Welcome to ATMS 111 Global Warming

http://www.atmos.washington.edu/2010Q1/111

Last Two Weeks Overview

Last quiz today. Buy scantron sheets at the break at By George candy stand

Today: Technological solutions
Thursday: Continued Technology and Geoengineering

Next week: Economics and politics, review for final

Correction to Slide from 25 February lecture

Global Warming and Glaciers

- The CEI commercial claims glaciers are growing
  - The paper cited refers only to interior Greenland

Recent Ice-Sheet Growth in the Interior of Greenland

Ola M. Johannessen,[1,2*] Kirill Khvorostovsky,[3] Martin W. Miles,[4,5] Leonid P. Bobylev[3]

A continuous data set of Greenland Ice Sheet altimeter height from European Remote Sensing satellites (ERS-1 and ERS-2), 1992 to 2003, has been analyzed. An increase of 6.4 ± 0.2 centimeters per year (cm/year) is found in the vast interior areas above 1500 meters, in contrast to previous reports of high-elevation balance. Below 1500 meters, the elevation-change rate is –2.0 ± 0.9 cm/year, in qualitative agreement with reported thinning in the ice-sheet margins. Averaged over the study area, the increase is 5.4 ± 0.2 cm/year, or ~60 cm over 11 years, or ~54 cm when corrected for isostatic uplift. Winter elevation changes are shown to be linked to the North Atlantic Oscillation.

- Interior Greenland and Antarctica are accumulating more snow in the high interior where it is always well below freezing. This is expected as the earth warms: higher temperature -> more water vapor -> more snow
- These ice sheets are losing mass on the edges, where ice is flowing faster into the oceans, likely due to sea level rise.
- In the net, Antarctic is X presently gaining mass.

Outdated. GRACE data indicates it is losing mass now

The Predicament: Can we solve Global Warming? (RG p278-285)

What should be the goal?

