Week 10 (the last week)

- Today: Mitigation (cont)
- Tuesday: Geo-engineering
- Wed: Media reports/class evaluation
- Thur: Summary of class

- Thur/Fri sections: HW/review/TA evaluation

- Reminders:
  - CLUE session on Tue 8pm & Wed at 6:30-8:00pm
  - HW #6 due on Thursday
  - Final Exam on Monday Dec 8th 8:30-10:20am (here)
    - More info on Wednesday
    - Help session on Sunday evening (TBA)

The Future

- Where are we heading (business as usual)?
  - Emission scenarios and projected climate change (review)

- What would it take to stabilize the climate so that the future was only, say, 3°C warmer than 2000?
  - What do we have to do to global emissions?
  - Is it doable?

- In the long run, how much can we emit and keep the climate stable (at 3°C warmer than 2000)?
  - What does this imply for US emissions?

- Alternatives to reduced emissions: geoengineering (tomorrow)

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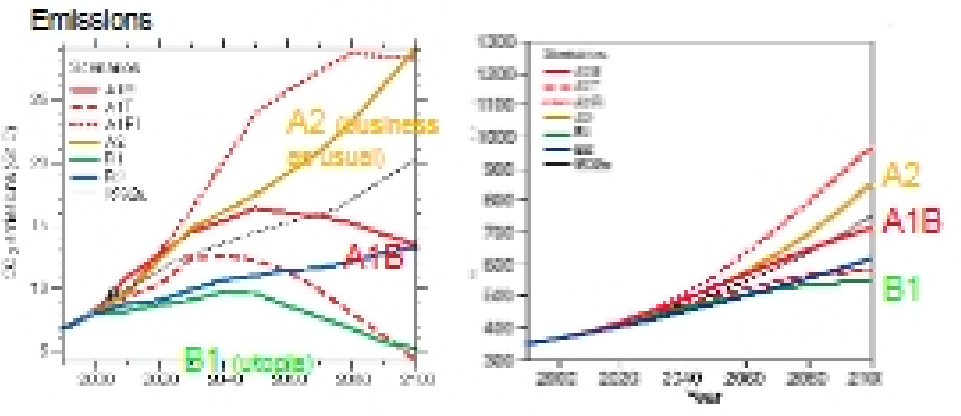
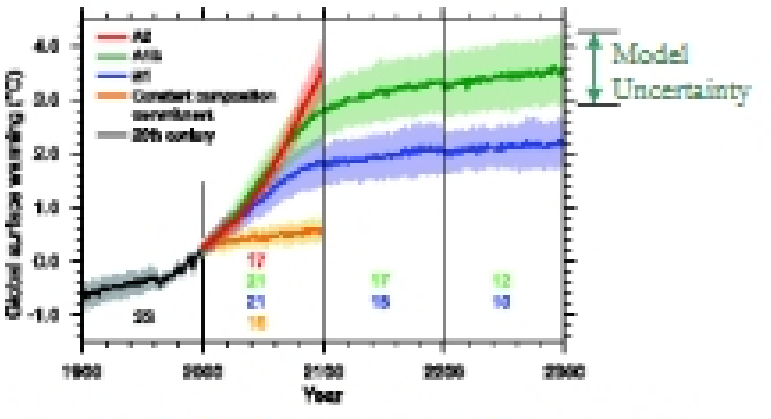
How much Carbon Dioxide will be released into the atmosphere?



Estimates depend on population and economic projections, future choices for energy, governance/policy options in development (e.g., regional vs. global governance)

Global Annual Average Surface Temperature



Referenced to the 1980-1999 Average Temperature

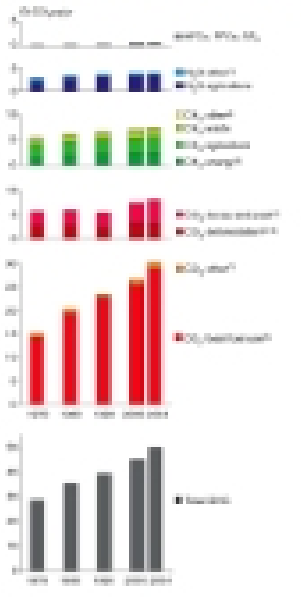
Solid lines: average of all models used. Number of models used varies; shaded area is the standard deviation of the models

