

Lesson 16: Climate Change Wedge Game

Adopted/Revised From

Princeton University's Carbon Mitigation Initiative

Grade Level

6-12

Objectives

- Evaluate the growth of carbon emissions over time at the global scale
- Compare current rate of emissions with past rates of emissions
- Identify actions that can help to curb the rate of carbon emissions
- Analyze costs and benefits associated with different emissions reductions actions
- Select a set of actions intended to reduce carbon emissions at the global scale
- Debate and defend the selected actions based on research

Overview

Students analyze different actions that would stabilize global carbon emissions at 2005 levels by 2055 and select the actions they think would be best.

Materials (per group)

- Wedge game worksheets (after this lesson plan)

Estimated Cost of Materials

None

Computer Required?

No

Duration

1-2 class periods

Primer References

4.0 Energy and Climate Change

Related Articles

- [“A Plan to Keep Carbon in Check”](#) – Scientific American, September 2006
- [“Can We Bury Global Warming”](#) – Scientific American, July 2005

Engagement

1. What do you know about global climate change?
2. Do you think climate change is a serious problem?
3. Do you think we can take actions to mitigate climate change?
4. What are some actions we can take to mitigate climate change?
5. What are the difficulties associated with taking action on climate change?

Investigation

Now we're going to examine the relationship between carbon dioxide and global climate change and analyze different options for reducing global carbon emissions:

1. Have students watch the seven minute online video entitled "[Why Greenhouse Gases Make the Planet Warmer](#)" (Colorado State University). For those without internet access, students should read Primer sections 4.1 and 4.2.
2. Project the Stabilization Triangle slide and explain how it works:
 - Carbon emissions are expected to follow the current path ramp.
 - The purpose of the Wedge Game is to identify ways to take the "flat path" instead, in which carbon emissions in 2055 would be the same as carbon emissions in 2005.
 - The difference between the current path and the flat path forms a triangle referred to as the "stabilization triangle".
3. Project the Eight Wedges slide and explain how it works:
 - The difference between the current path and the flat path of the stabilization triangle is 8 billion tons of carbon emitted/year.
 - If we divide the triangle by eight, each "wedge" represents 1 billion tons of carbon emissions avoided.
 - We can achieve one wedge of avoided carbon in a number of different ways.
4. Divide the students into small groups (no more than 5 per group recommended) and provide them with each with copies of the wedge game worksheets found after this lesson plan.
5. The groups of students then read through the 15 different strategies that will each achieve one wedge of carbon avoided.
6. They should debate and decide upon the eight strategies they want to select to make up their stabilization triangle.
7. They can either label, cut, and glue their selected strategies onto the gameboard provided (after this lesson plan), or they can simply list their selected eight strategies on the Wedge Worksheet. (If using the gameboard they should also use the Wedge Worksheet.)
8. Groups should fill out the Wedge Worksheet completely.

Class Review

1. Groups should present their stabilization triangles to their classmates, explaining total costs, summarizing challenges, and summarizing perceived stakeholder feedback.

Elaboration

Now let's reach some conclusions about the challenges we face in curbing global climate change:

1. What are the challenges we face in curbing global climate change?
2. What opportunities are most "ripe" for reducing carbon emissions?
3. How might different stakeholders view various strategies?
4. Are some strategies likely to be more widely accepted than others? Why or why not?
5. 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 CO₂.) 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?

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

Instructor Notes

1. To conduct a shortened version of the game, ask students to read only the summaries of the 15 Ways to Cut Carbon (below) and to list their strategies on the Wedge Worksheet instead of use the gameboard.
2. Ideally, students would select no more than 6 electricity wedges, 5 transportation wedges, and 5 heat/direct fuel use wedges so that emissions aren't "double counted".
3. There is no "right" solution to the game!

Extensions

- Ask judges from environmental, energy industry, and government organizations to judge the student presentations.
- Ask the students to make a powerpoint or poster presentation instead of an oral presentation defending their stabilization triangles.