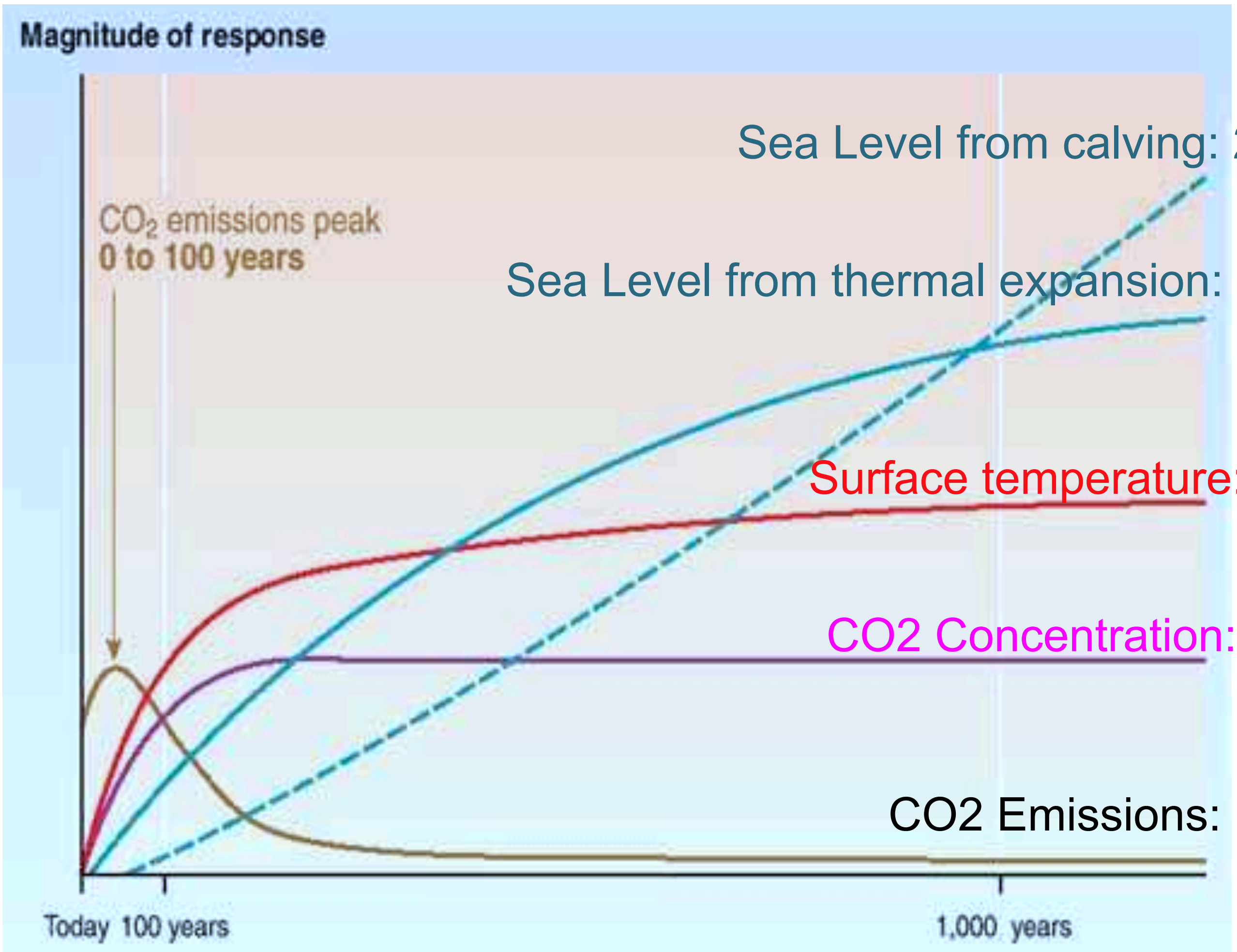
Stabilizing emissions

Stabilizing concentrations

Stabilizing temperature

stabilize = level-off or equilibrate

1) If we reduce emissions radically after ~2050
2) Concentration still rise until the emissions are nearly zero (carbon cycle taking up the small remainder)
3) The temperature keeps rising 500-1000 yrs from oceans time-lag. The deep oceans draw down heat, which maintains the flux imbalance at the top of the atmosphere (i.e., keeps the planet out of energy balance).



