Increased Efficiency & Conservation

1. <u>Transport Efficiency</u>

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 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. <u>Transport Conservation</u>

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. <u>Building Efficiency</u>

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. <u>Efficiency in Electricity Production</u>

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 CO_2 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 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 CO_2 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 CO_2 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 CO_2 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 CO_2 emissions in the world. **A wedge is an activity that, over 50 years, can capture the CO_2 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 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/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 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.

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 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 CO_2-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 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 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 CO_2 concentration.

The land constraints for biofuels, however, are more severe than for wind and solar electricity. Using cur- rent 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 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. How- ever, 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		CO_2 from fossil fuel power plants captured, then stored underground (700 large coal plants or 1400 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**	$$	Emissions still only break even with gasoline
8. Fuel Switching – Electricity		Replacing coal-burning electric plants with natural gas plants (1400 1 GW coal plants)	**… using an amount of natural gas equal to that used for all purposes today**	$	Natural gas availability
9. Nuclear Electricity		Displace coal-burning electric plants with nuclear plants (2 x current capacity)	**… ~3 times the effort France put into expanding nuclear power in the 1980's, sustained for 50 years**	$$	Weapons proliferation, nuclear waste, local opposition
10. Wind Electricity		Wind displaces coal-based electricity (30 x current capacity)	**… using area equal to ~3% of U.S. land area for wind farms**	$$	Not In My Back Yard (NIMBY)
11. Solar Electricity		Solar PV displaces coal-based electricity (700 x current capacity)	**.. using the equivalent of a 100 x 200 km PV array**	$$$	PV cell materials
12. Wind Hydrogen		Produce hydrogen with wind electricity	**… powering half the world's cars predicted for 2050 with hydrogen**	$$$	NIMBY, Hydrogen infrastructure, safety
13. Biofuels		Biomass fuels from plantations replace petroleum fuels	**… scaling up world ethanol production by a factor of 30**	$$	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 techiques increase carbon retention or storage in soils	**… practicing carbon management on all the world's agricultural soils**	$	Reversed if land is deep-plowed later