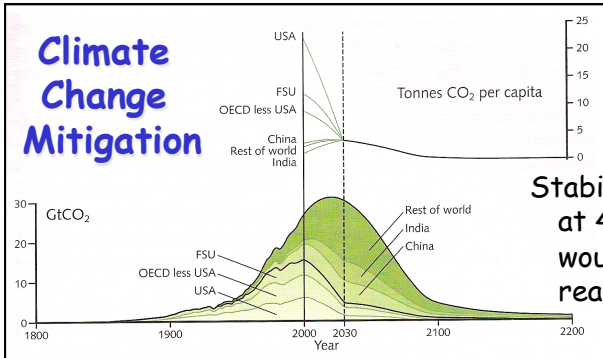
Climate Change: Adaptation and Mitigation

Please read the following (available from class website)

- "A Plan to Keep Carbon in Check" by Robert Socolow and Steve Pacala, *Scientific American*, 2006
- "Can we Bury Global Warming," by Robert Socolow, *Scientific American*, 2005
- "Building a Green Economy," by Paul Krugman, *New York Times Magazine*, 2010
- *Hot Flat, and Crowded*, Chapter 2, by Thomas Friedman, 2008

Climate Change Mitigation

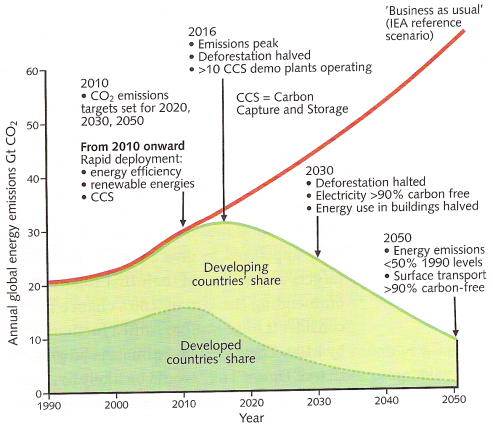


Stabilizing CO_2 at 450 ppm would be really hard!

Figure 10.5 The 'Contraction and Convergence' proposal of the Global Commons Institute for achieving stabilisation of carbon dioxide concentration. The envelope of carbon dioxide emissions illustrated is one that leads to stabilisation at 450 ppm (but the effect of climate carbon-cycle feedbacks is not included). For major countries or groups of countries, up to the year 2000, historic emissions are shown. After 2030 allocations of emissions are made on the basis of equal shares per capita on the basis of population projections for that date. From now until 2030, smooth 'convergence' from the present situation to that of equal shares is assumed to occur. In the upper part of the diagram the per capita contributions that apply to different countries or groups of countries are shown. For OECD and FSU see Glossary.

Paths to 450 ppm

Figure 11.27 Waymarks for annual global energy carbon di oxide emissions road map to 2050 showing International Energy Agency (IEA) Reference scenario (red) and a profile (green) aimed at targets of < 2°C temperature rise from pre-industrial and 450 ppm CO_2 stabilisation (cf Figure 10.3). The division between developed and developing countries from today until 2050 is a construction based on the developed countries' share, compared with that of developing countries, peaking earlier and reducing further e.g. by at least 90% by 2050..