times to stabilize

Sea Level from calving: 2000+ years

Sea Level from thermal expansion: 1000+ years

Surface temperature: 500-1000 yrs

CO2 Concentration: 100-500 yrs

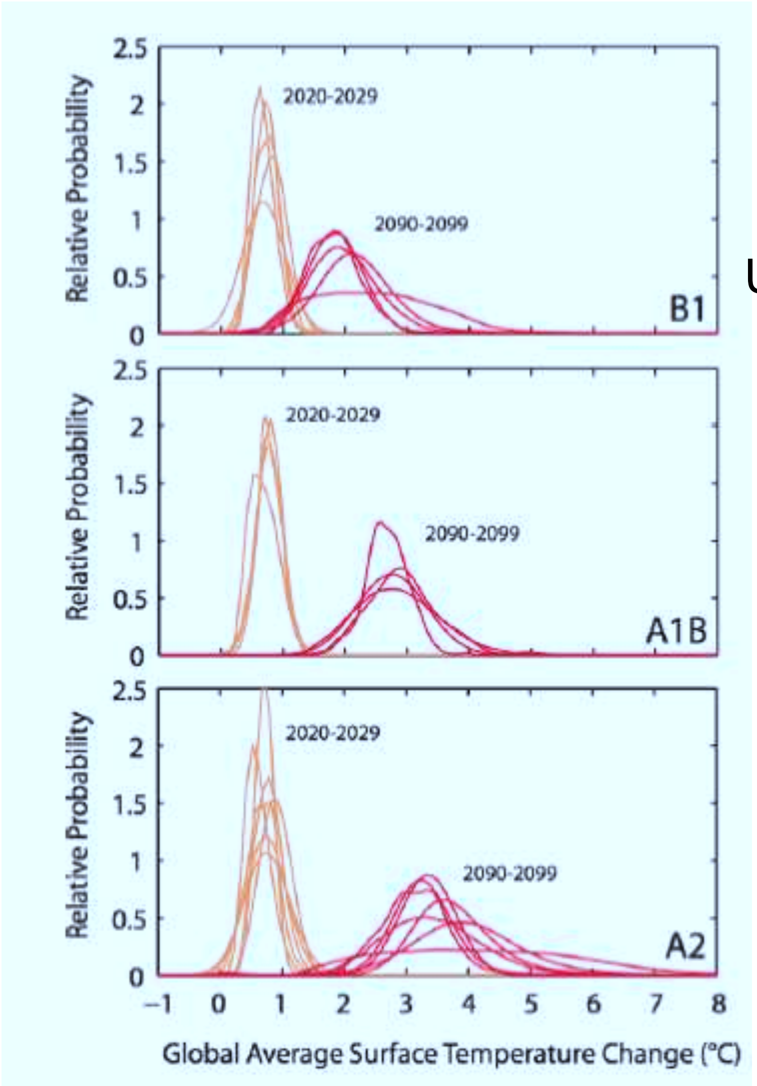
CO2 Emissions: 100-200yrs

Projections of Future Changes in Climate

Near term projections insensitive to choice of emissions scenario

Longer term projections depend on scenario and climate model sensitivities

Fig from IPCC AR4 Summary for Policy Makers. Lines are different studies.



Utopia

BAU

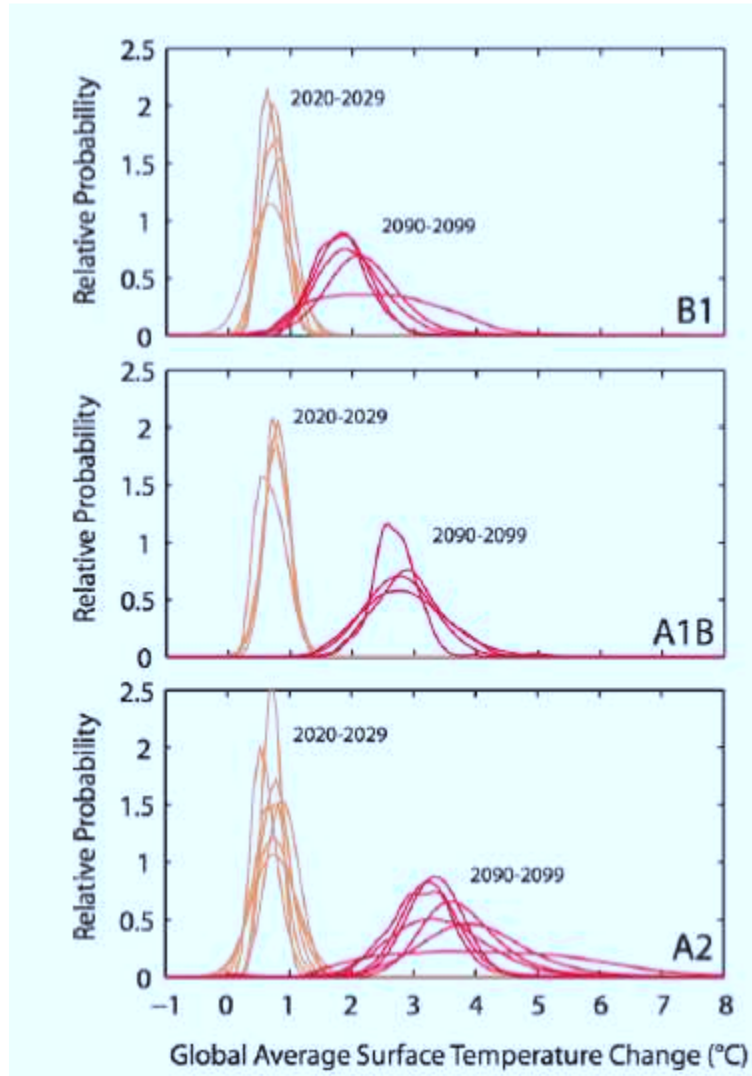
Relative to an average from 1980-1999

What is the projection by 2020-2029?

