# ATM S 111, Global Warming: Climate Wedges

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Day 40, August 16, 2010

# Assignments

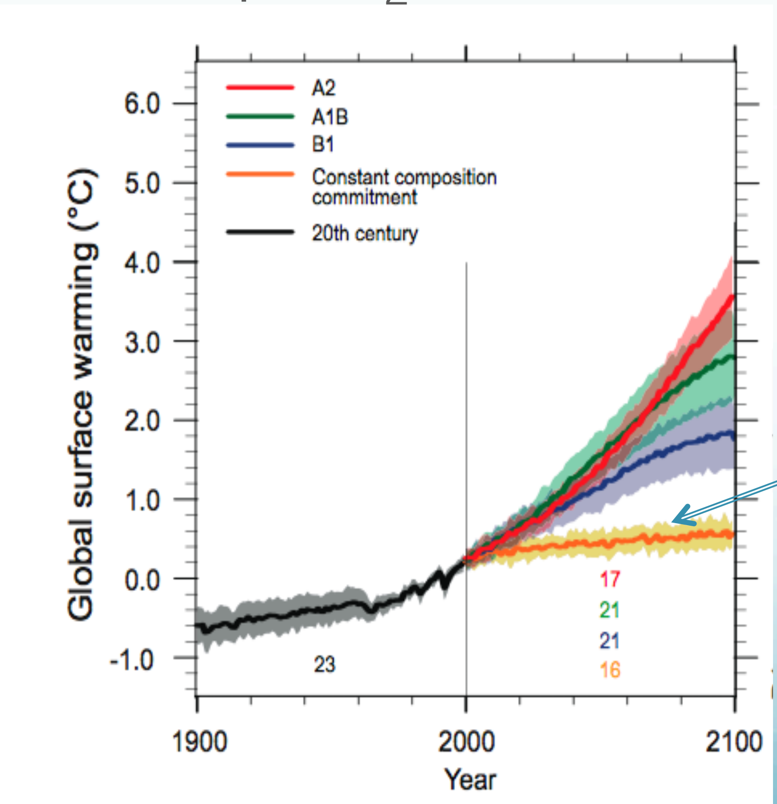
- Read “The Predicament” and “Political Solutions” p.278-305
- If you’re writing a paper, turn in the rough draft today.
- If you’re giving a presentation, be prepared to present on Thursday.
  - If you’re using power point, bring your own laptop or send me a PDF version of your presentation.
- Final paper is due on Friday.

# Today: Solutions continued

- First, the bad news
  - How much we will have to cut emissions to make a difference
- Then, the good news
  - What changes we can make to get this done: we can fix it!
  - And many of the changes we'll need to make will be beneficial in many other ways

# Goals for Fixing the Problem

- One goal: minimize temperature increase
- But recall that some warming is **locked in** even if we keep $CO_2$ concentrations *exactly at today's levels*

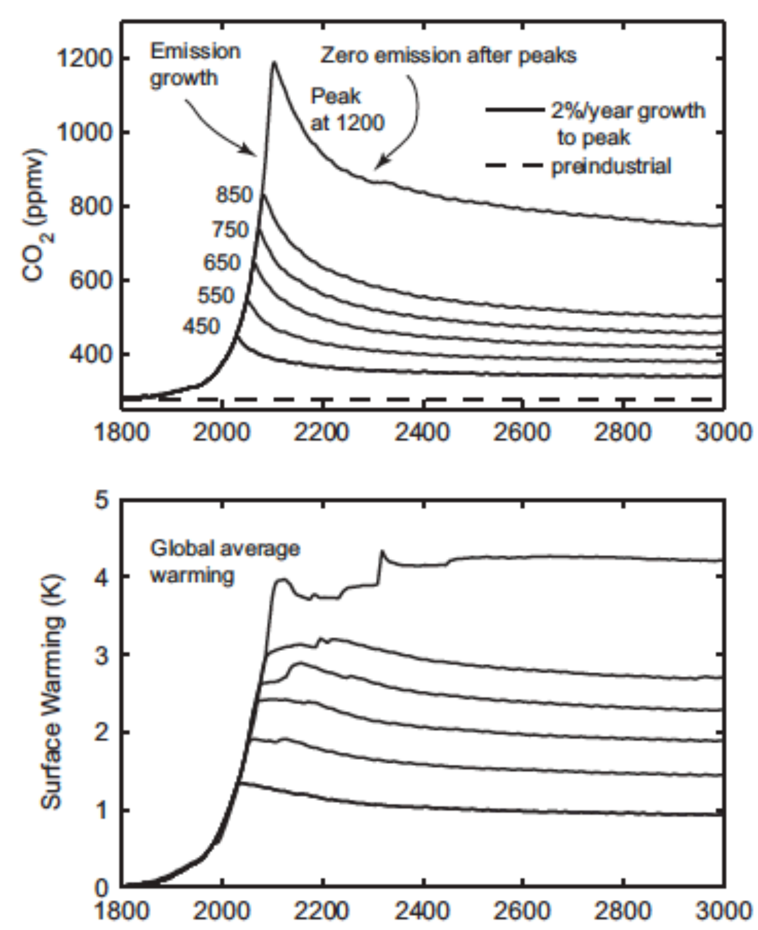



The yellow experiments assume concentrations are held constant at year 2000 values

Temperatures still increase by **0.5° C** (because the ocean takes time to warm)

# Warming locked in for hundreds of years

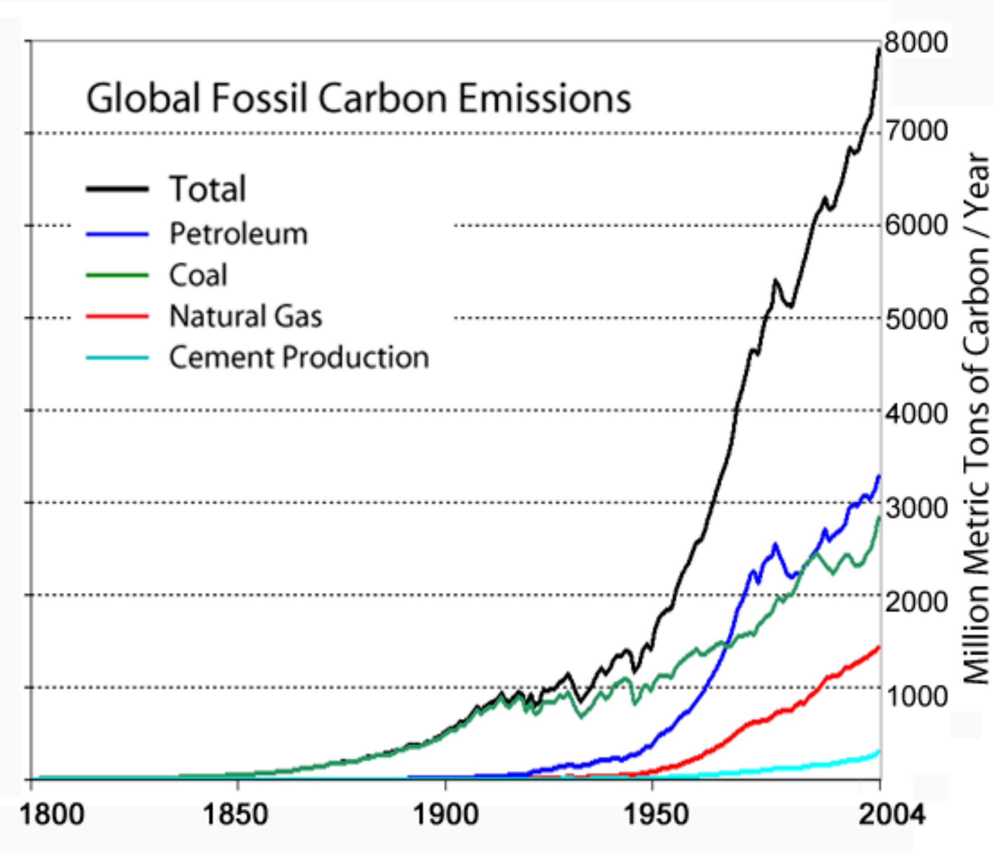
- After $CO_2$ emissions stop, there is an initial reduction for ~100 years, but then $CO_2$ amounts level off.
- They don't drop down to pre-industrial levels.
- It takes thousands of years for geological processes (chemical weathering) to remove $CO_2$.
- Release of heat from the ocean to atmosphere offsets a lot of the initial $CO_2$ reduction.