IPCC AR4, Fig 10.4

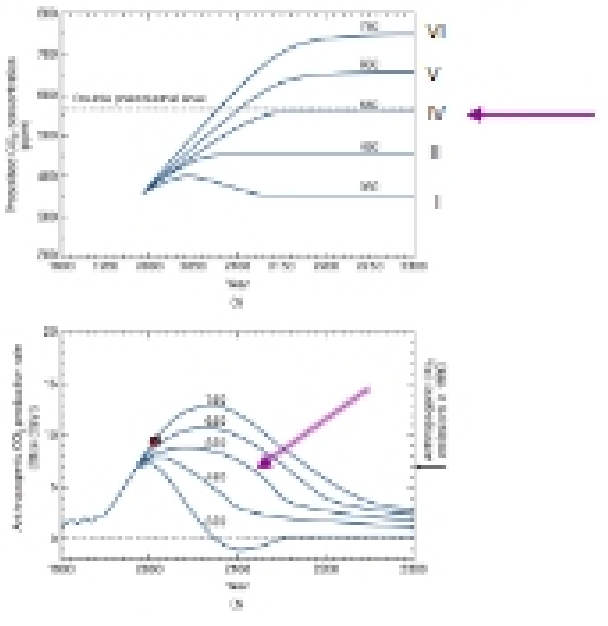
Reminder: more than CO_2 contributes to warming

- Usually convert other gases to an equivalent mass of CO_2 that would cause the same forcing

- Amount shown is emitted (equivalent) CO_2
  - To get emitted equivalent C, multiply by 12/44



Paths to CO_2 stabilization



Paths to CO_2 stabilization: emission reduction requirements by 2060

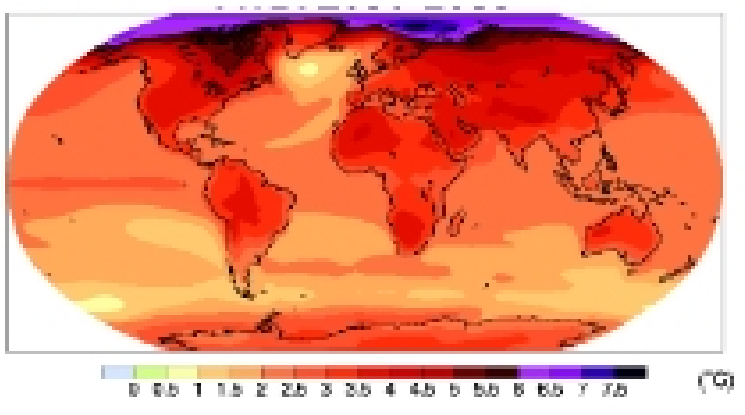
←------ At stabilization ------→					←-- Required Action --→		
Category	Radiative forcing (W/m²)	CO_2 concentration[1] (ppm)	CO_2-eq concentration[1] (ppm)	Global mean temperature increase above pre-industrial at equilibrium, using "best estimate" climate sensitivity[2, 3] (°C)	Peaking year for CO_2 emissions[4]	Change in global CO_2 emissions in 2050 (% of 2000 emissions)[4]	No. of assessed scenarios
I	2.5-3.0	350-400	445-490	2.0-2.4	2000-2015	-85 to -50	6
II	3.0-3.5	400-440	490-535	2.4-2.8	2000-2020	-60 to -30	18
III	3.5-4.0	440-485	535-590	2.8-3.2	2000-2030	-30 to +5	21
IV	4.0-5.0	485-570	590-710	3.2-4.0	2000-2060	+10 to +60	118
V	5.0-6.0	570-660	710-855	4.0-4.9	2000-2080	+35 to +85	9
VI	6.0-7.5	660-790	855-1130	4.9-6.1	2000-2090	+90 to +140	5
						Total	177

To achieve stabilization of CO_2 at ~ 500 ppm, global emissions will have to be level or even decrease over the next 40 years, while population increases by 50% and developing countries develop (and thus energy demand increases 70%)

Stabilizing atmospheric CO_2 at ~500ppm

- Stabilizing CO_2 at 500ppm (550 CO_2 equivalent) means that the global averaged temperature will increase by ~3°C
  - High latitudes will warm more than tropics, subtropics will be drier by about 20%, etc.

Not exactly the change in temperature at 500ppm, but close enough ....



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Climate Stabilization: The Pacala & Socolow analysis

How do we avoid exceding 500ppm of CO_2?

on the one hand...

IPCC (2001, WGIII): "technologies that exist in operation or pilot stages today" are sufficient to follow a less than doubling trajectory "over the next hundred years or more".

on the other hand...