We could more than double the warming we have experienced since the pre-industrial era

0.25 - 1.25°C

Nearly all the uncertainty is due to model uncertainty



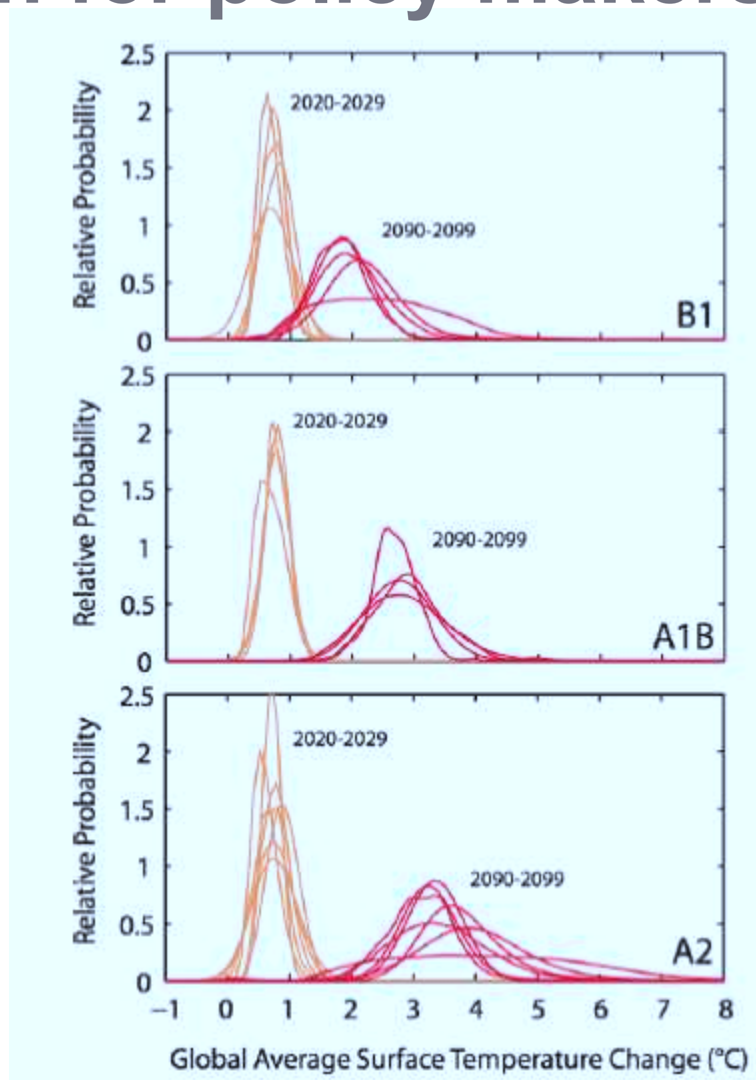
Relative to an average from 1980-1999

What does the insensitivity to emissions in the near term mean for policy makers?

Cutting emissions is mostly a benefit to future generations

How likely is it for politicians to protect future generations, let alone us when the harm comes after their term is up?

