Princeton University

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The Stabilization Triangle:

Tackling the Carbon and Climate Problem With Today's Technologies

CMI Carbon Mitigation Initiative

The Stabilization Triangle: A Concept & Game

Background

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 Steve Pacala created the concept of stabilization wedges – 25 billion ton "slices" that need to be cut out of predicted future carbon emissions to avoid a doubling of atmospheric carbon dioxide over pre-industrial levels.

The following pages contain:

- an introduction to the stabilization wedge concept
- descriptions of currently available mitigation tools that have the capacity to reduce future emissions by at least one wedge
- materials for a stabilization wedge game that drives home the scale of the carbon mitigation challenge and the tradeoffs involved in planning climate policy.

For more information, contact CMI.

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The Carbon Mitigation Initiative (CMI) is a 10-year program at Princeton University supported by BP and Ford Motor Company to find solutions to the greenhouse gas problem. Over 60 CMI researchers in science, engineering, and policy are developing strategies to reduce global carbon emissions safely, effectively, and affordably.

The Purpose of the Wedge Game

To provide hands-on experience with the challenges involved in cutting emissions, CMI developed the "Stabilization Wedge Game" in 2004. It was first used for CMI's annual meeting, where it was played by 50 players from industry, academia, and the non-profit sector. Subsequent games have been carried out with players from a variety of backgrounds, and the game is adaptable for use with different audiences.

The goal of the game is to build a plausible and politically acceptable portfolio of strategies to keep global carbon emissions flat for the next 50 years. Teams can choose to use each strategy more than once, but must consider the potential physical and economic limitations of each strategy.

In CMI workshops, the teams' triangles are evaluated and scored by judges with expertise in various fields and a variety of political viewpoints. The judging ensures that economic and political impacts of different wedges are considered and drives home the concept that a global solution will require participation by a broad coalition of stakeholders. Judges can be recruited from local government, universities, businesses, and non-profit organizations, or, if necessary, the judging component could be carried out by a game leader who probes each team about the viability of their strategies.

There is no "right answer" in the stabilization wedge game. Creativity is encouraged - there is an "Other" wedge for teams to use if they believe an approach not detailed in the materials promises a wedge worth of emission savings, and participants should feel free to critique any of the wedge strategies that CMI has identified. The core purpose of this game is to impress on participants the scale of the effort needed to cut carbon emissions, and the necessity of developing a portfolio of options for carbon mitigation.

If you play the game, we ask that you share the results with CMI. We are collecting data from games around the world to see what wedges different participants pick, and why, and we appreciate feedback to help us make the game a more useful educational tool for new audiences. The Wedge Game is always undergoing development, so make sure to check the CMI web page (http://www.princeton.edu/~cmi) for the latest materials.

What is the Stabilization Triangle ....

Carbon emissions from fossil fuel burning are projected to double in the next 50 years (Figure 1), keeping the world on course to more than **triple** the atmosphere's carbon dioxide (CO_2) concentration from its pre-industrial level. This path (black line) is predicted to lead to significant global warming by the end of this century, along with decreased crop yields, increased threats to human health, and more frequent extreme weather events.

In contrast, **if emissions can be kept flat** over the next 50 years (orange line), we can steer a safer course. The flat path, followed by emissions reductions later in the century, is predicted to limit CO_2 rise to less than a doubling and skirt the worst predicted consequences of climate change

Keeping emissions flat for 50 years will require **trimming projected carbon output by roughly 7 billion tons per year** by 2055, keeping a total of ~175 billion tons of carbon from entering the atmosphere (yellow triangle). We refer to this carbon savings as the **"stabilization triangle."**