From Solomon et al, 2009, *PNAS*

# How to Prevent Higher $CO_2$ Concentrations

- Higher CO2 levels mean higher temperatures eventually: how to avoid?



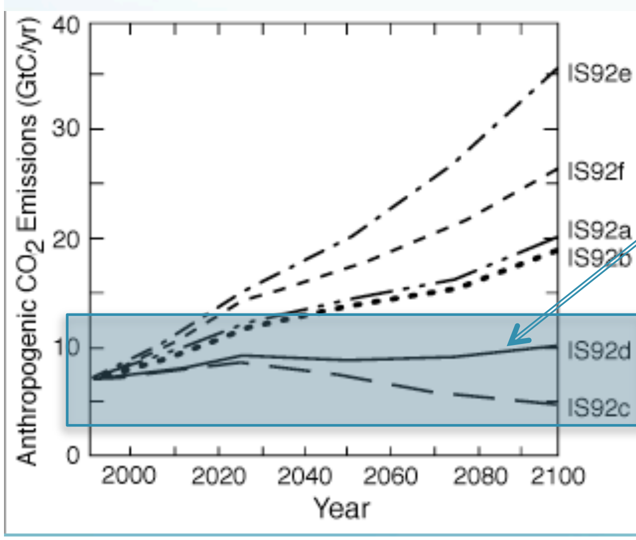

Emissions are increasing rapidly.

What if we just kept our emissions constant? Would that be enough?

# Is **Stabilizing Emissions** Enough?

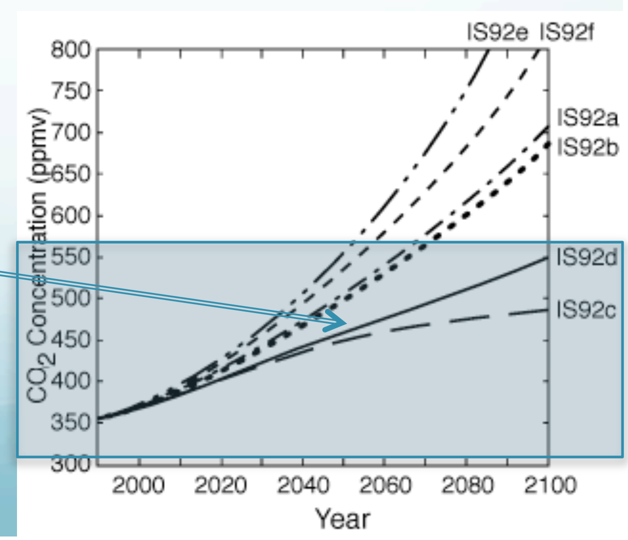
- **No!** Flattening out $CO_2$ emissions still leads to large increases in $CO_2$ concentrations
  - Imagining running water in a bathtub with a slow drain. The amount of water in the tub increases as long as the water comes in faster than it drains out.

