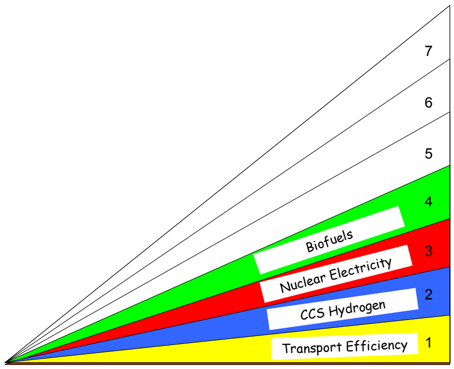
Climate Change 2001: Mitigation, "Land Use, Land-Use Change, and Carbon Cycling in Terrestrial Ecosystems"
http://www.grida.no/climate/ipcc_tar/wg3/158.htm

Student Game Instructions & Materials

The goal of this game is to construct a stabilization triangle using seven wedge strategies, with only a few constraints to guide you. From the 15 potential strategies, choose 7 wedges that your team considers the best global solutions. Keep costs and impacts in mind.

1) **Find the Wedge Gameboard** in the back of this packet and cut apart the red, green, yellow, and blue wedge pieces supplied (if not already done for you).

2) **Read the information** on each of the 15 strategies in the **Wedge Table** below. Costs ($, $$, $$$) are indicated on a relative basis, and are intended only to provide guidance, not a numerical score.



3) Each team should **choose one wedge strategy at a time** to fill the 7 spots on the wedge gameboard (see illustration of gameboard with 4 wedges filled in at left – this is only an example!).

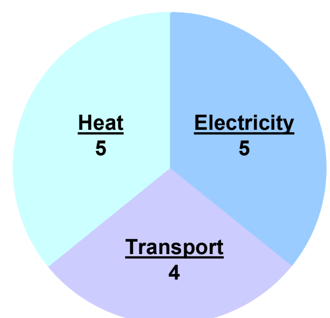
4) **The four colors of the wedge pieces indicate the major category** (fossil fuel-based (blue), efficiency and conservation (yellow), nuclear (red), and renewables and biostorage (green)). Choose a red, yellow, blue, or green wedge for your strategy, then **label the wedge to indicate the specific strategy** (examples shown in illustration at left).

5) **Most strategies may be used more than once**, **but not all cuts can come from one energy sector.**

Of the 14 billion tons of carbon emitted in the 2055 baseline scenario, we assume electricity production accounts for 5 wedges, transportation fuels accounts for 4 wedges, and direct fuel use for heat and other purposes accounts for 5 wedges (see pie chart right).

Because biostorage takes carbon from all sources out of the atmosphere, biostorage wedges do not count toward an energy sector.

Carbon Emissions by Sector



Need 7 wedges – not all wedges can come from one energy sector!

6) **Cost and impacts must be considered.** Each wedge should be viewed in terms of both technical and political viability.

7) For each of the 7 strategies chosen, each team should **fill out one line in the Wedge Worksheet**. After all 7 wedges have been chosen, tally total cuts from each energy sector (Electricity, Transport, and Heat) and costs. Use the scoring table to predict how different interest groups would rate your wedge on a scale from 1 to 5.

8) Each team should **give a 5-minute oral report** on the reasoning behind its triangle. The report should justify your choice of wedges to the judge(s) and to the other teams. **Note: There is no "right" answer** – the team that makes the best case wins, not necessarily the team with the cheapest or least challenging solution

Stabilization Wedges – 15 Ways to Cut Carbon

(Electricity icon) = Electricity Production, (House icon) = Heating and Direct Fuel Use, (Car icon) = Transportation, (Tree icon) = Biostorage