more about this next week



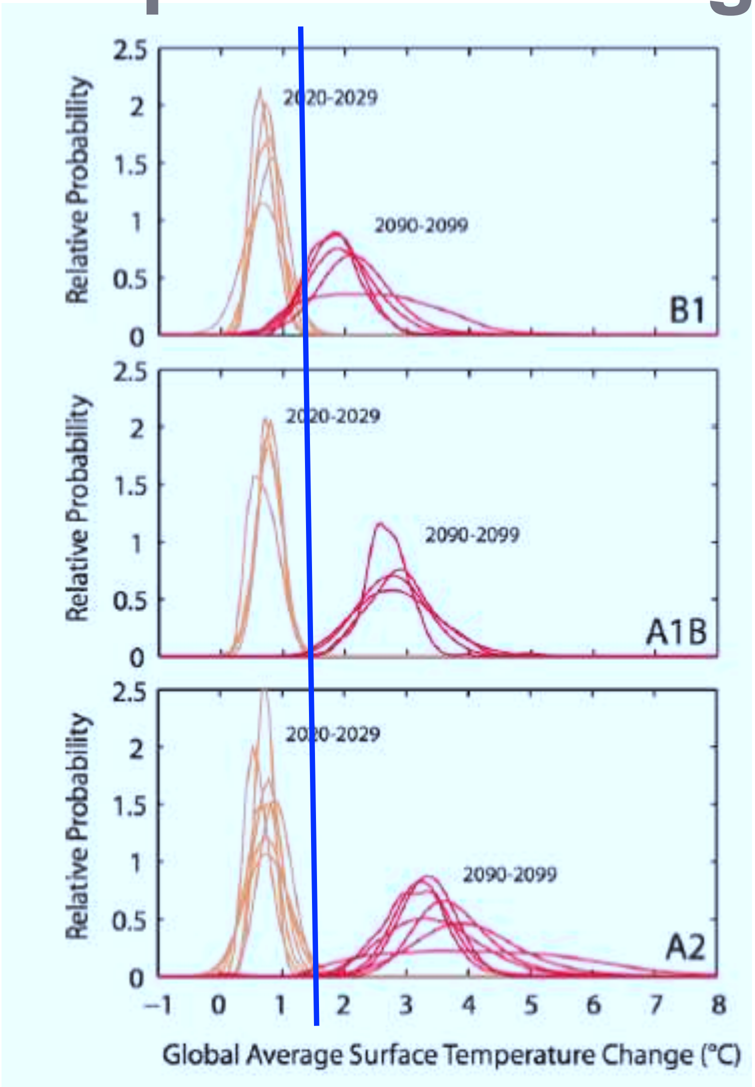
Relative to an average from 1980-1999

Instead frame the question: What is a dangerous level of temperature change?

Dangerous climate change is often given as a *2°C warming since pre-industrial times*. So a ~1.4°C change in the figures at right

Very likely "safe" until 2029.

The target is likely missed this century even with Utopian B1 emissions.