**Emissions**




Flat **emissions** lead to **concentrations** that increase…

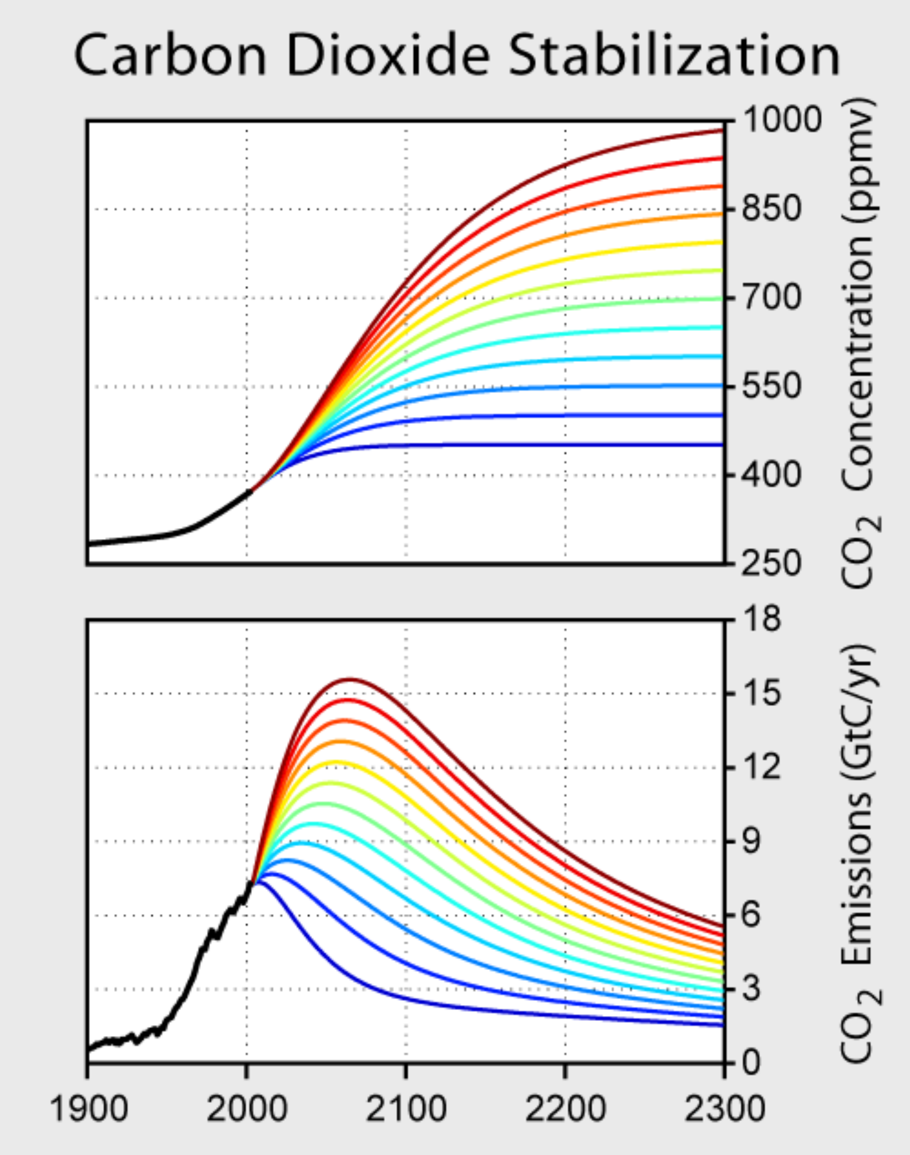
**Concentrations**



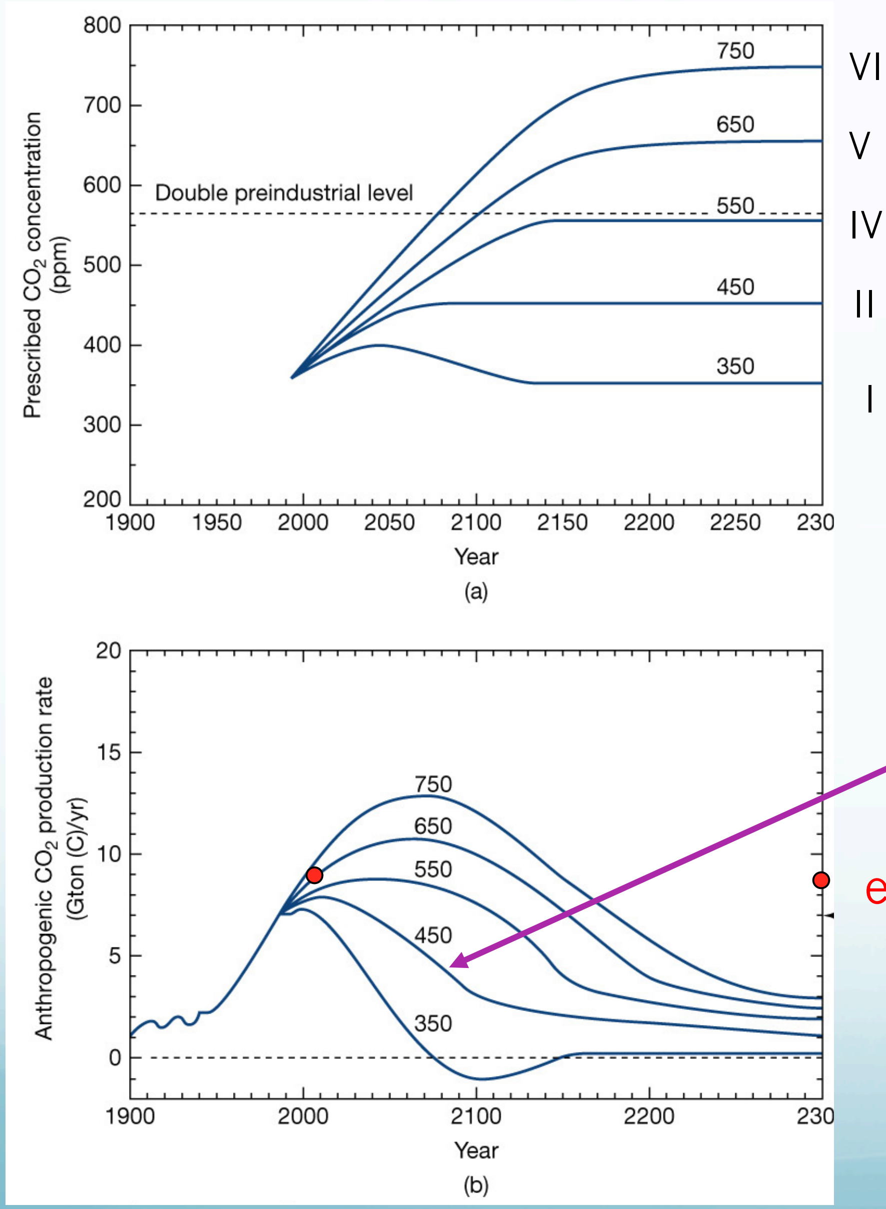
# How To Stabilize Concentrations

- Stabilization at these **concentrations**…. →

- …requires these cuts in **emissions** →



# Paths to $CO_2$ stabilization



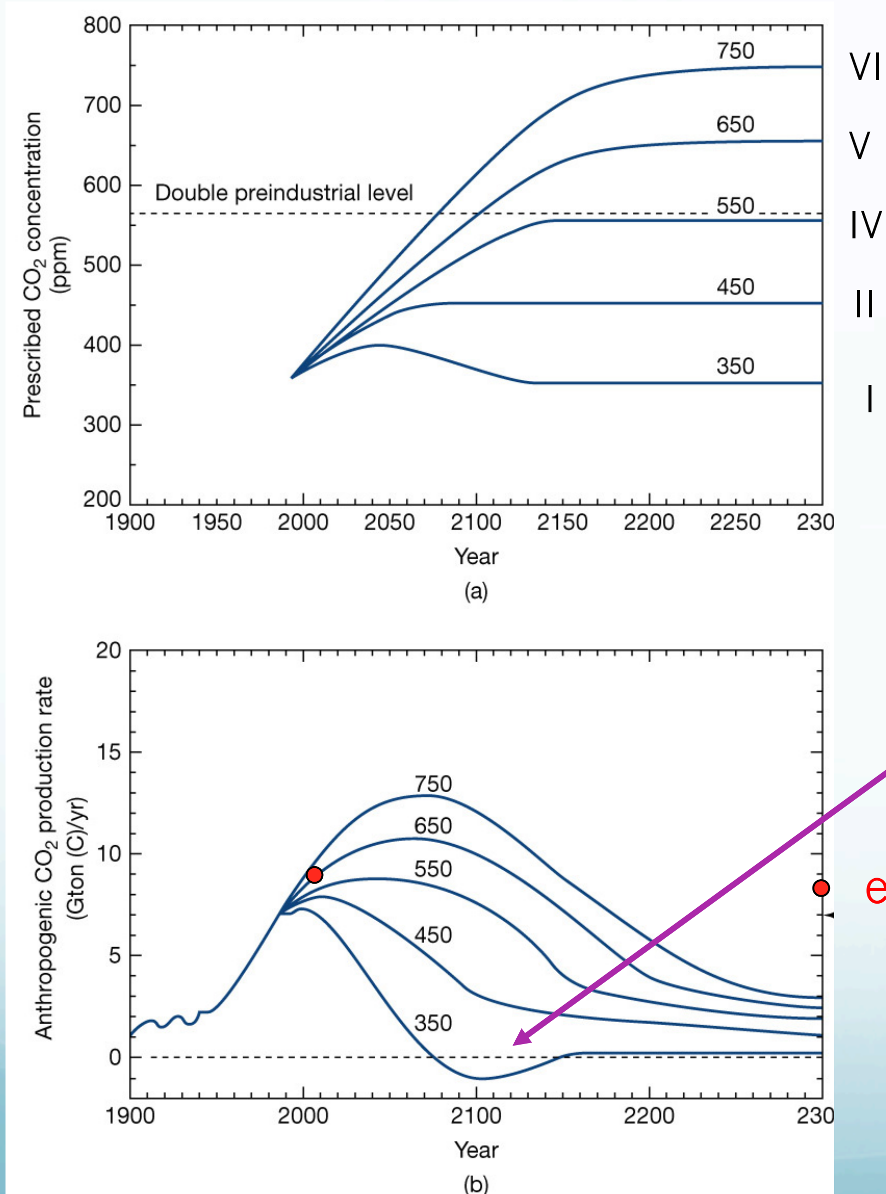

**To stabilize at 450 ppm…**

**…drastic & immediate emissions cuts are necessary**

# 350 ppm?

- James Hansen, NASA: scientist/activist
  - Brilliant scientist with many honors & awards (National Academy of Sciences, AMS Rossby Medal, Time Magazine's Most Influential People, etc.)
  - Not hesitant to move into the activist role (e.g., was arrested during a mountaintop removal protest)
  - Was muzzled by Bush administration officials, went on *60 Minutes* to whistleblow about this
  - "If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that $CO_2$ will need to be reduced from its current 385 ppm to at most **350 ppm**."

# Path to 350 ppm $CO_2$ concentration




**To stabilize at 350 ppm…**

**…emissions must *plummet* & we probably have to take some $CO_2$ *out* of the atmosphere**

emissions today

# Stabilizing $CO_2$

- Not sure how we could stabilize at 350 ppm, given our current global political & economic situation.
- There are proposals for ways to stabilize at 450 or 500 ppm.
- This is less than twice pre-industrial levels, and is likely to lead to roughly 2 °C warming.
- So Greenland will probably still melt (eventually), but Antarctica won't.
- How do we get there, given the trajectory we're on now?