References/For More Information

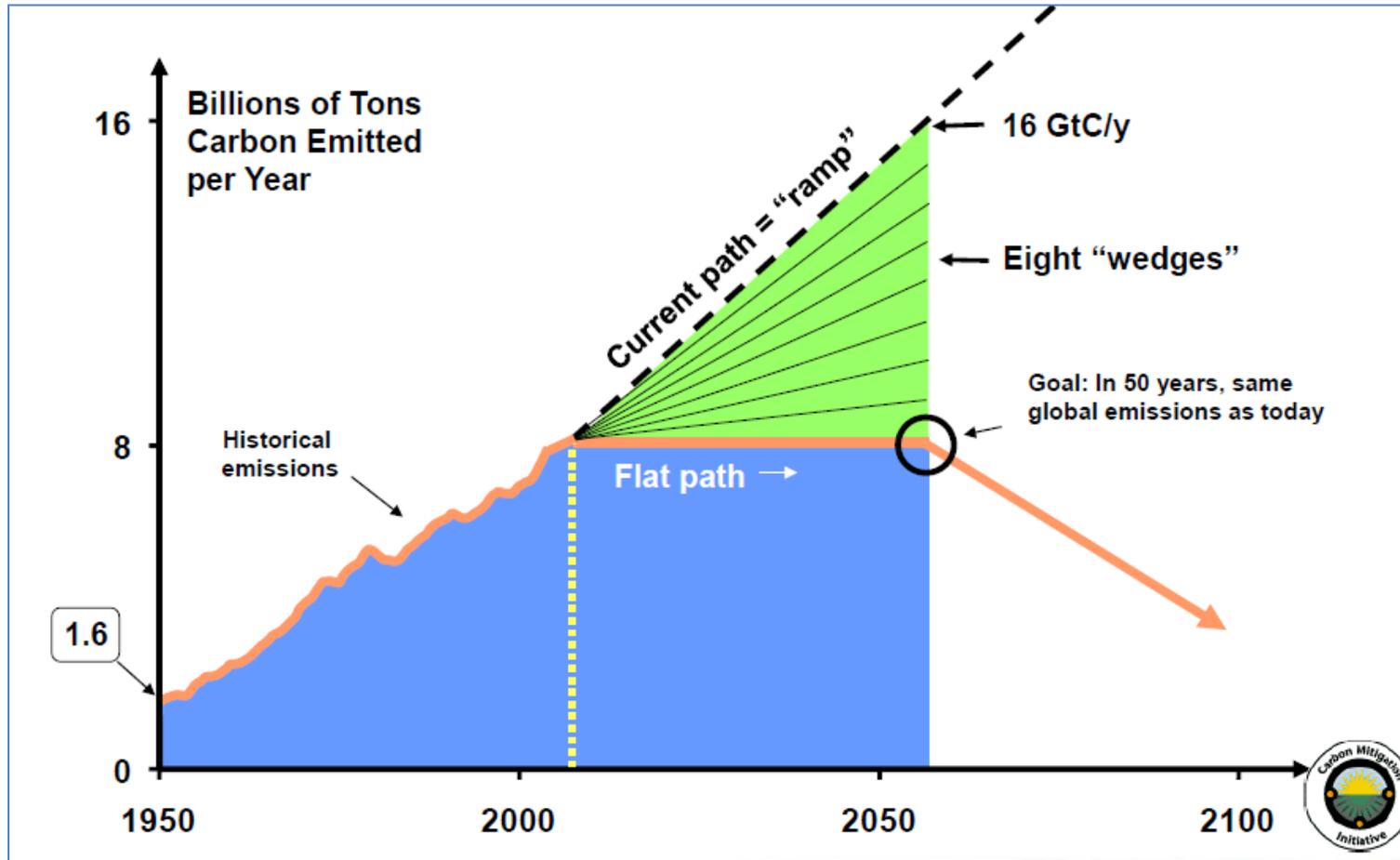
Princeton University Carbon Mitigation Initiative:

<http://cmi.princeton.edu/>

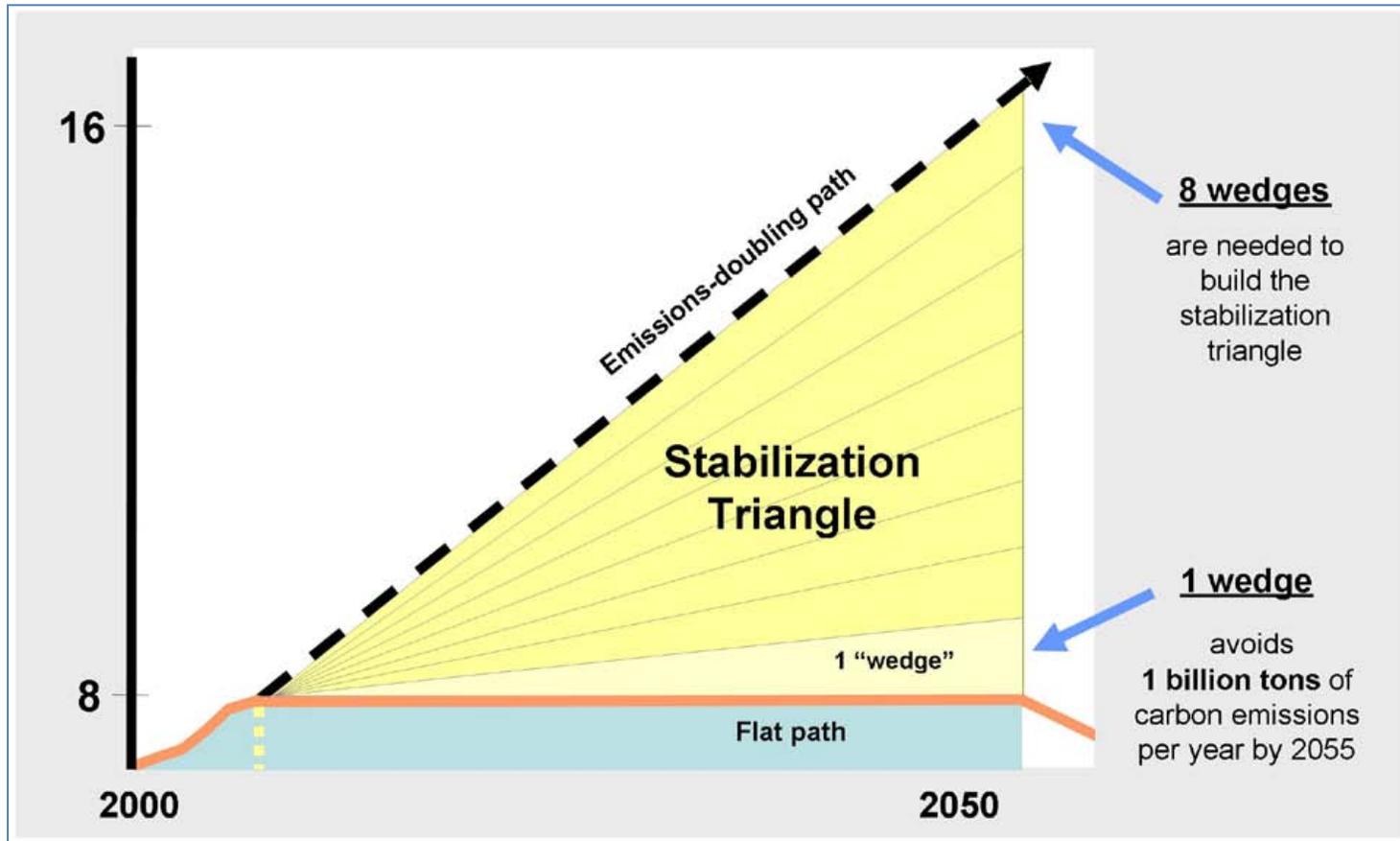
Changing Climates at Colorado State University:

<http://changingclimates.colostate.edu/>

THE STABILIZATION TRIANGLE



EIGHT WEDGES



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 2060 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 electronic communication becomes a good substitute for face-to-face meetings.