Hoffert et al. (Science, 2002) claim that the IPCC analysis involves "misperceptions of technological readiness". They call, instead, for "revolutionary changes" in energy technology.

Pacala and Socolow argue...

Basic research is needed to develop the revolutionary technologies needed for the 2nd half of this century and beyond.

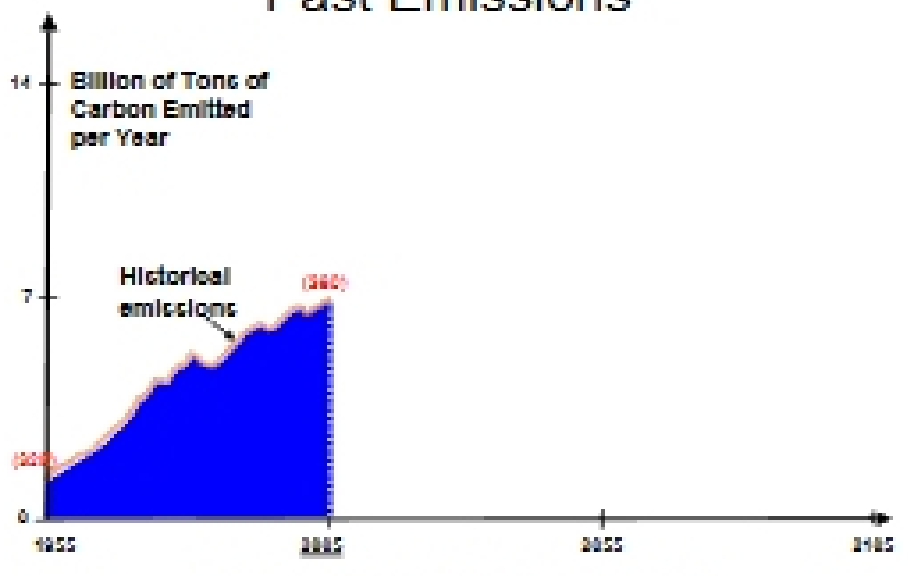
Meanwhile, we must (and can) start to solve the carbon/climate problem in the first half of the century **"simply by scaling up what we already know how to do."**

Pacala and Socolow (2004), *Science* 305, 968-972

Stabilizing atmospheric CO_2 at ~ 500ppm

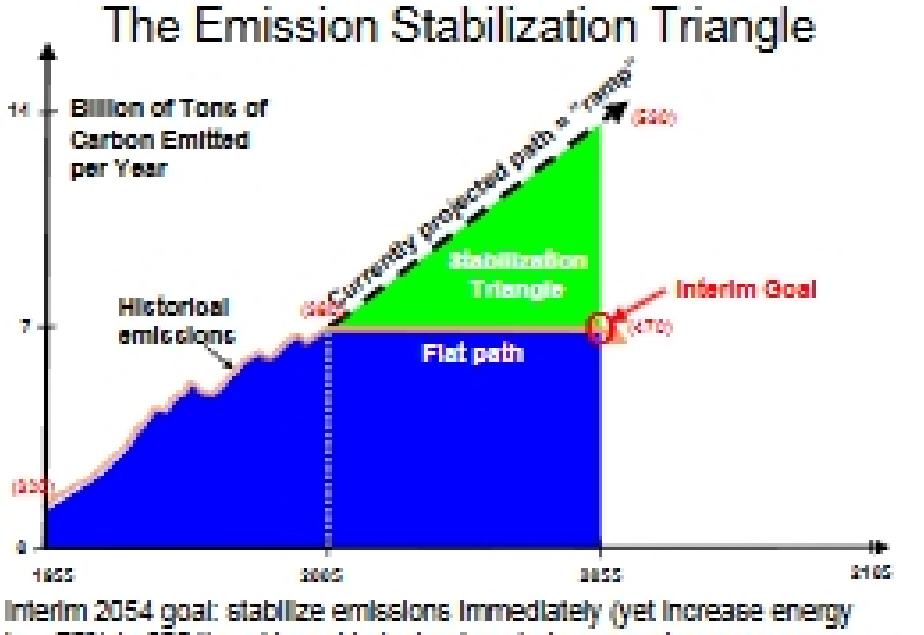
- In 2004, Pacala and Socolow proposed a scheme to achieve this goal
  - **Phase 1**: Requires immediate cap on global CO_2 emissions and that economic growth over the next 50 years be achieved by ramping up (scaling up) existing technologies without increasing CO_2 emissions
  - **Phase 2**: After 2054, requires rapid and substantial reductions in global emissions. Final emissions of all GH gases must level off by ~2100 to ~ 1.5 Gt/yr, or ~20% of present global emissions
  - At that time, the ocean uptake will balance the human input (and the ocean will continue to acidify).