# U.S. Energy Sources

U.S. **energy** sources (2007):

- Oil 40%,
- Coal 23%,
- Natural gas 22%,
- Nuclear 8%,
- Renewables:7%

Oil for transportation, coal for electricity

(U.S. **electricity** sources: coal, nuclear and renewables dominate)

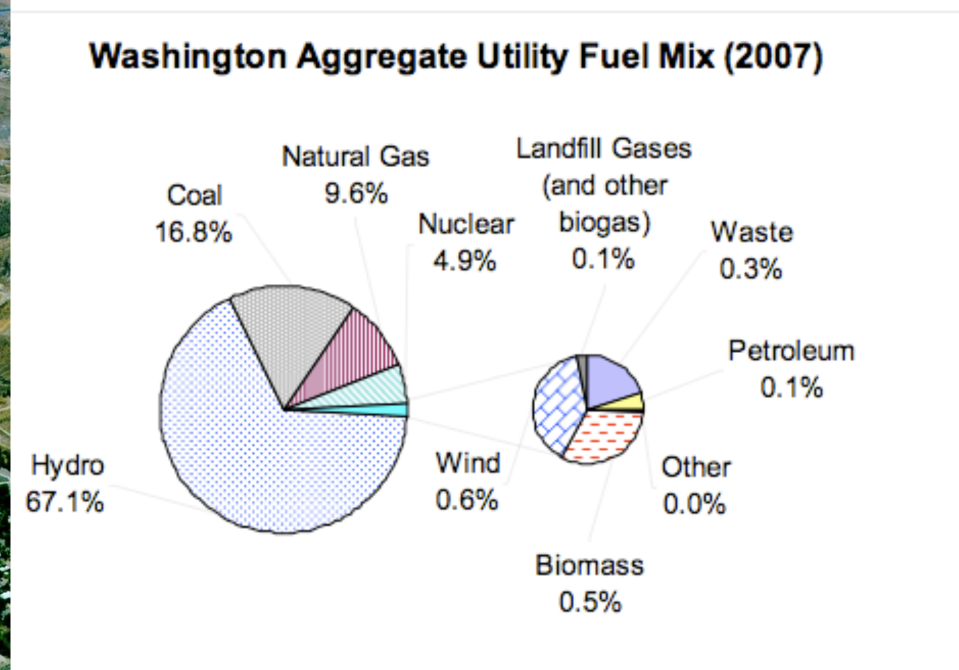
# Useful Facts about $CO_2$

- $CO_2$ per unit energy emitted:
  - Coal emits 67% more $CO_2$ than natural gas
  - Coal emits 30% more $CO_2$ than oil
  - Coal is a 'dirty fuel' – it emits a lot of other harmful stuff, including mercury, arsenic, etc.

- U.S. $CO_2$ emissions by energy sources (2007):
  - Oil 46%,
  - Coal 35%,
  - Gas 19%,
  - nuclear and renewables ~0%

# In Washington we have Hydro Power

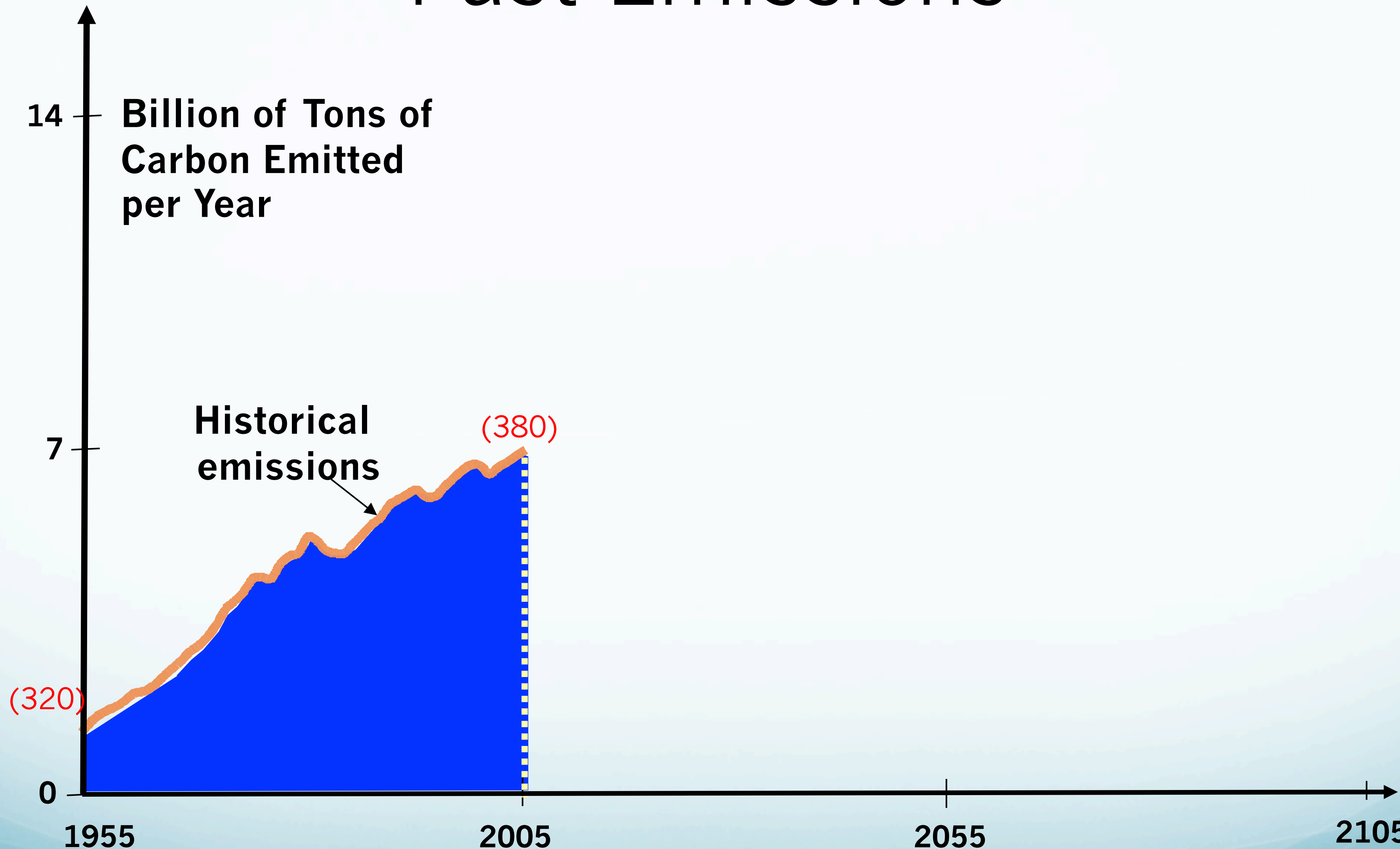
- About 7% of the U.S. *electricity* comes from hydropower
  - 67% of Washington's electricity
- Extremely expensive to build new facilities
- Possible extreme environmental damage to flooded area and fish migration
- Not likely to see more dams built in the U.S.