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:

IPCC Working Group III Report "Mitigation of Climate Change", Chapters 4, 5 & 6
http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg3_report_mitigation_of_climate_change.htm

Carbon Capture & Storage (CCS)



If the CO₂ emissions from fossil fuels can be captured and stored, rather than vented to the atmosphere, then the world could continue to use coal, oil, and natural gas to meet energy demands without harmful climate consequences. The most economical way to pursue this is to capture CO₂ 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 3500 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, 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 CCS hydrogen, however, requires building infrastructure to connect large hydrogen-producing 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."



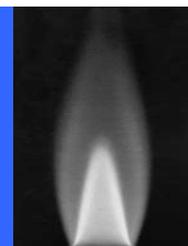
Coal-based synfuels result in nearly twice the carbon emissions of petroleum-derived fuels, since large amounts of excess carbon are released during the conversion of coal into liquid fuel. The world's largest synfuels facility, located in South Africa, is the largest point source of atmospheric CO₂ 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:

IPCC Special Report on Carbon dioxide Capture and Storage, SPM

http://www.ipcc.ch/pdf/specialreports/srccs/srccs_summaryforpolicymakers.pdf

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 1400 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 2060, 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/RDEE/energy-and-you/affect/natural-gas.html>

Nuclear Energy



9. Nuclear Electricity

Nuclear fission currently provides about 17% of the world's electricity, and produces no CO₂. **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 world's current capacity of nuclear power would require adding an additional half wedge of emissions cuts to keep emissions at today's levels.

Nuclear fission power generates plutonium, a fuel for nuclear weapons. These new reactors would add several thousand tons of plutonium to the world's current stock of reactor plutonium (roughly 1000 tons).

IPCC Working Group III Report "Mitigation of Climate Change", Chapter 4 - Energy Supply

<http://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4-wg3-chapter4.pdf>

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 10.**

This increase in capacity would require deployment of about 1 million large windmills. 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 km².** 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 100 in 50 years, or installing PV at about 2.5 times the 2009 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 produce hydrogen with 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 2 million (rather than 1 million) windmills would be needed for one wedge of emissions reduction.** That increase would require scaling up current wind capacity by about 20 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. Using current practices, 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 about 20 billion gallons of biofuel per year from corn and sugarcane. **One wedge of biofuels savings would require increasing today’s global ethanol production by about 12 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/>

IPCC Working Group III Report "Mitigation of Climate Change", Chapters 8 & 9

http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg3_report_mitigation_of_climate_change.htm

Stabilization Wedges – 15 Ways to Cut Carbon

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

Strategy	Sector	Description	1 wedge could come from...	Cost	Challenges
1. Efficiency – Transport		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		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	 	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		Increase efficiency of power generation	... raising plant efficiency from 40% to 60%	\$	Increased plant costs
5. CCS Electricity		90% of CO ₂ from fossil fuel power plants captured, then stored underground (800 large coal plants or 1600 natural gas plants)	... injecting a volume of CO ₂ every year equal to the volume of oil extracted	\$\$	Possibility of CO ₂ leakage
6. CCS Hydrogen	 	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	 	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		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		Displace coal-burning electric plants with nuclear plants (Add double 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		Wind displaces coal-based electricity (10 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		Solar PV displaces coal-based electricity (100 x current capacity)	.. using the equivalent of a 100 x 200 km PV array	\$\$\$	PV cell materials
12. Wind Hydrogen	 	Produce hydrogen with wind electricity	... powering half the world's cars predicted for 2050 with hydrogen	\$\$\$	NIMBY, Hydrogen infrastructure, safety
13. Biofuels	 	Biomass fuels from plantations replace petroleum fuels	... scaling up world ethanol production by a factor of 12	\$\$	Biodiversity, competing land use
14. Forest Storage		Carbon stored in new forests	... halting deforestation in 50 years	\$	Biodiversity, competing land use
15. Soil Storage		Farming techniques increase carbon retention or storage in soils	... practicing carbon management on all the world's agricultural soils	\$	Reversed if land is deep-plowed later

For more information, visit our website at <http://cmi.princeton.edu/wedges>.