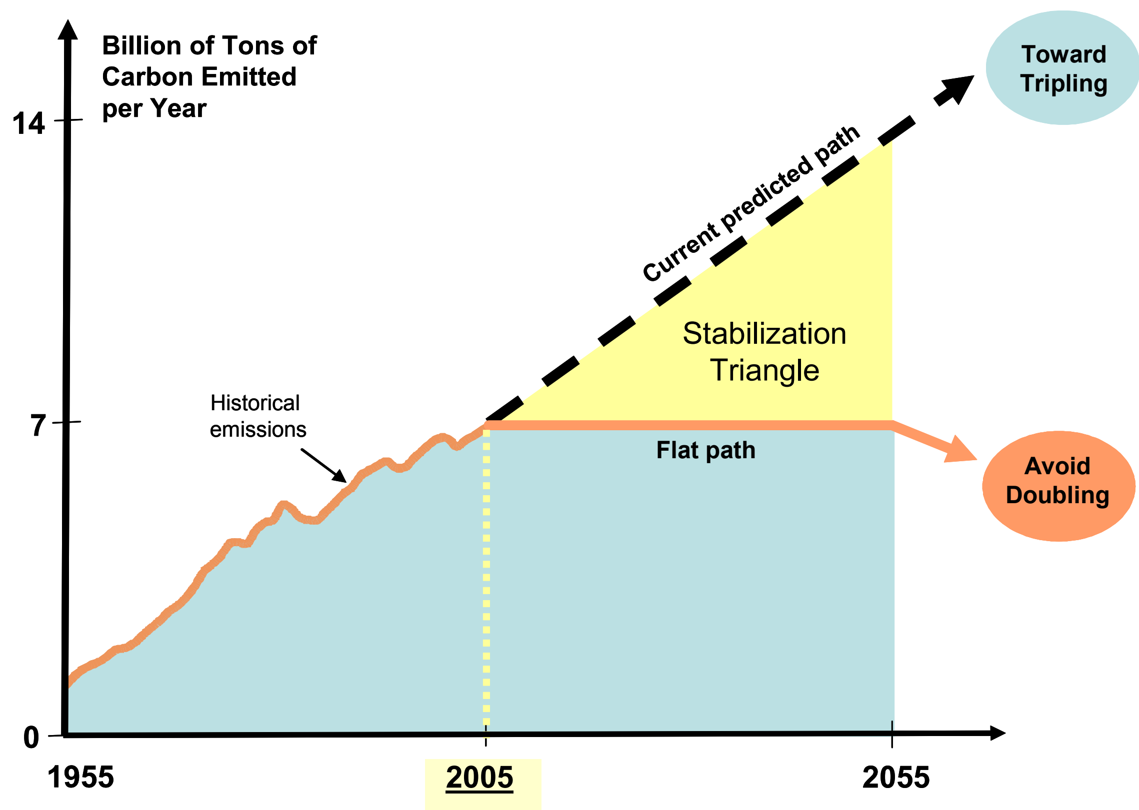


Figure 1

....................................and How Can We Build it?

To keep pace with global energy needs at the same time, the world must find energy technologies that emit **little to no carbon**, plus develop the capacity for carbon storage. Many strategies available today can be scaled up to reduce emissions by at least **1 billion tons of carbon per yea**r by 2055. We call this reduction a **"wedge"** of the triangle (Figure 2). By embarking on several of these wedge strategies now, the world can take a big bite out of the carbon problem instead of passing the whole job on to future generations.