Strategy	Sector	Description	1 wedge could come from...	Cost	Challenges
1. Efficiency – Transport	Transportation	Increase automobile fuel efficiency (2 billion cars projected in 2050)	**… doubling the efficiency of all world's cars from 30 to 60 mpg**	$	Car size & power
2. Conservation - Transport	Transportation	Reduce miles traveled by passenger and/or freight vehicles	**… cutting miles traveled by all passenger vehicles in half**	$	Increased public transport, urban design
3. Efficiency -Buildings	Electricity Production, Heating and Direct Fuel Use	Increase insulation, furnace and lighting efficiency	**… using best available technology in all new and existing buildings**	$	House size, consumer demand for appliances
4. Efficiency –Electricity	Electricity Production	Increase efficiency of power generation	**… raising plant efficiency from 40% to 60%**	$	Increased plant costs
5. CCS Electricity	Electricity Production	CO_2 from fossil fuel power plants captured, then stored underground (700 large coal plants or 1400 natural gas plants)	**… injecting a volume of CO2 every year equal to the volume of oil extracted**	$$	Possibility of CO_2 leakage
6. CCS Hydrogen	Transportation, Heating and Direct Fuel Use	Hydrogen fuel from fossil sources with CCS displaces hydrocarbon fuels	**… producing hydrogen at 10 times the current rate**	$$$	New infrastructure needed, hydrogen safety issues
7. CCS Synfuels	Transportation, Heating and Direct Fuel Use	Capture and store CO_2 emitted during synfuels production from coal	**… using CCS at 180 large synfuels plants**	$$	Emissions still only break even with gasoline
8. Fuel Switching – Electricity	Electricity Production	Replacing coal-burning electric plants with natural gas plants (1400 1 GW coal plants)	**… using an amount of natural gas equal to that used for all purposes today**	$	Natural gas availability
9. Nuclear Electricity	Electricity Production	Displace coal-burning electric plants with nuclear plants (2 x current capacity)	**… ~3 times the effort France put into expanding nuclear power in the 1980's, sustained for 50 years**	$$	Weapons proliferation, nuclear waste, local opposition
10. Wind Electricity	Electricity Production	Wind displaces coal-based electricity (30 x current capacity)	**… using area equal to ~3% of U.S. land area for wind farms**	$$	Not In My Back Yard (NIMBY)
11. Solar Electricity	Electricity Production	Solar PV displaces coal-based electricity (700 x current capacity)	**.. using the equivalent of a 100 x 200 km PV array**	$$$	PV cell materials
12. Wind Hydrogen	Transportation, Heating and Direct Fuel Use	Produce hydrogen with wind electricity	**… powering half the world's cars predicted for 2050 with hydrogen**	$$	NIMBY, Hydrogen infrastructure, safety
13. Biofuels	Transportation, Heating and Direct Fuel Use	Biomass fuels from plantations replace petroleum fuels	**… scaling up world ethanol production by a factor of 30**	$$	Biodiversity, competing land use
14. Forest Storage	Biostorage	Carbon stored in new forests	**… halting deforestation in 50 years**	$	Biodiversity, competing land use
15. Soil Storage	Biostorage	Farming techiques increase carbon retention or storage in soils	**… using conservation tillage on all the world's agricultural soils**	$	Reversed if land is deep-plowed later

For more information, go to the Carbon Mitigation Initiative website at http://www.princeton.edu/~cmi

Wedge Worksheet

1. Record your strategies to reduce total fossil fuel emissions by 7 wedges by 2055

(1 "wedge" = 1 billion tons carbon per year)

- You may use a strategy more than once
- Use only whole numbers of wedges
- You may use a maximum of
  - 5 electricity wedges (E)
  - 4 transportation wedges(T)
  - 5 heat or direct fuel use wedges (H)