Current Energy Supply & Usage

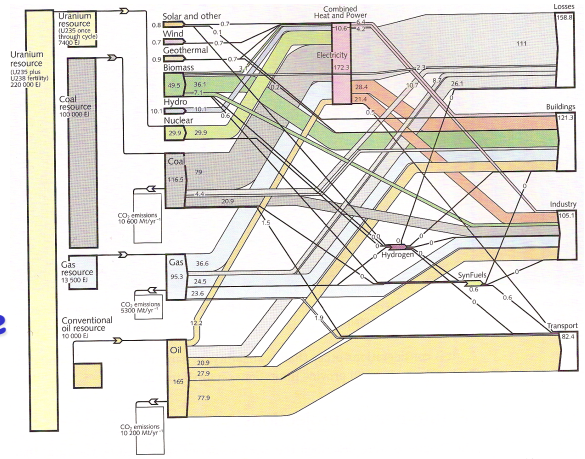
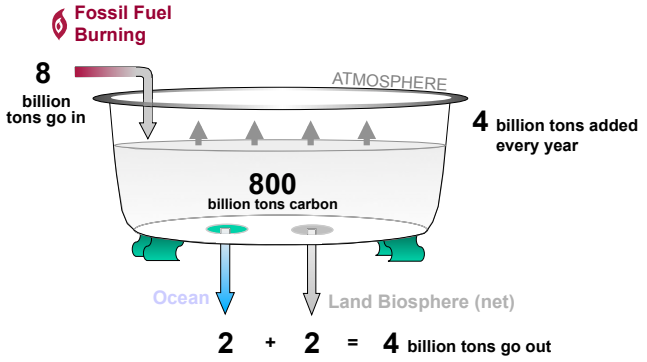


Figure 11.2 Global energy flows (EJ in 2004) from primary energy through carriers to end-users and losses in transmission, etc. Related carbon dioxide emissions from coal, oil and gas combustion are also shown as well as the size of known resources. Further energy conversions occur in the end-use sectors. Peat is included with coal, organic waste is included with biomass. The resource efficiency ratio by which fast-neutron technology increases the power-generation capability per tonne of natural uranium varies greatly in different assessments. In this diagram the ratio used is up to 240:1.

Adaptation and Mitigation

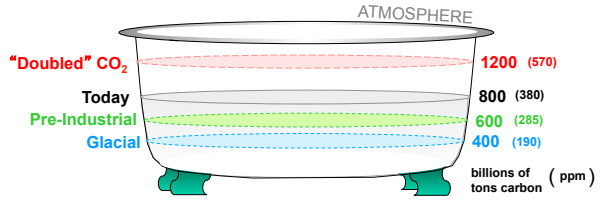
1. Why they must to do this
2. Magnitude of the challenge
3. **Engineering solutions**
4. Economics and Policy
5. Political considerations
6. Be an optimist

CO_2 "Budget" of the Atmosphere



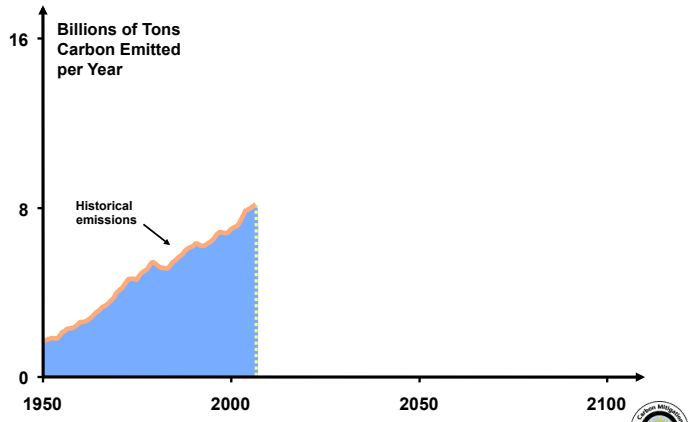
Rob Socolow and Steve Pacala *http://www.princeton.edu/wedges/*
Climate Mitigation Initiative, Princeton University

How Far Do We Choose to Go?