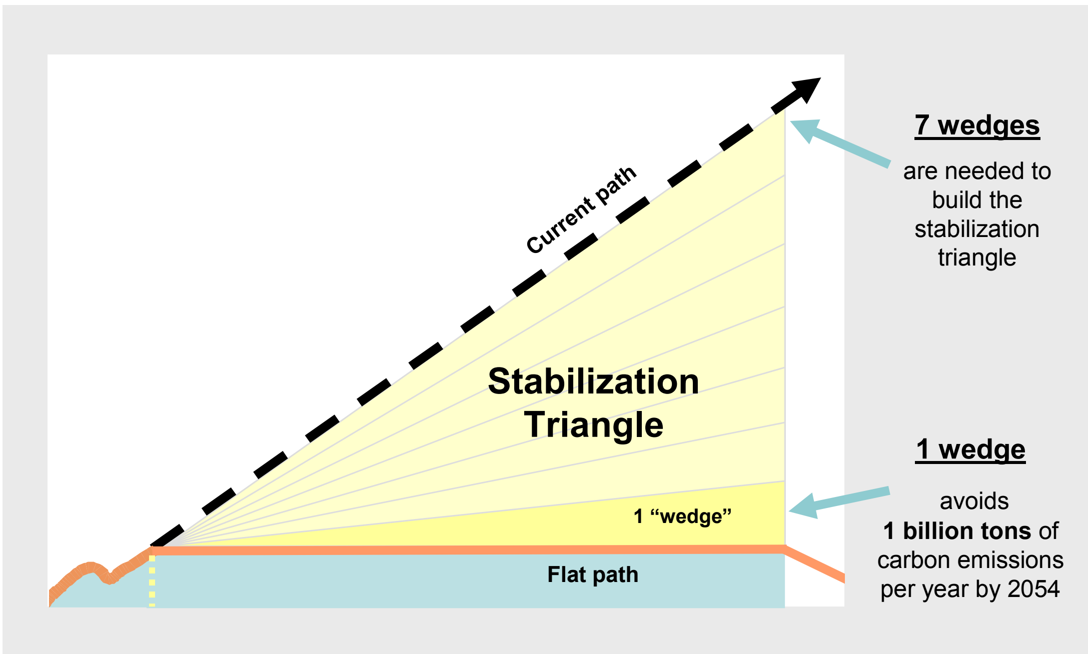


Figure 2

Each of the **14 strategies** on the following pages has the potential to reduce global carbon emissions by **at least 1 billion tons per year by 2055, or 1 wedge**. A combination of strategies will be needed to build the **7 wedges** of the stabilization triangle.

No one strategy will suffice to build the entire stabilization 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. Still, there is a more than adequate **portfolio of tools already available** to build the stabilization triangle and **control carbon emissions for the next 50 years.**

Wedge Strategies Currently Available ………………..

Below are descriptions of **14 strategies already available** that be scaled up to reduce global carbon emissions by 1 billion tons per year, or **one wedge**, in the next 50 years.

Increased Electric 1, Transportation 2, or Heating 3 Efficiency

There are many opportunities for reducing emissions by increasing efficiencies in the three major sectors of the energy economy – electricity production, transportation fuels, and direct use of fuels in residences and industry.

A wedge would be achieved in the transportation sector if the fuel efficiency of all cars projected for 2055 were doubled from 30 miles per gallon (mpg) to 60 mpg. In the electric sector, producing twice today's electricity at double today's efficiency would save a wedge's worth of emissions. A wedge could also be supplied if best practices were used in all residential and commercial buildings by 2055.

Fuel Switching for Electricity 4 or Heat 5

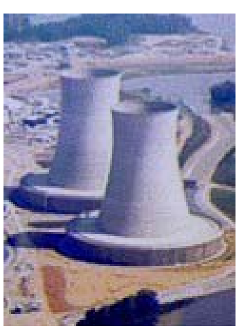
Because combustion of natural gas for electricity and heat produces about half the emissions of coal used for the same purposes, displacing coal with natural gas can provide substantial emissions savings.

Displacing 1400 large coal-plants in favor of natural gas electric plants would save one wedge worth of emissions. Ending all small-scale coal use, practiced primarily in the developing world, or displacing coal used for industrial purposes might each also supply a wedge.

Carbon Capture and Storage (CCS) for Electricity 6 or Hydrogen 7

If the CO_2 emissions from fossil fuels can be captured and stored, rather than being vented to the atmosphere, then coal and natural gas could continue to be used to meet world electricity demands without harmful climate consequences.

To achieve a wedge worth of emissions savings from electricity, CO_2 would need to be captured from about 800 large coal-electric plants, or 1600 natural gas plants. This CO_2 must also be stored. Current storage demonstration projects are each injecting about 1 million tons of CO_2 underground per year – a wedges' worth of storage will require about 3500 more of these projects by 2055.



Nuclear Electricity 8 or Hydrogen 9

Nuclear fission currently provides about 17% of the world's electricity, and produces no CO_2. New nuclear plants providing double the world's current nuclear capacity would be needed to cut emissions by one wedge. Although more expensive than fossil-fuel based electricity, subsidies and high coal and natural gas prices can make this technology economically competitive.