Relative to an average from 1980-1999

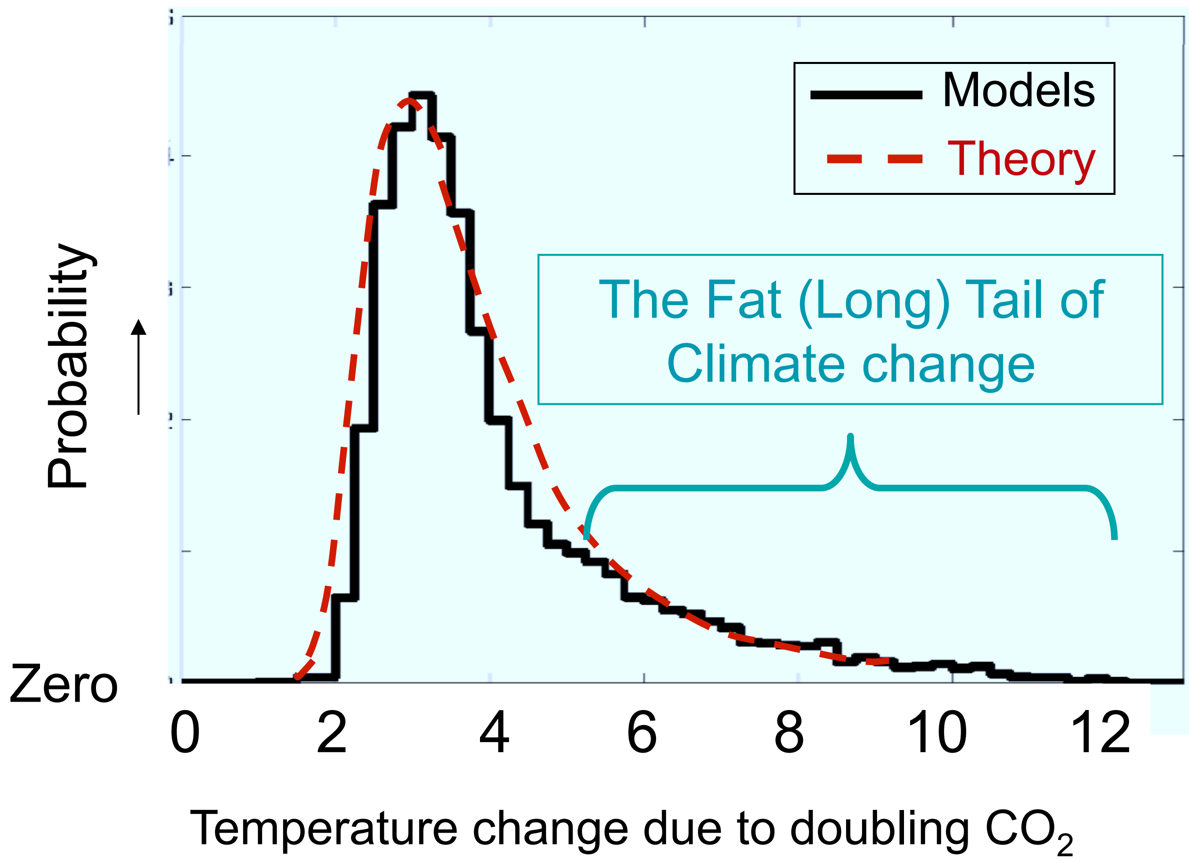
What's so dangerous about a 2°C global warming?

IPCC AR4 WGII
Impacts Book
Table 19.1

	Relationship between temperature and risk. Temperature change by 2100 (relative to 1990-2000) 0°C 1°C 2°C 3°C 4°C 5°C	
Food supply [19.3.2.2]	Productivity decreases for some cereals in low latitudes */• [5.4] Productivity increases for	Cereal productivity decreases in ... /•
Infrastructure [19.3.2]	Damages likely to increase exponentially, sensitive to rate of climate change, change in extreme events and adaptive capacity ** [3.5, 6.5.3, 7.5].	
Health [19.3.2]	Current effects are small but discernible * [1.3.7, 8.2].	Although some risks would be reduced, aggregate health impacts would increase, particularly from malnutrition, diarrhoeal diseases, infectious diseases, floods and droughts, extreme heat, and other sources of risk */**. Sensitive to status of public health system *** [8.ES, 8.3, 8.4, 8.6].
Water resources [19.3.2]	Decreased water availability and increased drought in some mid latitudes and semi-arid low latitudes ** [3.2, 3.4,	Severity of floods, droughts, erosion, water-quality deterioration will increase with increasing climate change ***. Sea-level rise will extend areas of salinisation of groundwater, decreasing freshwater availability in coastal areas *** [3.ES]. Hundreds of millions people would face reduced water supplies ** [3.5].