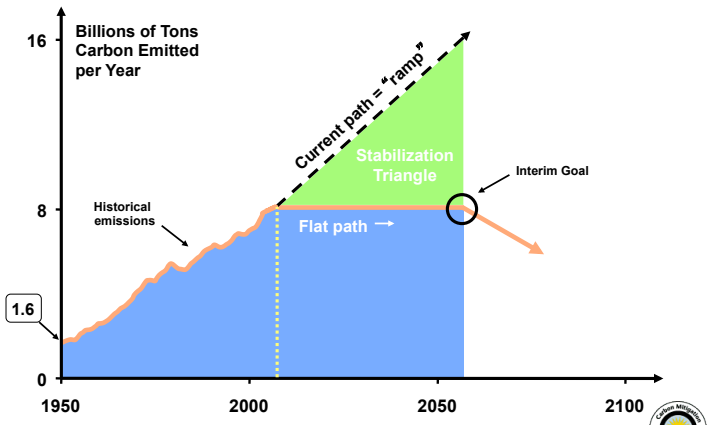


Past, Present, and Potential Future
Carbon Levels in the Atmosphere

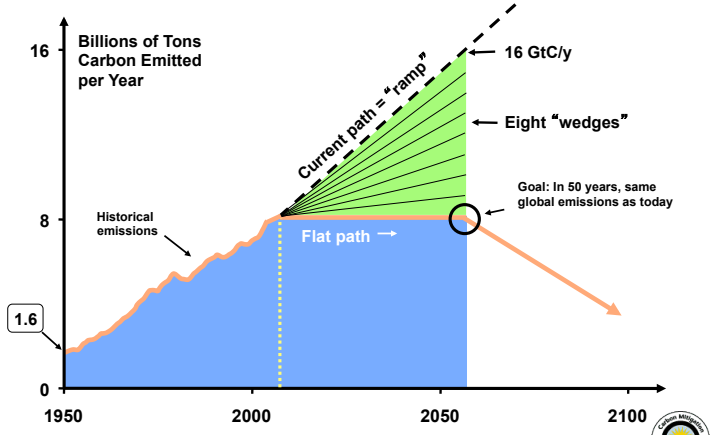
Historical Emissions



The "Stabilization Triangle"



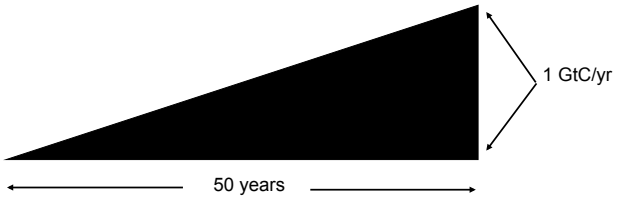
"Stabilization Wedges"



http://www.princeton.edu/wedges/

What is a "Wedge"?

A "wedge" is a strategy to reduce carbon emissions that grows in 50 years from zero to 1.0 GtC/yr. The strategy has already been commercialized at scale somewhere.



Cumulatively, a wedge redirects the flow of 25 GtC in its first 50 years. This is 2.5 trillion dollars at $100/tC.

A "solution" to the CO_2 problem should provide at least one wedge.

Helpful (?) "Rules of Thumb" for Emissions vs Climate

- 1 Wedge = 1 GtC/yr in 2050 = 50 fewer GtC by 2100 = 100 ppm less atmospheric CO2
- Average warming ~ 3 C per doubling of CO2 (note logarithmic scale!)
- Wedges help logarithmically … last wedge helps a lot more than first wedge!
- Business as usual CO2 ~ 1000 ppm by 2100 ~ 4x preindustrial ~ 6 C warming ~ 10 F
- Central North America gets ~ 1.5x - 2x global average warming (on land, NH, some snow)

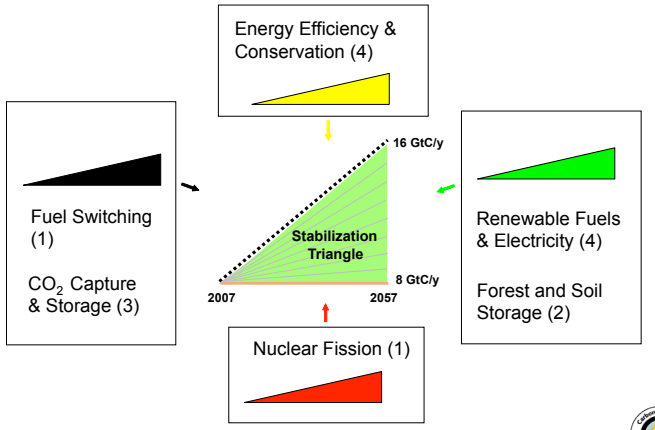
Bottom Line: Wedges and Warming

- Average Warming (in C) = 3 * $\log_2(CO_2/280)$
  = 3 * $\log_{10}(CO_2/280)$ / $\log_{10}(2)$
- Each wedge ~ 100 ppm less atmospheric CO_2