Next generation nuclear fission plants might be designed to produce the high-temperatures necessary for thermochemical electrolysis of water and generate hydrogen fuel. Construction costs plus the expense of new infrastructure required for delivering hydrogen fuel add to the cost of this strategy.

Wind Electricity (10) or Hydrogen (11)

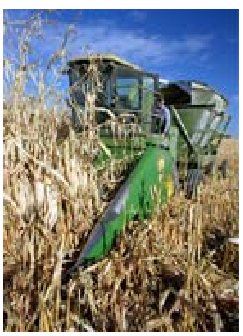
Thousands of giant turbines that harness the wind's energy to make electricity have already been installed around the world, with capacity increasing at about 30% per year. It would take the installation of 2 million additional windmills covering an area about the size of Germany to provide a wedge worth of emissions reduction. Wind's contribution may be limited by its intermittent nature.

The electricity produced by windmills could also be used to split water molecules and make carbon-free hydrogen fuel for transportation or heat. Because making the fuel involves an extra step, 4 million windmills would be needed to provide a wedge worth of emissions reductions by replacing fossil fuels with hydrogen. The costs of new infrastructure requirements for hydrogen add to this strategies' cost.

Solar Electricity (12)

Photovoltaic (PV) cells convert sunlight to electricity, providing a source of CO2-free andrenewable energy. Solar PV capacity has recently been expanding at a rate of about 30% per year, but still provides less than 0.1% of the world's energy.

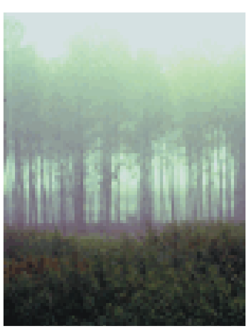
The land demand for solar is less than with other renewables, but installing a wedge worth of PV would still require arrays with a combined area the size of New Jersey. A more important drawback for PV is it's price, which is declining but is still 2-5 times higher than fossil-fuel-based electricity. Like wind, PV is an intermittent energy source.



Biofuels (13)

Because plant matter is created by photosynthesis using carbon dioxide from the atmosphere, combustion of "biofuels" made from plants like corn and sugar cane simply returns borrowed carbon to the atmosphere. Burning biofuels from plants that are grown sustainably thus has no net effect on the atmosphere's carbon dioxide 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. 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.



Natural Sinks (14)

Land plants store huge amounts of carbon, so fostering that reservoir by creating forest plantations and limiting deforestation can combat the emissions humans release to the atmosphere. Conservation tillage, in which farmers use practices designed to avoid carbon loss from soils, also has the potential to provide substantial emissions reductions if used around the globe.

Like biofuels, though, natural sinks have finite capacities constrained by land area. For example, halting global deforestation and increasing the current rate of forest planting by a factor of 2 would only store enough carbon to provide one wedge of the stabilization triangle. Similarly, conservation tillage would have to be used on all soils worldwide to cut emissions by one wedge.

The Wedge Game - Overview

The wedge game is an interactive activity for **3 or more teams** of **at least 4 players**.

The Scenario:

It is the summer of 2005 and the world's stakeholders will soon be attending a meeting convened by the Secretariat of the U.N. Framework Convention to plan the post-Kyoto world. Its premise is that the world response will be some "stabilization wedge."

You are part of a team planning the United States' proposal for a post-Kyoto global stabilization triangle.

The Goal:

Your team will **construct a stabilization triangle of seven wedges** using the strategies outlined above, with only a few constraints to guide you.

Choose wedges that your team considers the **best global solution that will also satisfy the team of U.S. stakeholders** who will
osal.

The Rules:

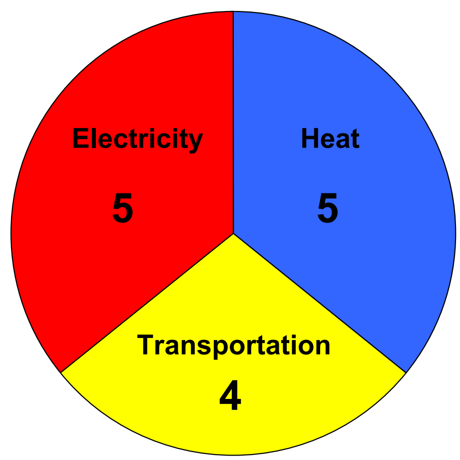
Each strategy can be used more than once, BUT:

1. **Not all cuts can come from one sector.** Of th billion tons of carbon emitted in the 2055 baseline nario, we assume electricity production accounts f wedges, transportation fuels accounts for 4 wedges, and direct fuel use for heat and other purposes accounts for 5 wedges (see pie chart right).