# Stabilizing atmospheric $CO_2$ at ~ 500ppm

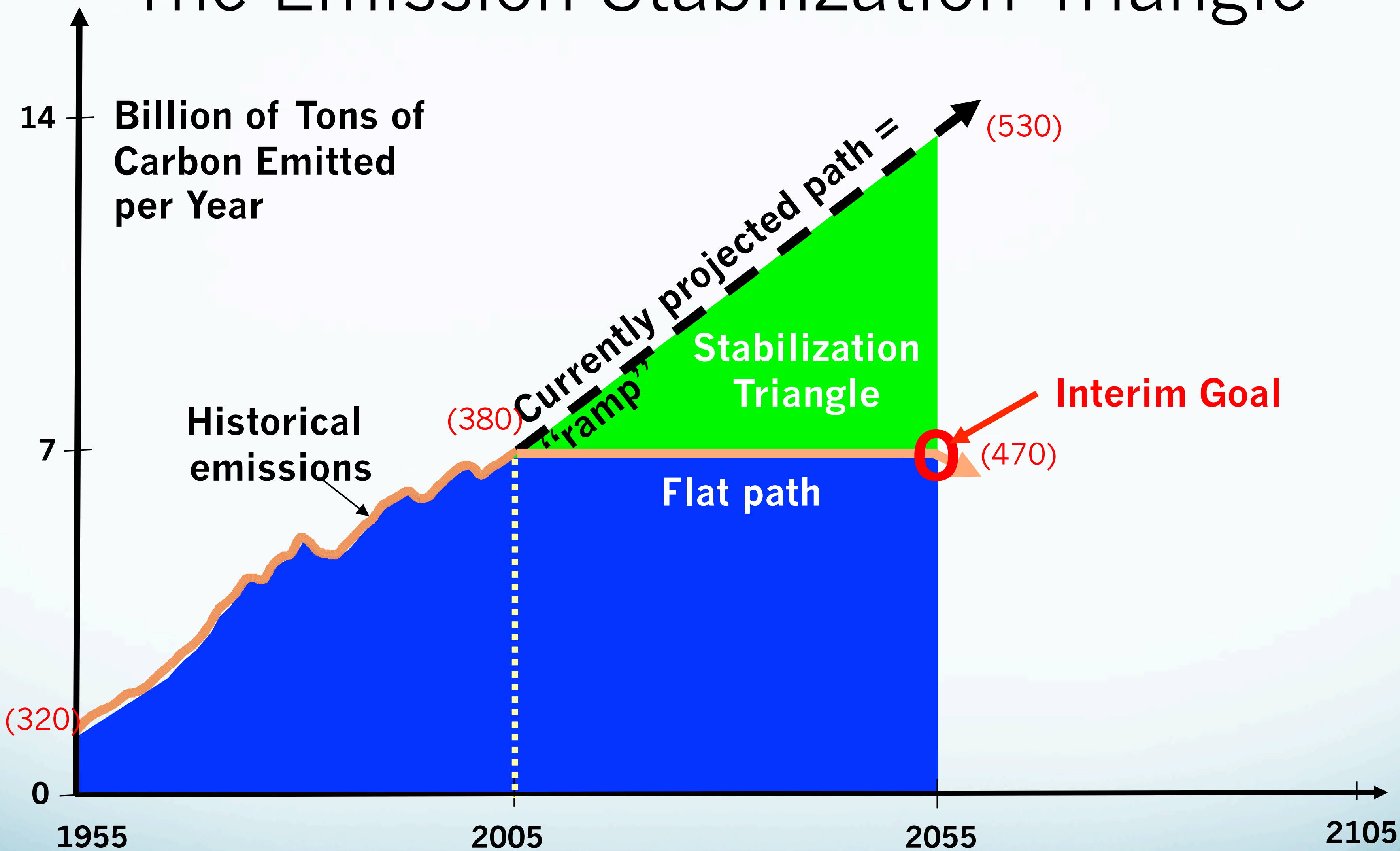
- In 2004, Pacala and Socolow proposed a scheme to achieve this goal
  - **Phase 1**: **No further increase** in emissions until 2054, with energy production still increasing rapidly. Ramping up existing technologies to do this. (So we're already behind, but it's not too late).
  - **Phase 2**: After 2054, **rapid reductions** in global emissions. Final emissions of all GHGs must level off by ~2100 to ~ 1.5 Gt/yr, or ~20% of present global emissions.

# Past Emissions




Values in parentheses are ppm of $CO_2$

# The Emission Stabilization Triangle

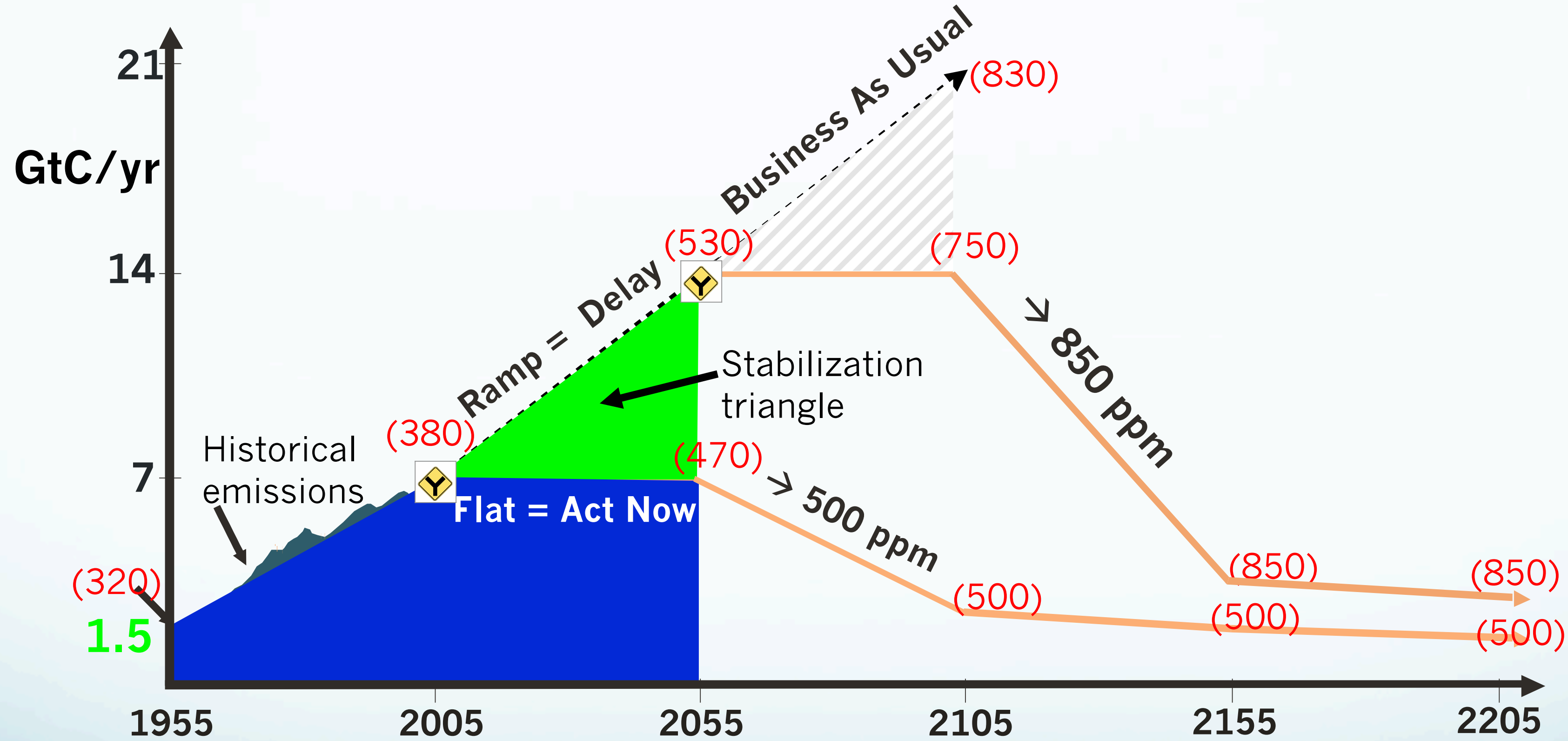



Interim 2054 goal: stabilize emissions immediately (yet increase energy by ~70% in 2054) and invest in technology to have much more energy with reduced emissions after that

Pacala and Socolow (2004)

# The Stabilization Triangle:

settle for **double** (560) or **triple** (840) pre-industrial $CO_2$? Or more???