Wedge Worksheet

1. Record your strategies to reduce total fossil fuel emissions by 8 wedges by 2060.

(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
 - 6 electricity wedges (E)
 - 5 transportation wedges(T)
 - 5 heat or direct fuel use wedges (H)

	Strategy	Sector (E,T,H or B)	Cost (\$)	Challenges
1				
2				
3				
4				
5				
6				
7				
8				
	TOTALS	E = ___ (6 max) T = ___ (5 max) H = ___ (5 max) B = ___	_____	

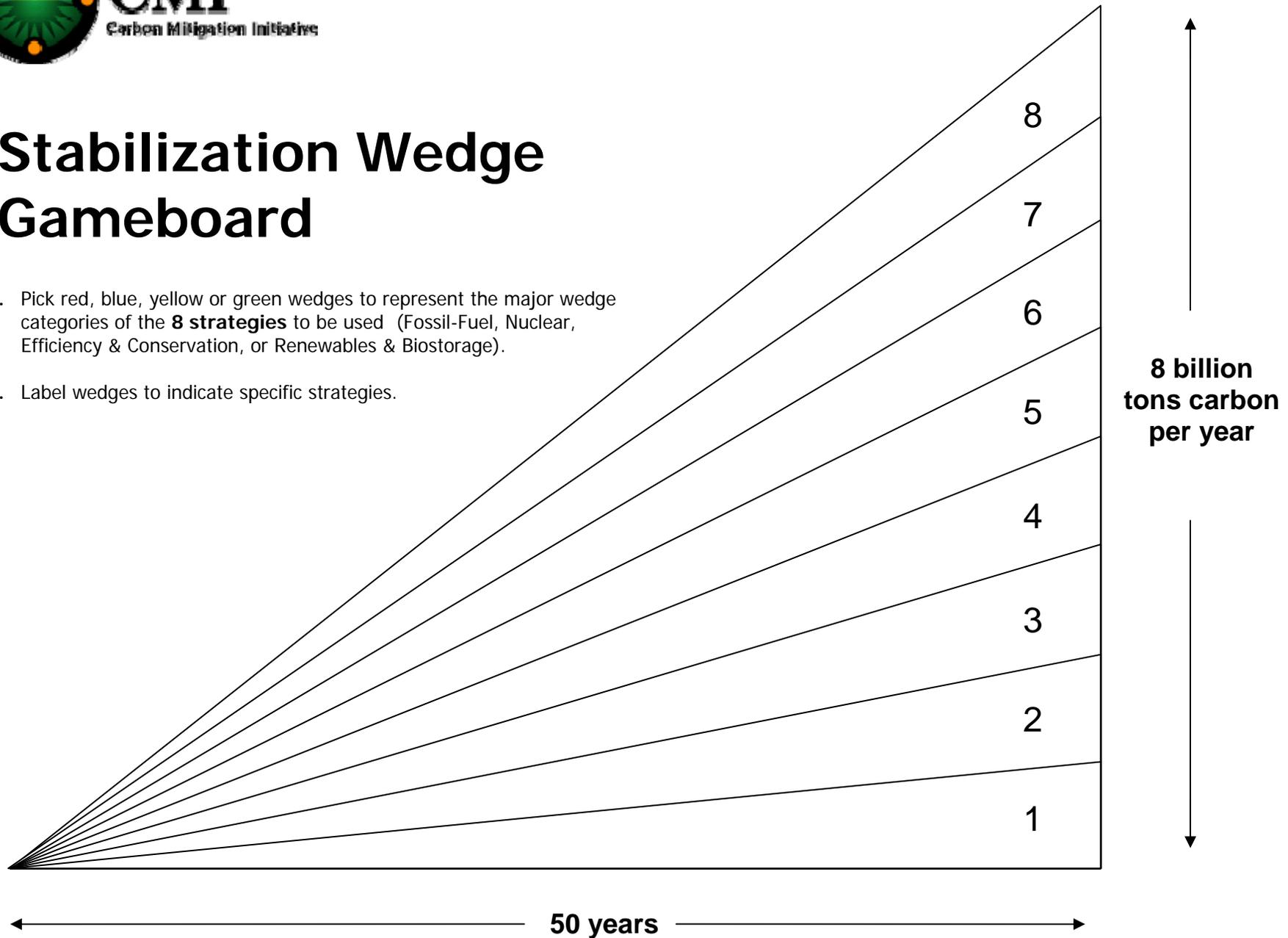
2. Guess the score each stakeholder group would give your team's triangle on a scale of 1 to 5 (5 = best).