Past Emissions



Values in parentheses are ppm (1 ppm = 2.1 GtC).

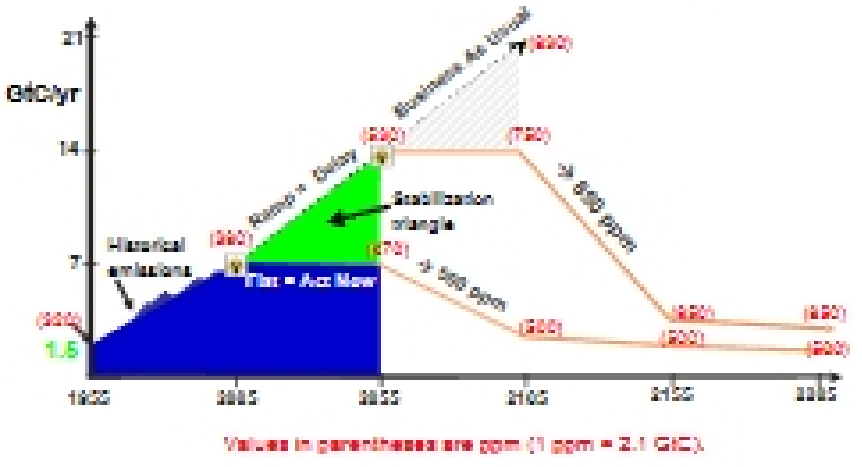
The Emission Stabilization Triangle



Interim 2054 goal: stabilize emissions immediately (yet increase energy by ~70% in 2054) and invest in technology to have much more energy with reduced emissions after that

The Stabilization Triangle:

settle for double or triple pre-industrial CO_2?



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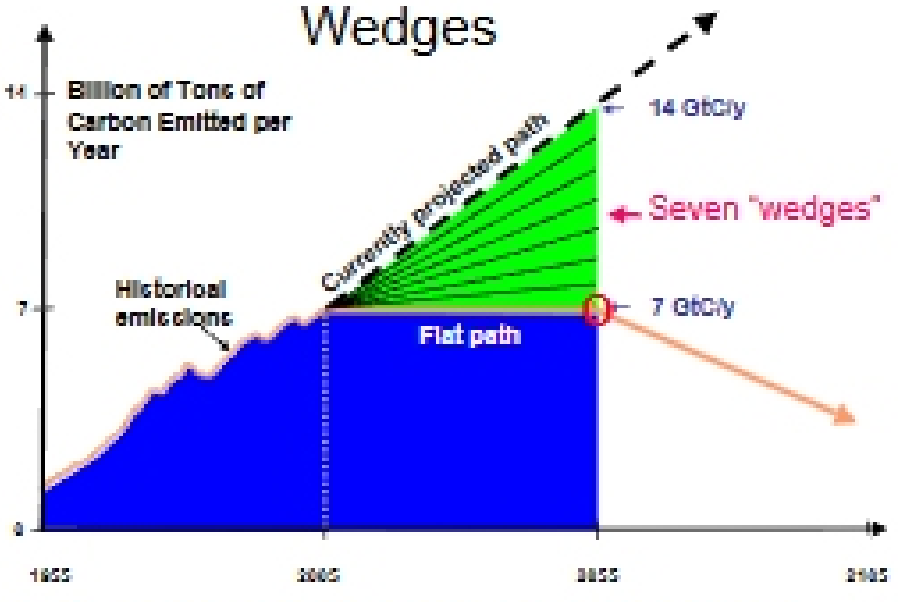
Stabilizing at 500ppm requires the global emission be 1.5 Gt/yr

Wedges



How do we meet the increase in energy demand (projected to increase by 70% by 2050 and 200+% by 2100) without increasing emissions of CO_2?

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 would cost $1.25 trillion at $50/tC. A $50/tC tax or carbon trading value would raise electricity prices by almost 1 cent per kWh (~ 10%).

The Interim Goal is Within Reach

Reasons for optimism that global emissions in 2055 need not exceed today's emissions:

- The world today has a terribly inefficient energy system.
- Carbon emissions have just begun to be priced.
- Most of the 2055 physical plant is not yet built