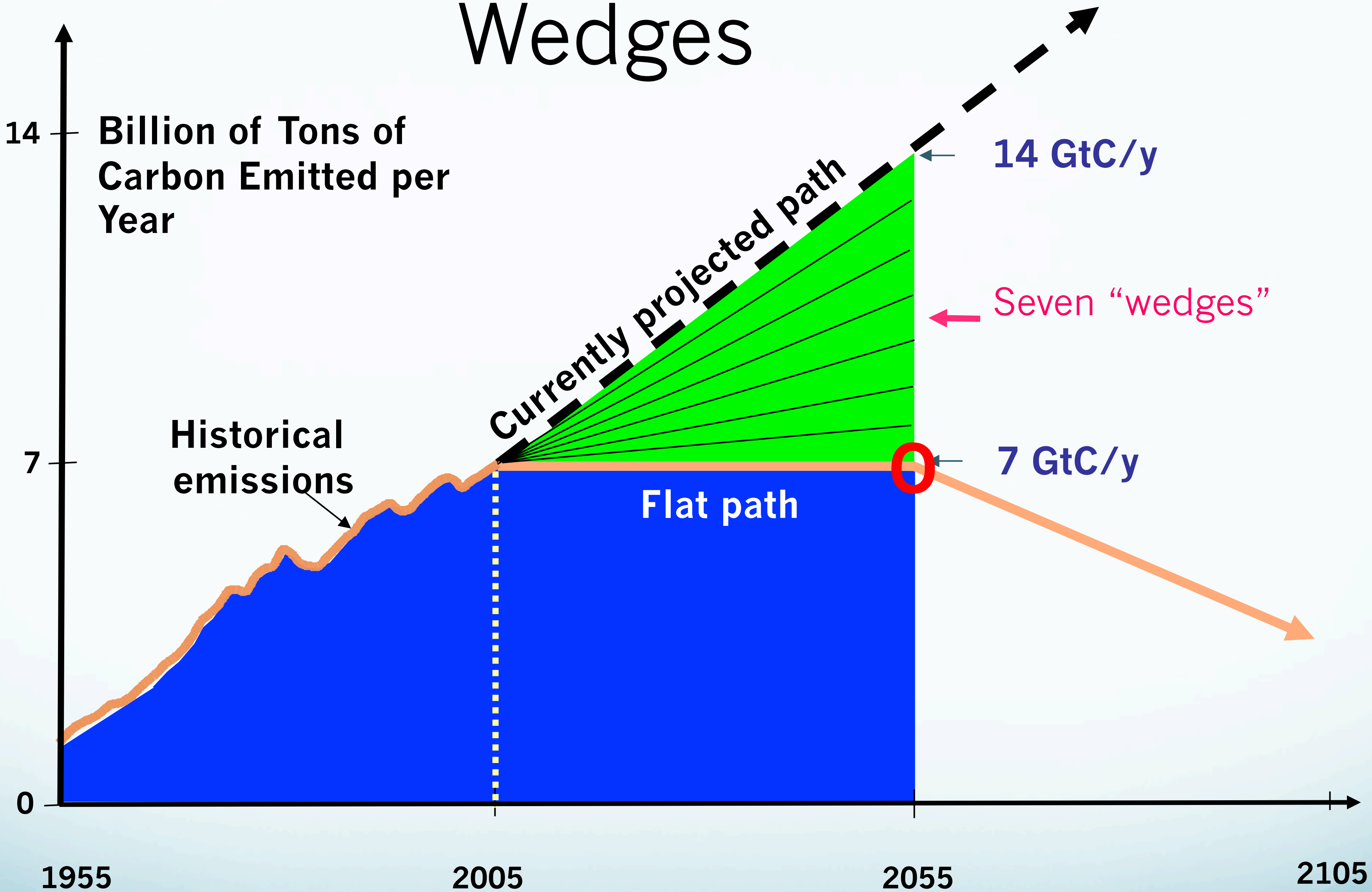



Values in parentheses are ppm (1 ppm = 2.1 GtC).

*Stabilizing at 500ppm requires the global emission be 1.5 Gt/yr by 2100*

Pacala and Socolow (2004)

# Wedges

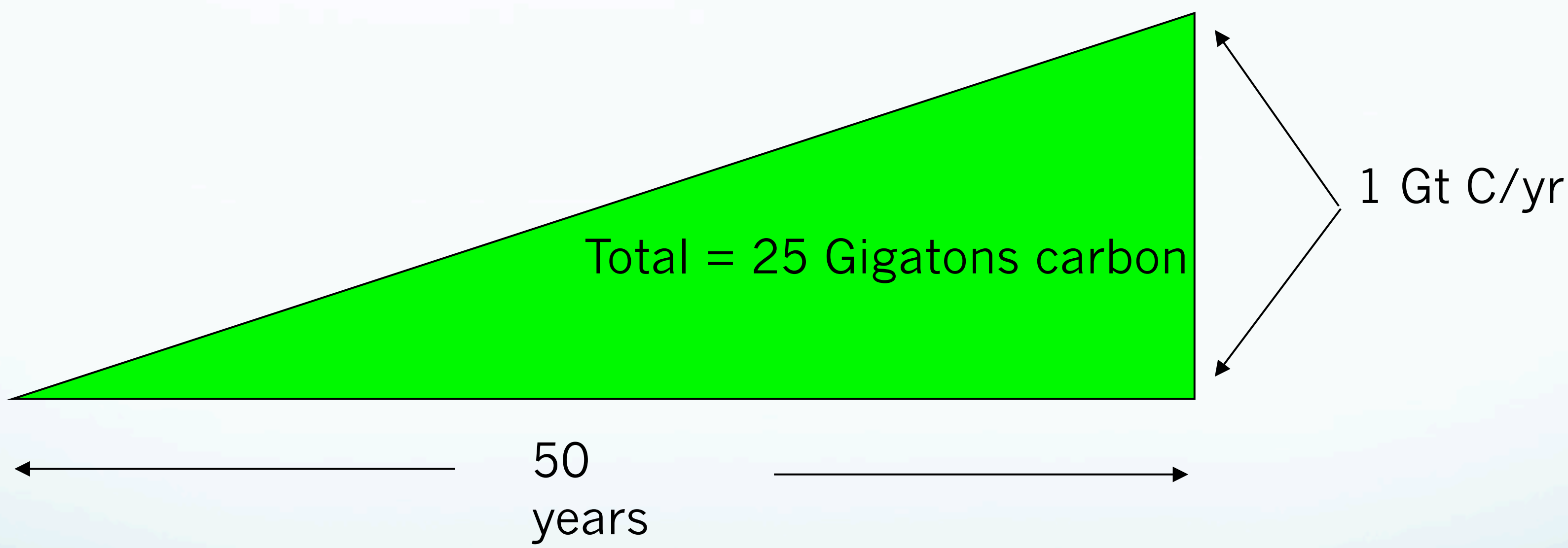



How do we meet the *increase* in energy demand (projected to increase by 70% by 2050 and 200+% by 2100) without increasing emissions of $CO_2$?

Pacala and Socolow (2004)

# 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.




Cumulatively, a wedge redirects the flow of 25 Gt C in its first 50 years.