Do the math …

- 1st wedge reduces warming by ~ 0.46 C
- 2nd wedge reduces warming by another ~ 0.51 C
- 3rd wedge reduces warming another 0.58 C
- 4th wedge reduces warming by another 0.67 C
- 5th wedge reduces warming by another 0.79 C

Fifteen Wedges in 4 Categories



http://www.princeton.edu/wedges/

Efficiency

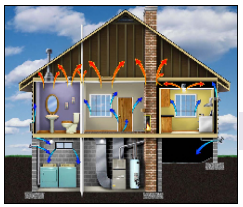
Photos courtesy of Ford Motor Co., DOE, EPA

Double the fuel efficiency of the world's cars or halve miles traveled

There are about 600 million cars today, with 2 billion projected for 2055

Produce today's electric capacity with double today's efficiency

Average coal plant efficiency is 32% today



Use best efficiency practices in all residential and commercial buildings

Replacing all the world's incandescent bulbs with CFL's would provide 1/4 of one wedge

E, T, H / $

Sector s affected:
E = Electricity, T =Transport, H = Heat

Cost based on scale of $ to $$$

Fuel Switching

Substitute 1400 natural gas electric plants for an equal number of coal-fired facilities

Photo by J.C. Willett (U.S. Geological Survey).

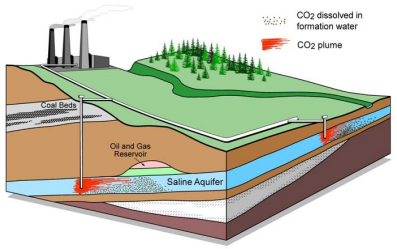
A wedge requires an amount of natural gas equal to that used for all purposes today

E, H / $

Carbon Capture & Storage

Implement CCS at

- 800 GW coal electric plants or
- 1600 GW natural gas electric plants or
- 180 coal synfuels plants or
- 10 times today's capacity of hydrogen plants



Graphic courtesy of Alberta Geological Survey

There are currently three storage projects that each inject 1 million tons of CO_2 per year – by 2055 need 3500.

E, T, H / $$

Nuclear Electricity

Triple the world's nuclear electricity capacity by 2055

Graphic courtesy of NRC

The rate of installation required for a wedge from electricity is equal to the global rate of nuclear expansion from 1975-1990.

E/ $$

Wind Electricity

Photo courtesy of DOE

Install 1 million 2 MW windmills to replace coal-based electricity,

OR

Use 2 million windmills to produce hydrogen fuel

A wedge worth of wind electricity will require increasing current capacity by a factor of 30

E, T, H / $-$$

Solar Electricity

Install 20,000 square kilometers for dedicated use by 2054

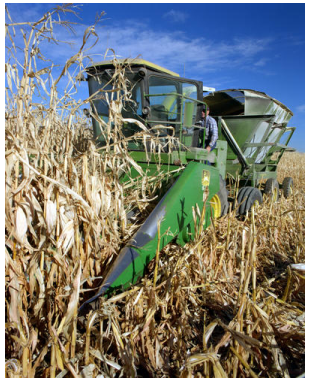
Photos courtesy of DOE Photovoltaics Program

A wedge of solar electricity would mean increasing current capacity 700 times

E / $$$

Biofuels

Scale up current global ethanol production by 30 times



T, H / $$

Using current practices, one wedge requires planting an area the size of India with biofuels crops

Photo courtesy of NREL

Natural Sinks

Conservation tillage is currently practiced on less than 10% of global cropland

B / $

Eliminate tropical deforestation

OR

Plant new forests over an area the size of the USA

OR

Use conservation tillage on *all* cropland

Photos courtesy of NREL, SUNY Stonybrook, United Nations FAO

Efficiency

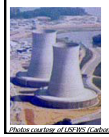
1. Double fuel efficiency of 2 billion cars from 30 to 60 mpg
2. Decrease the number of car miles traveled by half
3. Use best efficiency practices in all residential and commercial buildings
4. Produce current coal-based electricity with twice today's efficiency