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



Stabilization Wedge Gameboard

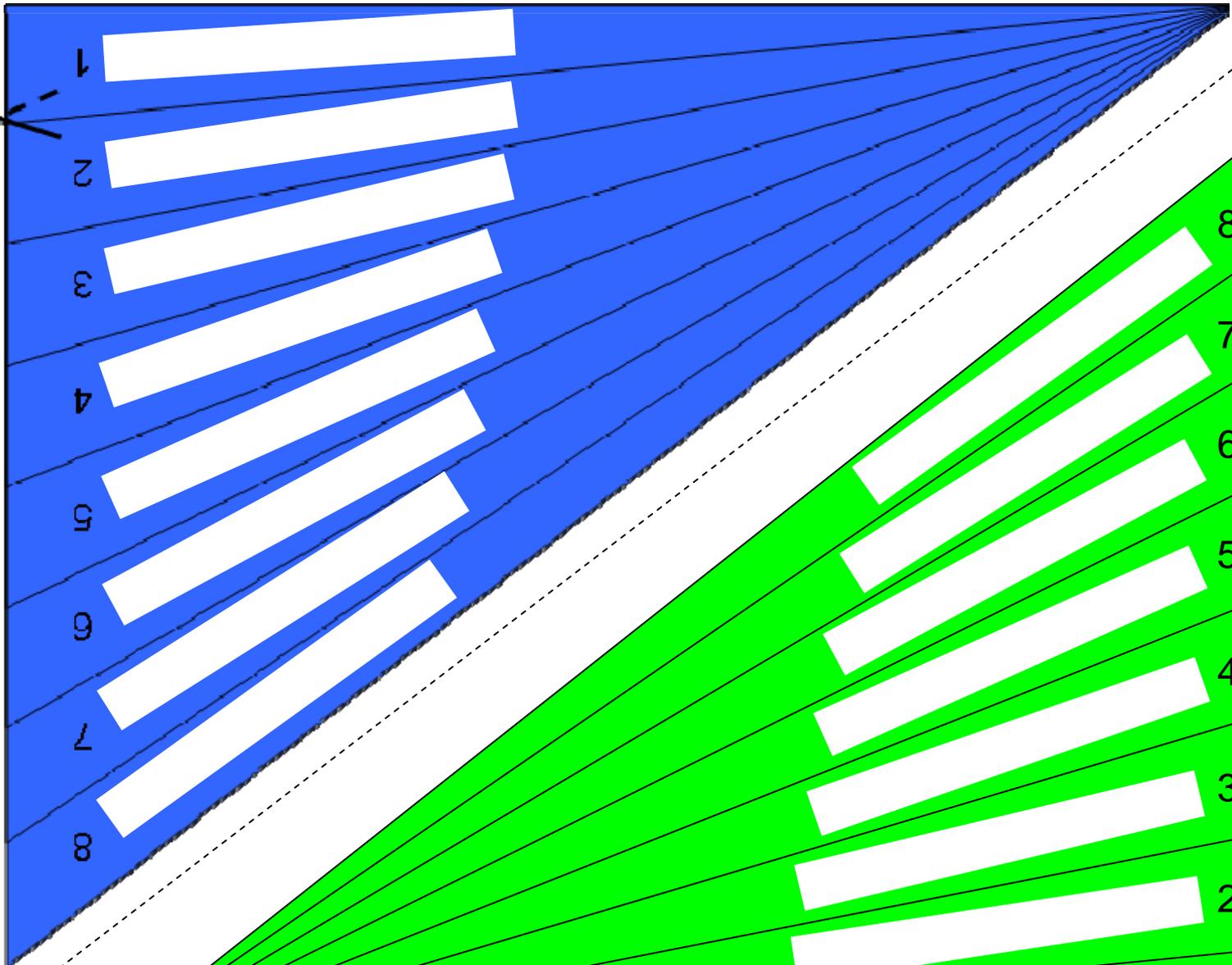
1. Pick red, blue, yellow or green wedges to represent the major wedge categories of the **8 strategies** to be used (Fossil-Fuel, Nuclear, Efficiency & Conservation, or Renewables & Biostorage).
2. Label wedges to indicate specific strategies.