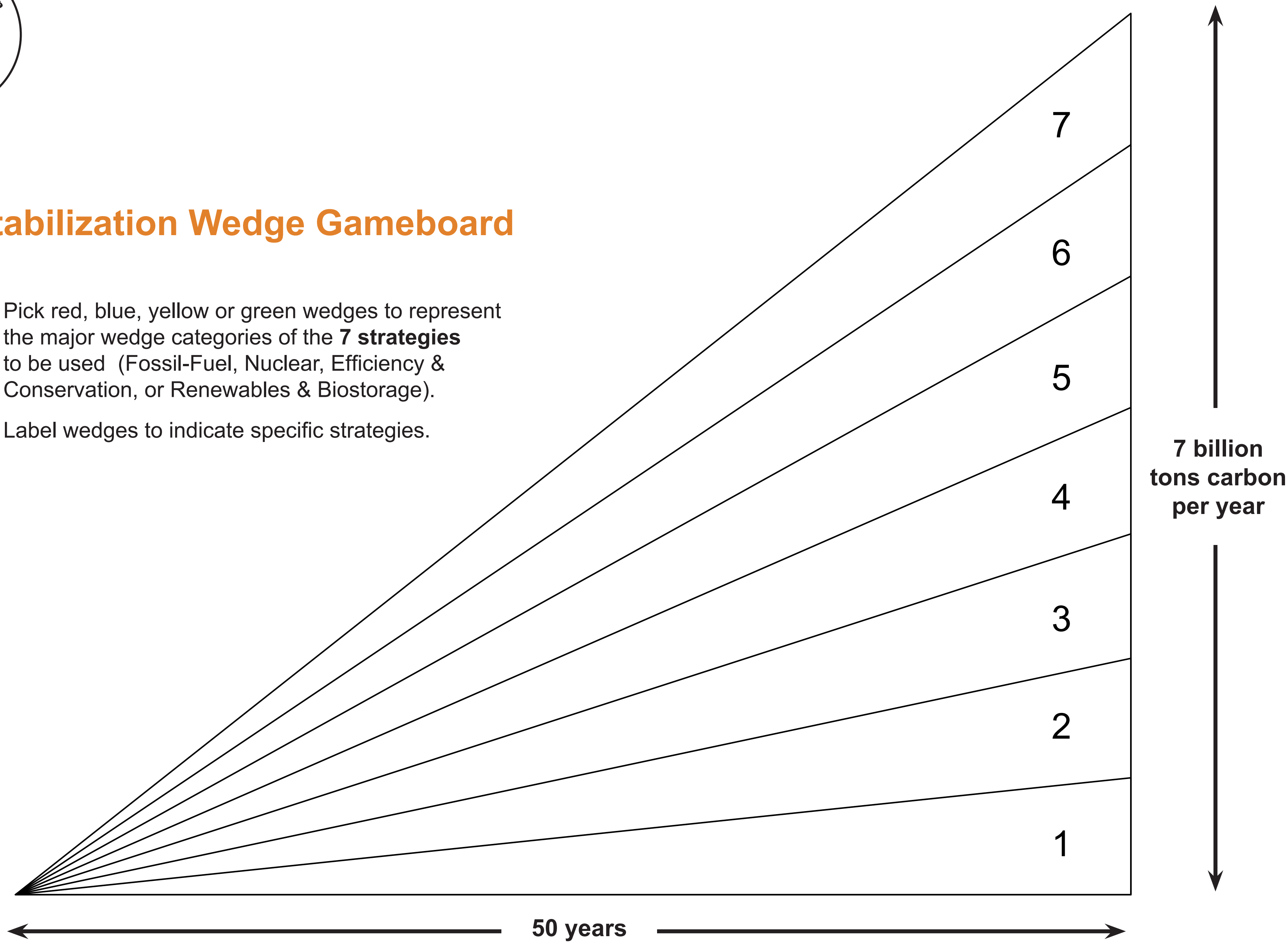
Wedge #	Strategy	Sector E,T,H, or B	Cost $	Challenges
1				
2				
3				
4				
5				
6				
7				
	TOTALS	E=_____ (5 max) T=_____ (4 max) H=_____ (5 max) B=_____	_____	