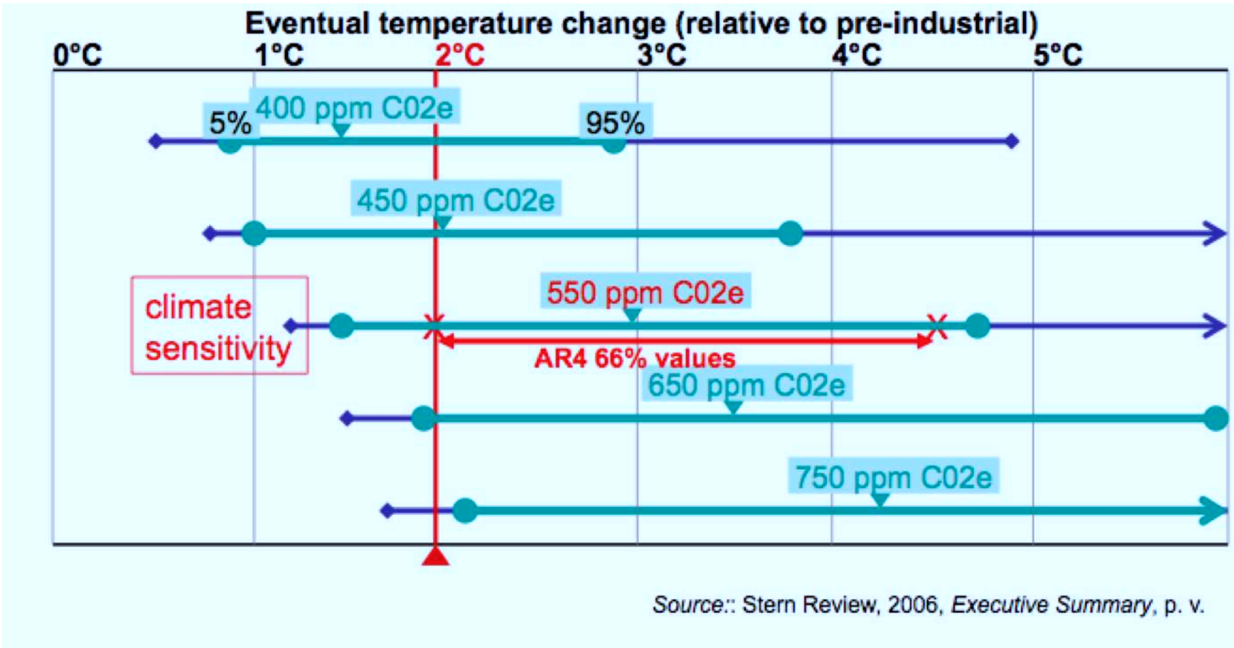
"There is no line in the sand, with safety on one side and disaster on the other." Stern Review 2006

Uncertainty of Equilibrium Climate Sensitivity from ClimatePrediction.net



Probability of warming from doubling CO2 (560ppm compared to 280ppm) at equilibrium (after 500-1000 yrs or in reality from runs with shallow ocean).

The Fat Tail of Climate Change



Unfortunately, the Fat Tail of climate change means even 500ppm is terribly risky. The utopian B1 scenario reaches 500ppm by 2100 – and keeps rising.