Pacala and Socolow (2004)

# The Interim Goal is Within Reach

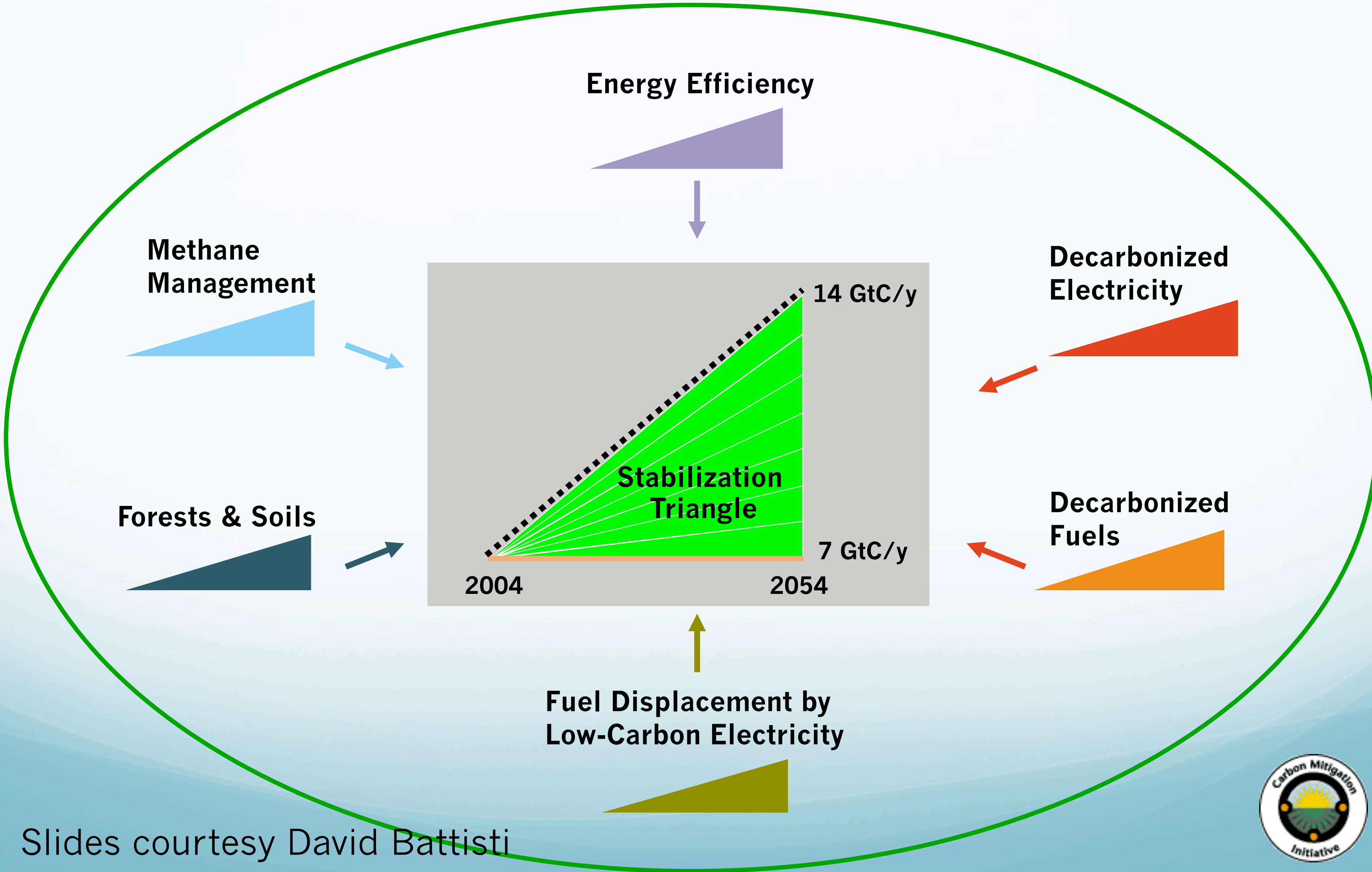
Reasons for optimism that global emissions in 2055 need not exceed today's emissions:

- 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

Pacala and Socolow (2004)

# Fill the Stabilization Triangle with Seven Wedges

There are 15 different options for this!  Each **challenging** but **feasible**




Slides courtesy David Battisti

# *Wind Electricity*

*Prototype of 80 m tall Nordex 2.5 MW wind turbine located in Grevenbroich, Germany (Danish Wind Industry Association)*

**Effort needed by 2055 for 1 wedge:**

One million 2-MW windmills displacing coal power.

Today we have about 50,000 MW (1/40 of this)

R. Socolow (per. comm.)

# *Wind Electricity*

*Prototype of 80 m tall Nordex 2.5 MW wind turbine located in Grevenbroich, Germany (Danish Wind Industry Association)*

One million 2-MW windmills displacing coal power.

Would require land space the size of Germany (but land below could be used for grazing, farmland, etc)

Wind energy would only have to increase by 8% per year to achieve this (and recent increases have been 30% per year)

R. Socolow (per. comm.)

# *Pholtovoltaic (solar) Power*

**Effort Needed by 2055 for one wedge:**

2000 $GW_{peak}$ (700 times current capacity)

2 million hectares (about the size of New Jersey): roofs can be used though

Would require 14% increase per year (we're currently increasing at 30% per year)