2. Guess the score each stakeholder group would give your team's triangle on a scale of 1 to 5 (5 = best).

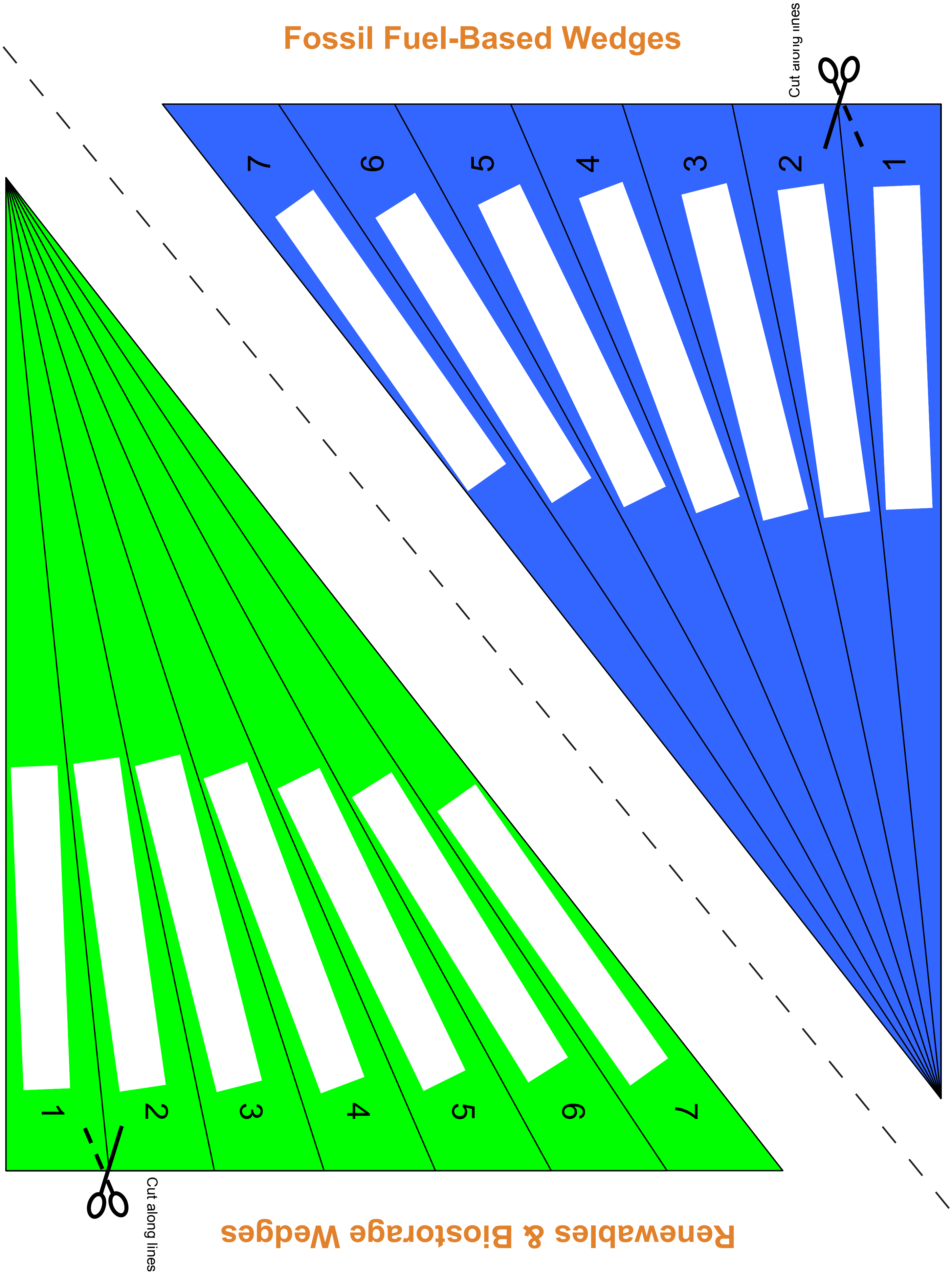
Judge:	Taxpayers/ Consumers	Energy Companies	Environmental Groups	Manufacturers	Industrialized country governments	Developing country governments
Score:						

Stabilization Wedge Gameboard

1. Pick red, blue, yellow or green wedges to represent the major wedge categories of the **7 strategies** to be used (Fossil-Fuel, Nuclear, Efficiency & Conservation, or Renewables & Biostorage).
2. Label wedges to indicate specific strategies.