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

3. **The baseline scenario assumes some changes already made.** Our baseline scenario assumes that in 50 years, renewables and nuclear energy increase by 50%, and efficiency increases follow historical trends.

Carbon Emissions by Sector



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

Judging:

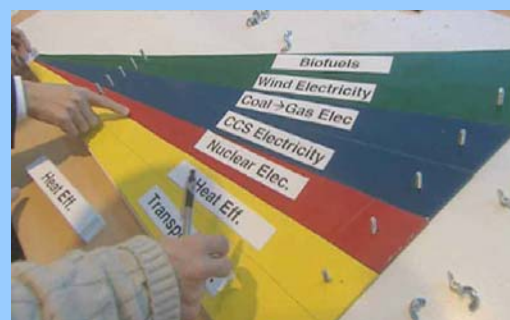
Each team will be judged on its ability to defend its portfolio of strategies, considering both capacity constraints and social (political and economic) impacts of each technology. The team with the highest-scoring stabilization triangle wins the game.

The Wedge Game – Instructions for Play

1) **Read the information** on each of the 15 strategies in the **Wedge Table** below. Cost and impacts are indicated on a relative basis only.

2) Each team should **choose one wedge strategy at a time** to fill the 7 spots on the wedge gameboard.

If not using actual CMI gameboards pictured here, make paper version at the back of this packet.



3) The four colors of the wedge pieces indicate the major category (fossil fuel, efficiency, nuclear, and renewable) – <u>labels should be used to indicate the specific strategy as shown in Wedge Key</u>.

4) For each strategy, each team should **fill out one line in the Wedge Worksheet** to make sure no constraints have been violated, and to tally cost and impacts.

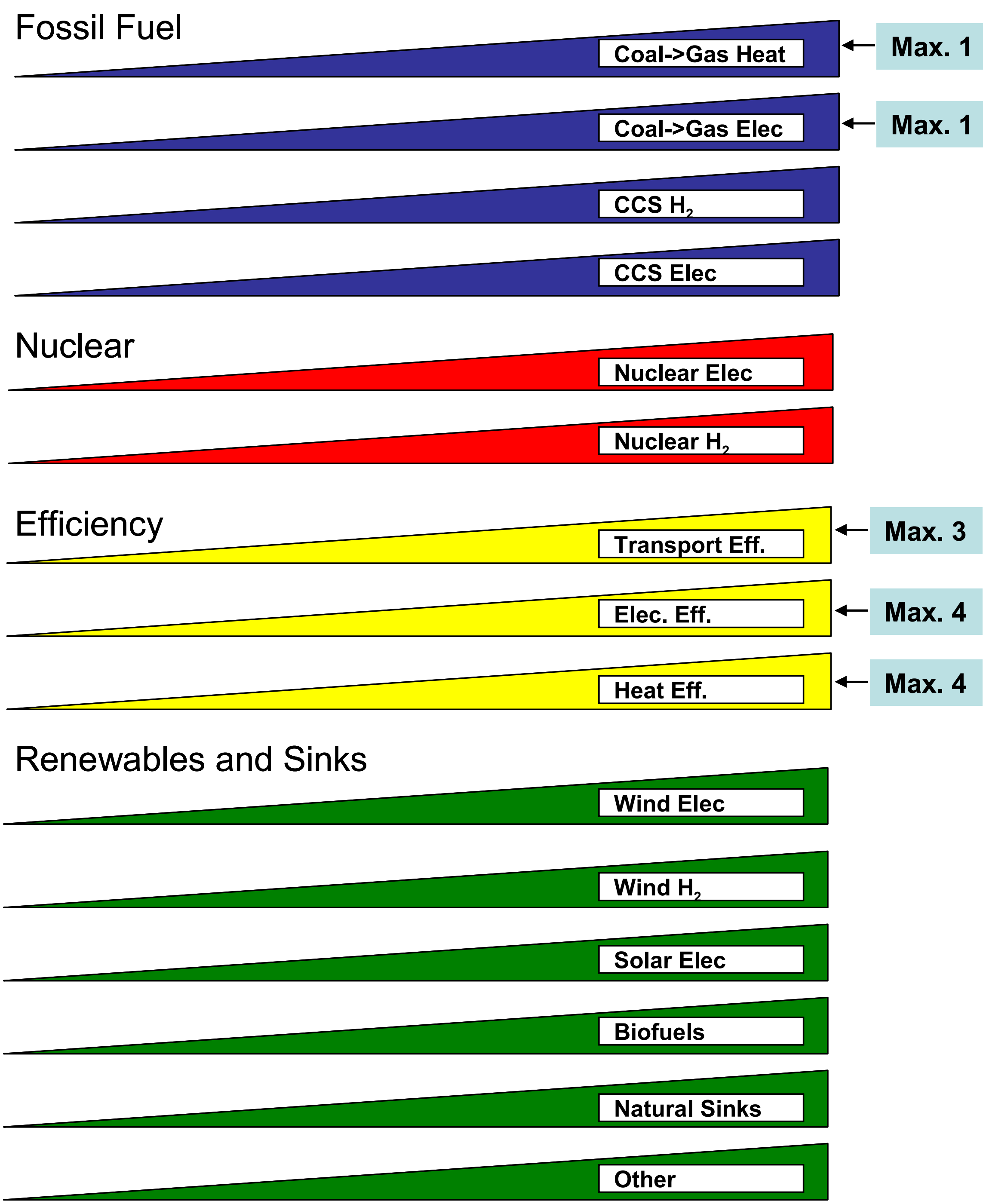
5) Use the **Scoring Worksheet** to predict how the judges will grade your team.