Fossil Fuel-Based Wedges



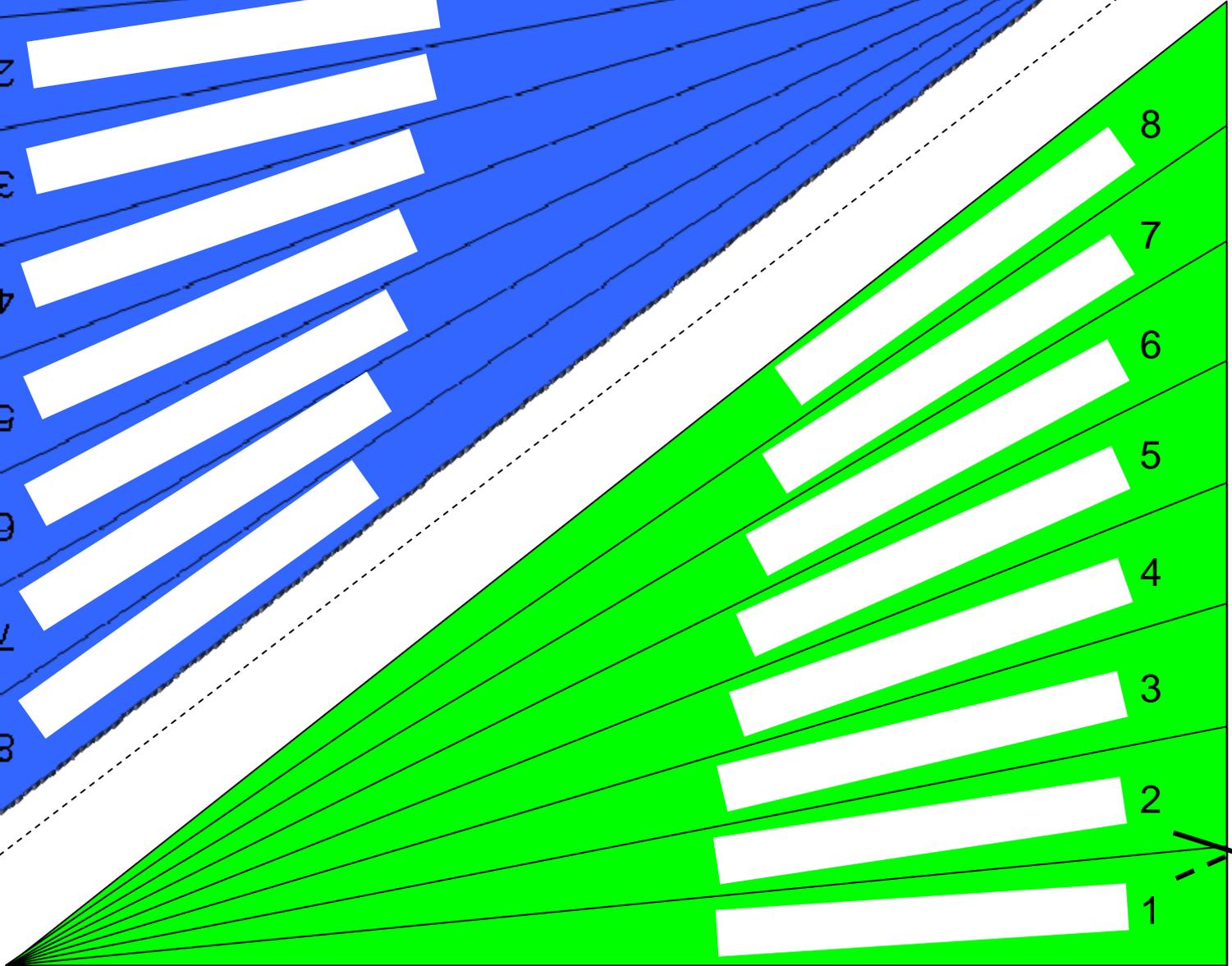
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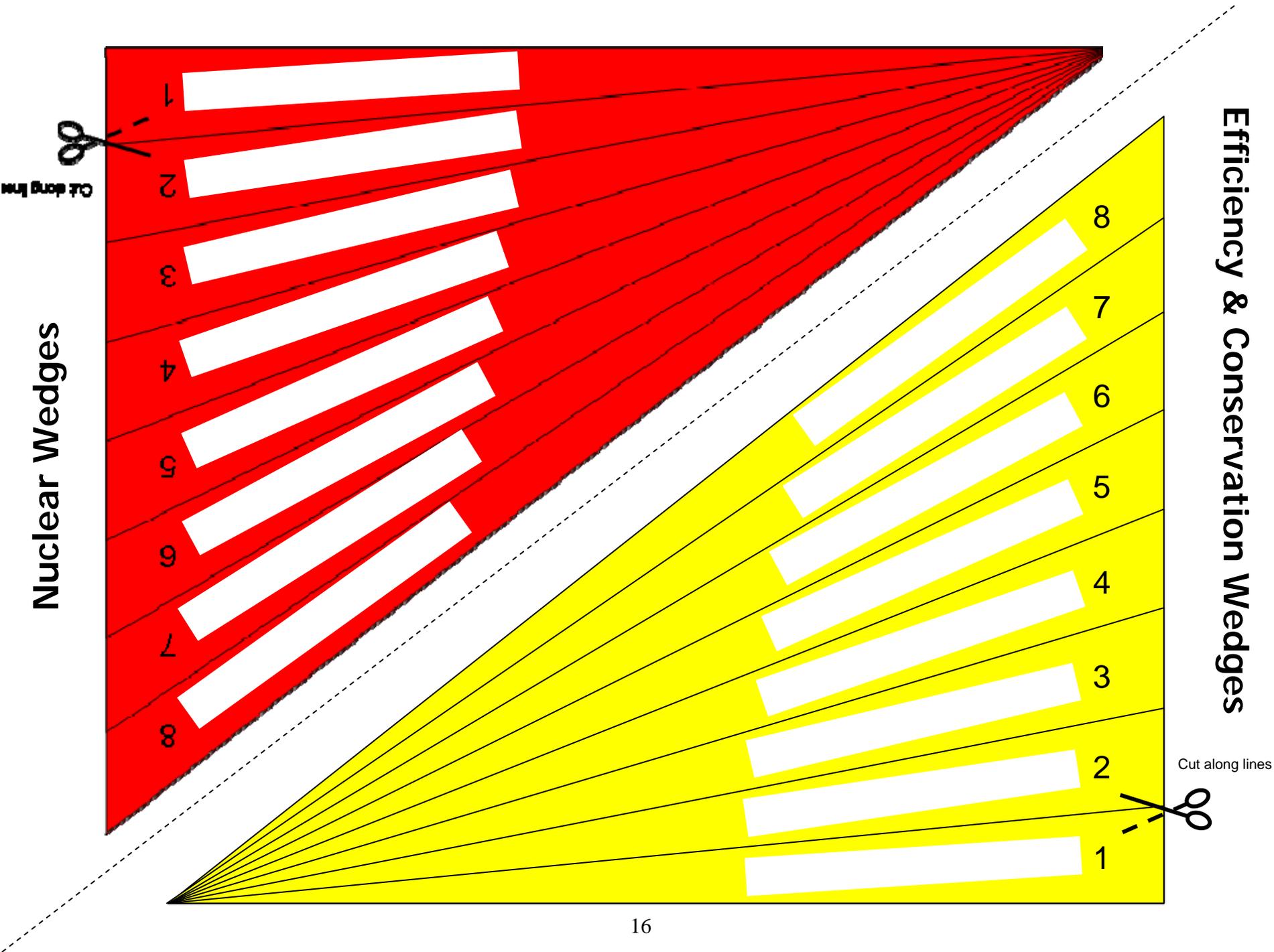


Renewables & Biostorage Wedges



Cut along lines





Nuclear Wedges

Efficiency & Conservation Wedges

Cut along lines

Cut along lines