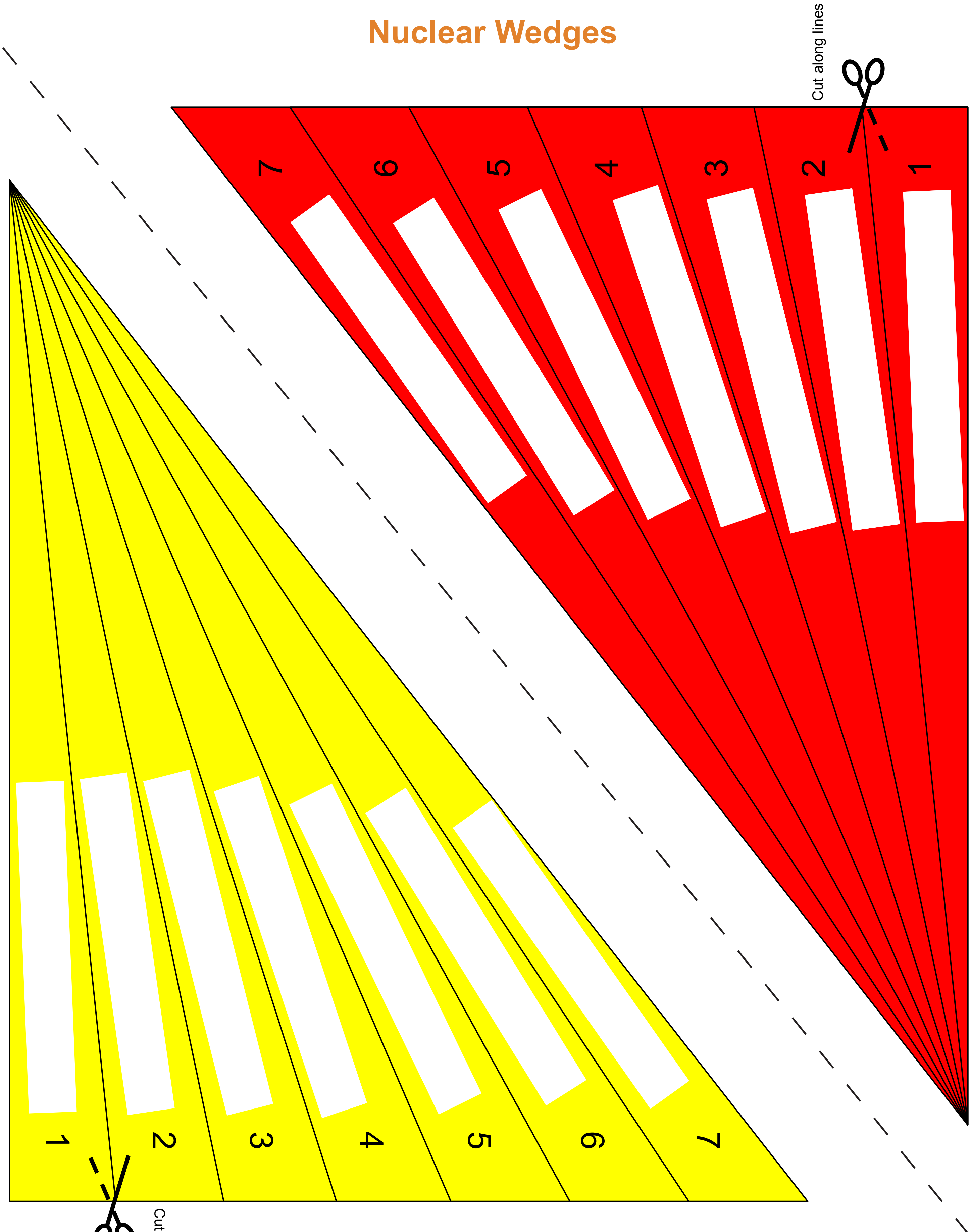


Fossil Fuel-Based Wedges



Renewables & Biostorage Wedges

Nuclear Wedges

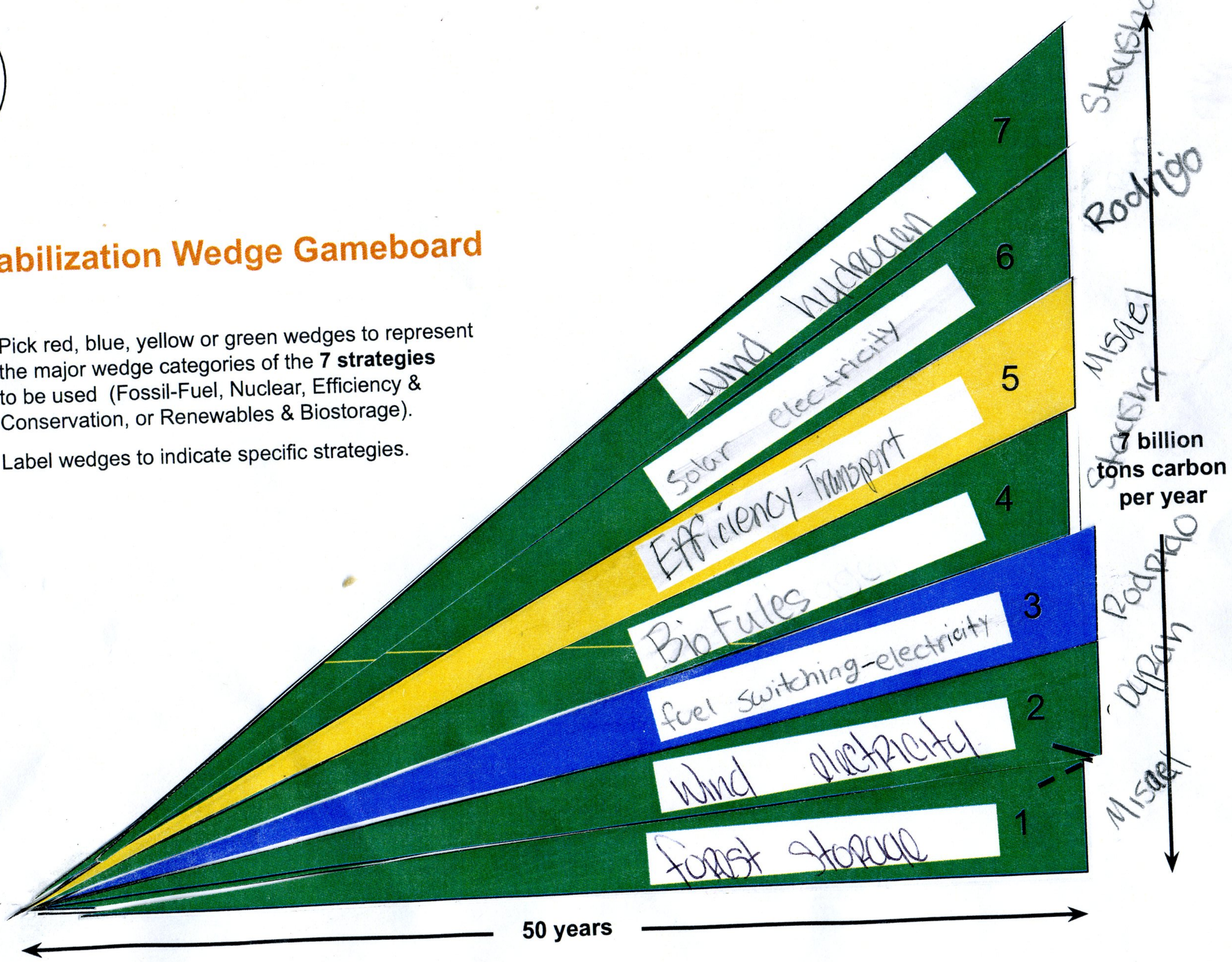


Efficiency & Conservation Wedges

Appendix B

Stabilization Wedge Gameboard

1. Pick red, blue, yellow or green wedges to represent the major wedge categories of the **7 strategies** to be used (Fossil-Fuel, Nuclear, Efficiency & Conservation, or Renewables & Biostorage).
2. Label wedges to indicate specific strategies.



Appendix C

A 3rd Period (Sperber) Jessica Vences.

Read the quotes and additional information provided and answer the questions below.

1. "The U.S. Environmental Protection Agency is carrying out one of the biggest power grabs in American history. The agency has positioned itself to regulate fuel economy, set climate policy for the nation and amend the Clean Air Act--powers never delegated to it by Congress. It has done this by declaring greenhouse gas emissions a danger to public health and welfare, in a proceeding known as the "endangerment finding.'"

— By George Allen and Marlo Lewis, Published in Forbes Magazine and on the Heartland's Environment and Climate News website on 05/19/2010

George Allen is a former U.S. senator and governor from Virginia. He is also chairman of the American Energy Freedom Center. Marlo Lewis is a senior fellow in environmental policy at the Competitive Enterprise Institute. This article was initially published at Forbes.com.

a. Does the information seem to be truthful? Why?
yes because they include a lot of information and a lot of stuff that's real.

b. Do the authors seem to have an opinion about the subject or are they simply reporting the facts? I think that the authors seem to be telling the facts.

c. Do the authors appear to be credible (Worthy of confidence; reliable) sources?
yes because it soods like they are trying to help the envroment.

2. "In a sharp change from its cautious approach in the past, the National Academy of Sciences on Wednesday called for taxes on carbon emissions, a cap-and-trade program for such emissions or some other strong action to curb runaway global warming.

Such actions, which would increase the cost of using coal and petroleum — at least in the immediate future — are necessary because "climate change is occurring, the Earth is warming ... concentrations of carbon dioxide are increasing, and there are very clear fingerprints that link [those effects] to humans," said Pamela A. Matson of Stanford University, who chaired one of five panels organized by the academy at the request of Congress to look at the science of climate change and how the nation should respond."

— By Thomas H. Maugh II, Published in the Los Angeles Times on May 19, 2010

No additional information was provided about the author.

a. Does the information seem to be truthful? Why?
yes. because they say alot of info.

b. Do the authors seem to have an opinion about the subject or are they simply reporting the facts? I think they are simply telling the facts.

c. Do the authors appear to be credible (Worthy of confidence; reliable) sources?
yes.