6) 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.

PROCEED TO NEXT PAGE TO BEGIN GAME

Wedge Key

When adding a wedge to your stabilization triangle, first pick a wedge color that indicates the appropriate category (fossil fuel, nuclear, efficiency, or renewables). Use labels supplied (label with pen) to indicate the specific strategy, as shown below in this key.



Wedge Worksheet

Choose 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 slices
- You may only use
  - 5 "E" slices (Electricity)
  - 4 "T" slices (Transportation)
  - 5 "H" slices (Heat)

Slice #	Strategy	E, T, or H	Cost ($)	Challenges (!)
1				
2				
3				
4				
5				
6				
7				
	TOTALS	E=____ (5 max) T=____ (4 max) H=____ (5 max)		

Wedge Table

Strategy	Use Electricity (E), Transport. (T), or Heat (H)	Description	Size of a Wedge	U.S. Potential	Cost	Challenges
Coal to Gas Electricity	**E**	Replacing coal-burning electric plants with natural gas plants (1400 1 GW coal plants)	**1 wedge will require an amount of natural gas equal to that used for all purposes today**	About 100 Gigawatts of new coal electric capacity is predicted to be built in the U.S. through 2025	**$ (max 1)**	Natural gas, geo-politics **!**
Coal to Gas Heat	**H**	Substitute natural gas for domestic heating or industrial processes	**A wedge may be available from displacement of coal in all home heating (DW) or all industrial processes**	U.S. industrial emissions from coal equaled about 5% of a wedge in 2002	**$ (max 1)**	Natural gas, geo-politics **!**
CCS Elec-tricity (Coal or NG)	**E**	CO2 from fossil fuel power plants stored and captured (700 GW of coal or 1400 GW of gas plants)	**1 wedge will require inject-ing a volume of CO_2 every year equal to the volume of oil extracted**	Current U.S. injection of CO_2 for enhanced oil re-covery is the about 1/100 of a wedge (must be permanently stored)	**$$**	CO_2 leakage **!**
CCS H_2	**H,T**	Hydrogen automotive fuel from fossil sources with CCS (displaces 1 billion 30mpg cars)	**1 wedge would require H_2 production at 10 times the current rate**	The U.S. currently pro-duces about 1/4 of the world's hydrogen	**$$$**	Infrastructure; H_2 safety **! !**
Nuclear Electricity	**E**	Displace coal-burning electric plants with nuclear plants (2 x current capacity)	**1 wedge is ~3 times the ef-fort France put into nuclear expansion in a typical year in the 1980's, sustained for 50 years**	104 power plants were built in the U.S. from 1957 to 1979 (~25% of world's plants)	**$$**	proliferation, nu-clear waste, NIMBY **! ! !**
Nuclear H_2	**H,T**	Produce hydrogen with nuclear en-ergy to replace petroleum fuels	**1 wedge is ~5 times the ef-fort France put into nuclear expansion in a typical year in the 1980's, sustained for 50 years**	"	**$$$**	proliferation, nu-clear waste, NIMBY **! ! !**