Fuel Switching

5. Replace 1400 coal electric plants with natural gas-powered facilities

Carbon Capture and Storage

6. Capture AND store emissions from 800 coal electric plants
7. Produce hydrogen from coal at six times today's rate AND store the captured CO_2
8. Capture carbon from 180 coal-to-synfuels plants AND store the CO_2



Nuclear

9. Add double the current global nuclear capacity to replace coal-based electricity

Photos courtesy of UKFIRS (Carbon Capture and Storage), US DOE, US NRC

Wind

10. Increase wind electricity capacity by 50 times relative to today, for a total of 2 million large windmills

Solar

11. Install 700 times the current capacity of solar electricity
12. Use 40,000 square kilometers of solar panels (or 4 million windmills) to produce hydrogen for fuel cell cars

Biomass Fuels

13. Increase ethanol production 50 times by creating biomass plantations with area equal to 1/6th of world cropland

Credit: Warren Gretz

Natural Sinks

14. Eliminate tropical deforestation AND double the current rate of new forest planting
15. Adopt conservation tillage in all agricultural soils worldwide

Credit: David Parsons

Wedges Summary

For stabilization of emissions (not CO_2) pick any 8 of these 15

Adaptation and Mitigation

1. Why they must to do this
2. Magnitude of the challenge
3. Engineering solutions
4. Economics and Policy
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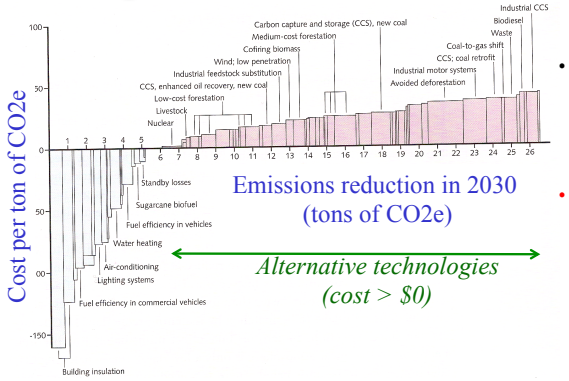
Mitigation Costs and Savings



- Meets stabilization at 450 ppm trajectory
- **Savings from efficiency largely offset new costs**

McKinsey & Company report, '*Pathways to a low-carbon economy - Version 2 of the Global Greenhouse Gas Abatement Cost Curve.*'

Free Market Solutions

- A new industrial revolution won't happen because people want to "do the right thing"
- The government can't just pass a law and create a new global energy economy, any more than they could 200 years ago
- If low-carbon-footprint goods and services cost less than "dirtier" ones, people will buy them

A Policy Spectrum

"command and control" — "market capitalism"

direct subsidy — "cap and trade" — "tax and rebate"

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Imagine it's 1800, and you're in charge …

Somebody presents you with a grand idea for transforming the world economy:

- ✓ Dig 8 billion … t of the ground every year
- ✓ Build a syst… …ertankers, railroads, hi… …s to deliver it to every stree… …net
- ✓ Build million… …ar, and millions of miles of roa… …n
- ✓ Generate an… …tricity to every house to power lights & stereos & plasma TVs

… *"and here's the itemized bill …"*

Thinking about Cot

- Our global society built that very system
- We didn't all go broke building it …
- We got rich beyond the avarice of kings!

Discussion Questions

- Can't we just wait until the market sorts this out?
- Can we solve this by
  - bicycling to work?
  - Eating a vegan/locavore diet
  - Turning down the thermostat?
  - Changing our light bulbs?
- Are we just screwed?

Choose Your Future

- Many academics believe:

  "Modern economy is possible only through the subsidy of cheap fossil energy. When we stop burning coal we'll freeze in the dark!"

- I prefer:

  "Modern wealth results from ingenuity and hard work. Before we run out of oil, we'll invent better technologies for the 21st Century. The future is bright."