*Graphics courtesy of DOE Photovoltaics Program*

# *Nuclear Electricity*

**Effort needed by 2055 for 1 wedge:**

700 GW displacing coal power (tripling current capacity).

*Graphic courtesy of NRC*

R. Socolow (per. comm.)

# *Fuel Switching*


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

**Effort needed by 2055 for 1 wedge:**

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

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

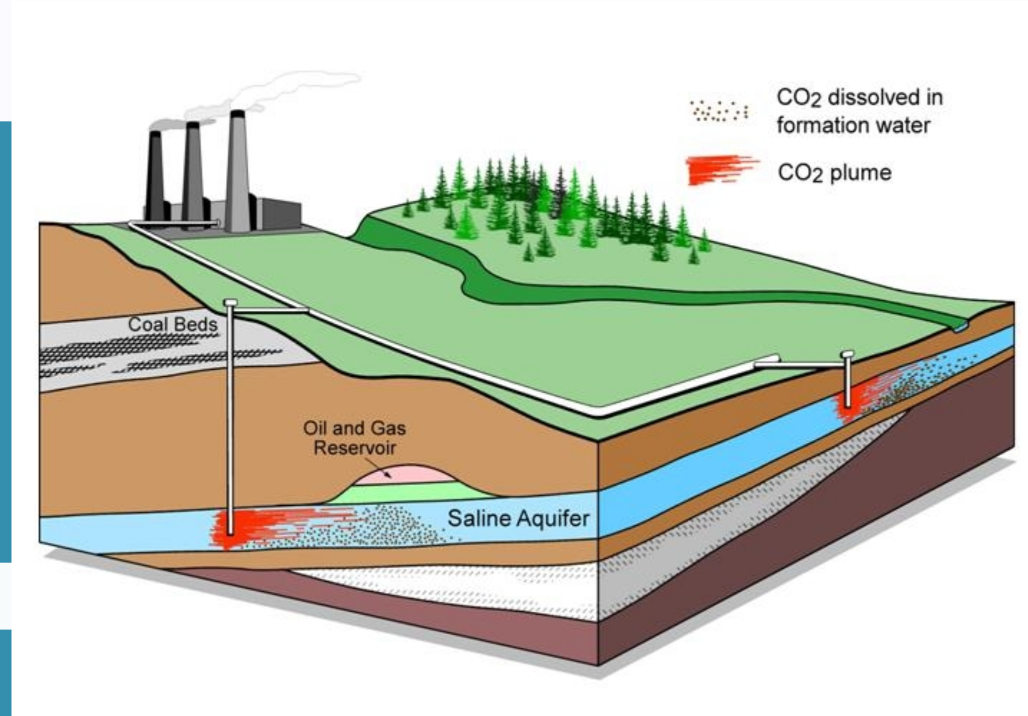
# *Carbon Capture & Storage*

**Effort needed for 1 wedge by 2055**

Implement CCS at 800 GW coal electric plants

**Effort needed for 1 wedge each by 2055**

Implement CCS at 1600 GW natural gas electric plants

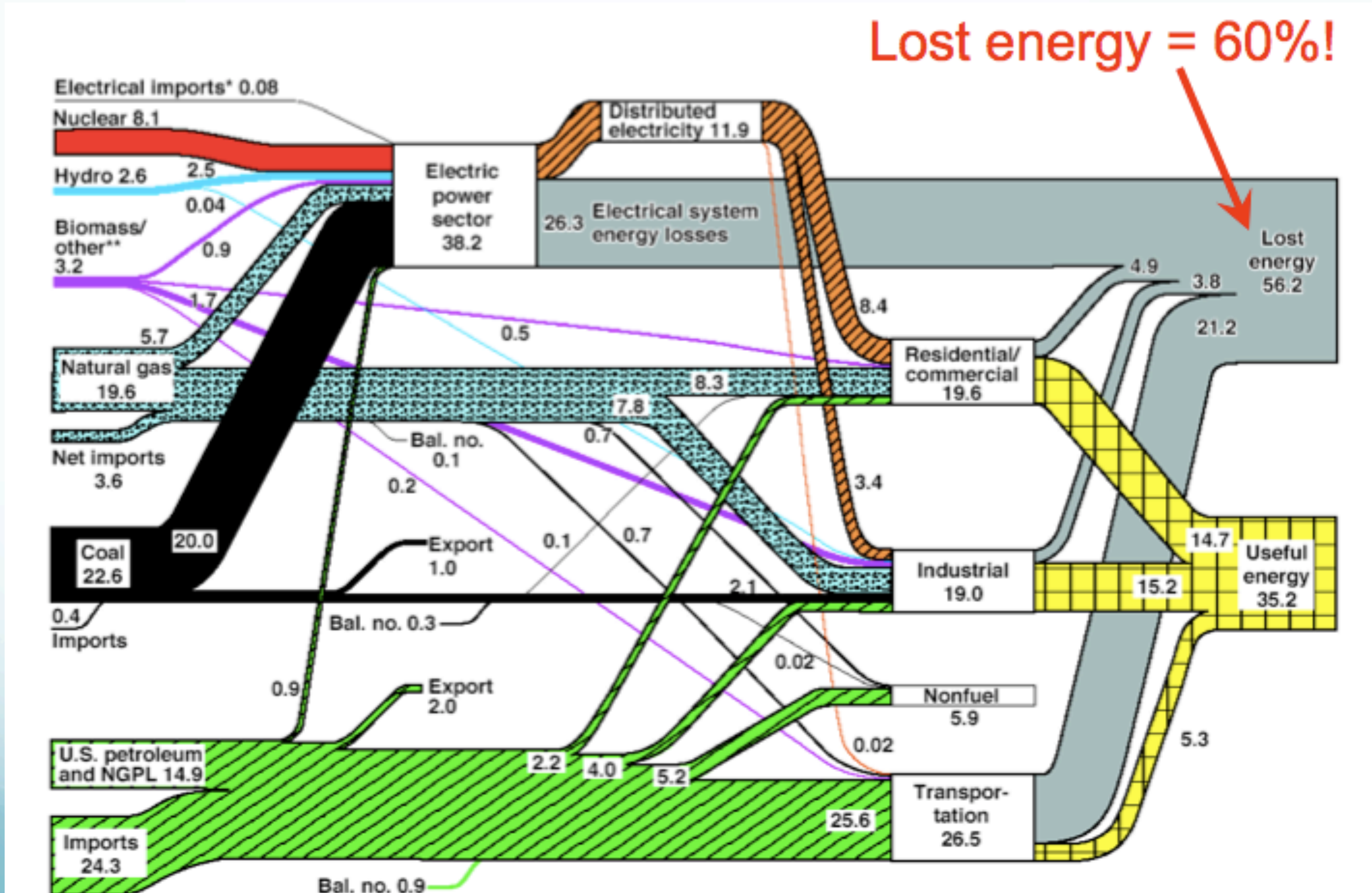



Graphic courtesy of Alberta Geological Survey

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

# Lots of potential for increased efficiency in US

## example electricity production and use



# *Efficient Use of Electricity*

industry

buildings

power

**Effort needed by 2055 for 1 wedge:**

Use best efficiency practices in all residential & commercial buildings

25% - 50% reduction in expected 2055 electricity use in commercial and residential buildings

Changing all light bulbs to CFL would be 1/3 of a wedge!

R. Socolow (per. comm.)

# *Efficient Generation of Electricity*

**Effort needed by 2055 for 1 wedge:**

Improve the efficiency of coal power plants from 40% to 60%, and double efficiency from which we take fossil fuels from the ground.

power

R. Socolow (per. comm.)

# *Efficient Use of Fuel*

**Effort needed by 2055 for 1 wedge:**

Decrease the **number of miles** driven per car: 5,000 instead of 10,000 miles per year.

**Effort needed by 2055 for 1 *more* wedge:**

Double **fuel efficiency** of cars: 60 mpg instead of 30 mpg.

# *Biofuels*

**Effort needed by 2055 for 1 wedge:**

2 billion 60 $mpg_e$ cars running on biofuels instead of gasoline and diesel.

To produce these biofuels: 250 million hectares of high-yield (15 t/ha) crops, one sixth of world cropland.

Challenge: To find ecologically responsible ways to grow biomass for power and fuel on hundreds of millions of hectares.

Usina Santa Elisa mill in Sertaozinho, Brazil (http://www.nrel.gov/data/pix/searchpix.cgi?getrec=5691971&display_type=verbose&search_reverse=1_

# *Natural Sinks*

**Eliminate tropical deforestation**

**OR**

**Plant new forests over an area the size of the continental U.S.**

**OR**

**Use conservation tillage on *all* cropland (1600 Mha)**

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

Photos courtesy of NREL, SUNY Stonybrook, United Nations FAO

# Do wedge strategies get used up?

Is the second wedge **easier** or **harder** to achieve than the first?

Are the first million two-megawatt wind turbines more expensive or cheaper than the second million two-megawatt wind turbines?

The first million will be built at the more favorable sites.

But the second million will benefit from the learning acquired building the first million.

The question generalizes to almost all the wedge strategies:

Geological storage capacity for $CO_2$, land for biomass, river valleys for hydropower, uranium ore for nuclear power, semiconductor materials for photovoltaic collectors.

# Summary: What's appealing about wedges?

- The stabilization triangle
  - Does not concede that doubling CO2 is inevitable
  - Shortens the time frame to within business horizons
- The wedge
  - Decomposes a heroic challenge (the Stabilization Triangle) into a limited set of monumental tasks
  - Establishes a unit of action that permits quantitative discussion of cost, pace, risk, trade-offs, etc
- The wedge strategy
  - Does not change the fact there are winners (alternative energies) and losers (coal and oil become more expensive sources of energy), but brings many options to the table

# How do we want to end the class?

- Option 1:
  - Lecture on political solutions (Kyoto, Copenhagen, etc) tomorrow.
  - Lecture on grassroots campaigns (e.g., 350.org, The World People's Climate Conference in Bolivia, etc) on Wednesday.
- Option 2:
  - Lecture on political/grassroots solutions tomorrow.
  - Class discussion on Wednesday (I can bring discussion questions).
- Either case: Final presentations on Thursday