Strategy	**Use** Electricity (E), Transport. (T), or Heat (H)	**Description**	**Size of a Wedge**	**U.S. Potential**	**Cost**	**Challenges**
Efficiency – Transport	**T**	Increase automobile fuel efficiency (2 billion cars projected in 2050)	**1 wedge would require doubling the efficiency of the all world's cars from 30 to 60 mpg**	The efficiency of U.S. new passenger cars doubled from 1974-1985	**$* (max 3)**	Car size & power, Urban design **! ***
Efficiency – Electricity	**E**	Increase efficiency of lighting, motors, power generation	**1/4 wedge would require replacing ~500 million incandescent bulbs with compact fluorescents annually**	There are about 7 billion incandescent billion bulbs in the U.S.	**$* (max 4)**	Tropical A.C **! ***
Efficiency – Heat	**H**	Increase insulation, furnace efficiency	**1 wedge could be achieved by using best available technology in all new and existing buildings**	The entire U.S. "ENERGY STAR" program saved about $1/40^{th}$ of a wedge in 2003	**$* (max 4)**	House size **! ***
Wind Electricity	**E**	Wind displaces coal (50 x current capacity)	**1 wedge will require area equal to ~3% of U.S. land area**	~6% of U.S. land area is suitable for wind development	**$$**	Regional climate change, NIMBY **!**
Solar Electricity	**E**	Solar PV displaces coal (700 x current capacity)	**1 wedge will requires the equivalent of a 100 x 200 km PV array**	An area 7% the size of Nevada would supply enough energy for an entire wedge	**$$$**	PV cell materials **!**
Biofuels	**T,H**	Biomass fuels from plantations replace petroleum fuels	**1 wedge requires scaling up world ethanol production by a factor of 50**	The U.S. ethanol program currently uses 10% of the corn crop and generates 0.6% of a wedge of emissions savings	**$$**	Biodiversity, competing land use **! ***
Natural Sinks	**n/a**	Storage in new forest, soils	**1 wedge would be achieved by halting deforestation in 50 years and doubling the rate of new plantation creation**	The current rate of forest planting in the U.S. is about 10% of the rate needed for a wedge	**$***	Biodiversity, competing land use **! ***
Wind H_2	**T,H**	Produce H_2 with wind electricity	**1 wedge would require that half the world's cars predicted for 2050 be powered by H_2**	About 17 million cars and light trucks are sold annually in the U.S.	**$$**	Same as wind Electricity **!**

***Strategy becomes increasingly expensive with increasing number of slices: 1st slice = $ or !, 2nd slice = $$ or !!, 3rd slice = $$$ or !!!**

Scoring Worksheet

Guess the score each judge will give your team's wedge on a scale of 1 to 5 (5 = best).

Judge:					
Score:					

Feedback

Please help us evaluate this outreach activity by providing comments on the following:

Introductory Material

Wedge Game Materials

Group Work

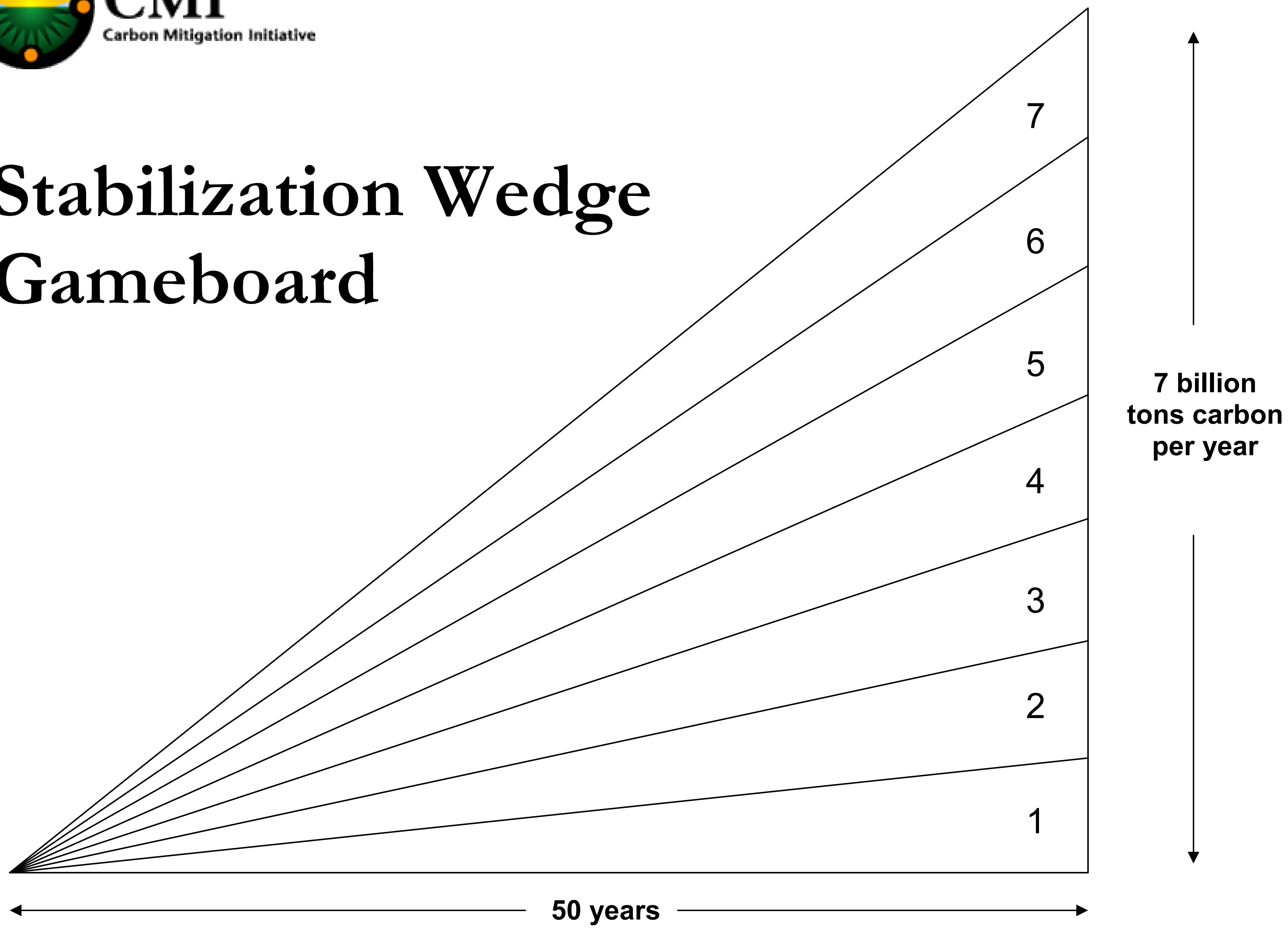
Judging

Discussion

Value of overall learning experience

CMI
Carbon Mitigation Initiative

Stabilization Wedge Gameboard



Wedge Pieces

To fill in the wedge:

- Need 4 copies of entire triangle (print on colored paper or color in):

  1 red triangle (nuclear)
  1 yellow triangle (efficiency)
  1 green triangle (renewables/other)
  1 blue triangle (fossil fuels)

- Cut along lines of each colored triangle to make <u>7 wedges</u> in each color (each "wedge" on gameboard can be filled with any of the four colors)