Paths to CO_2 stabilization: emission reduction requirements by 2050

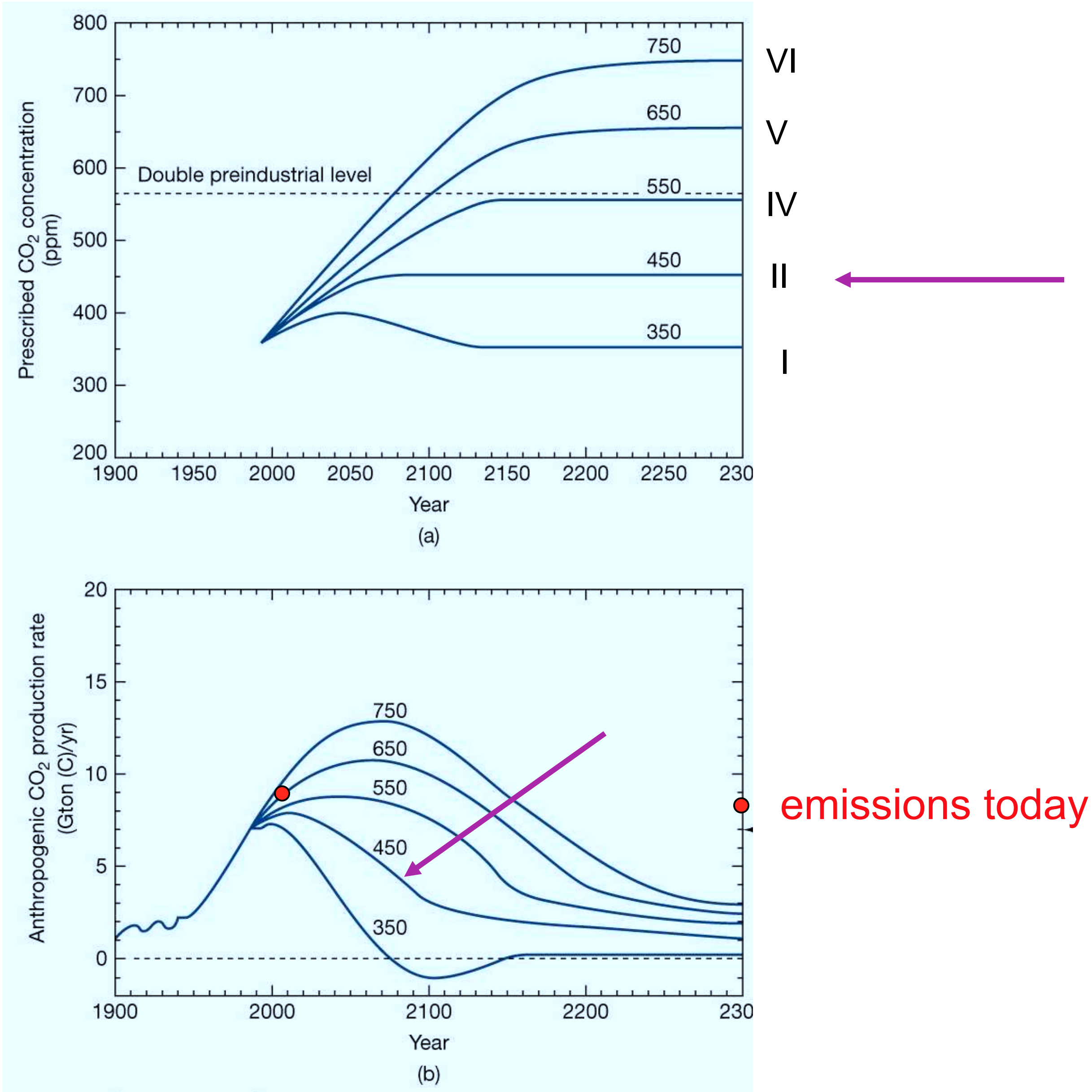
<-------- At stabilization ------->				<-- Required Action -->	
Category	**Radiative forcing** (W/m^2)	**CO_2 concentration**[c)] (ppm)	**CO_2-eq concentration**[c)] (ppm)	**Peaking year for CO_2 emissions**[d)]	**Change in global CO_2 emissions in 2050** (% of 2000 emissions)[d)]
I	2.5-3.0	350-400	445-490	2000-2015	-85 to -50
II	3.0-3.5	400-440	490-535	2000-2020	-60 to -30
III	3.5-4.0	440-485	535-590	2010-2030	-30 to +5
IV	4.0-5.0	485-570	590-710	2020-2060	+10 to +60
V	5.0-6.0	570-660	710-855	2050-2080	+25 to +85
VI	6.0-7.5	660-790	855-1130	2060-2090	+90 to +140

To achieve stabilization of CO_2 (and other GHGs) at ~ 500 ppm, global emissions have to level off immediately and decrease severely by 2050

and even this will likely warm the planet above 2°C

IPCC 2007 WG III Mitigation Book Table SPM.5

Paths to CO_2 stabilization



What can be done?

1) Take CO_2 out of the air using mechanical means (unlikely)

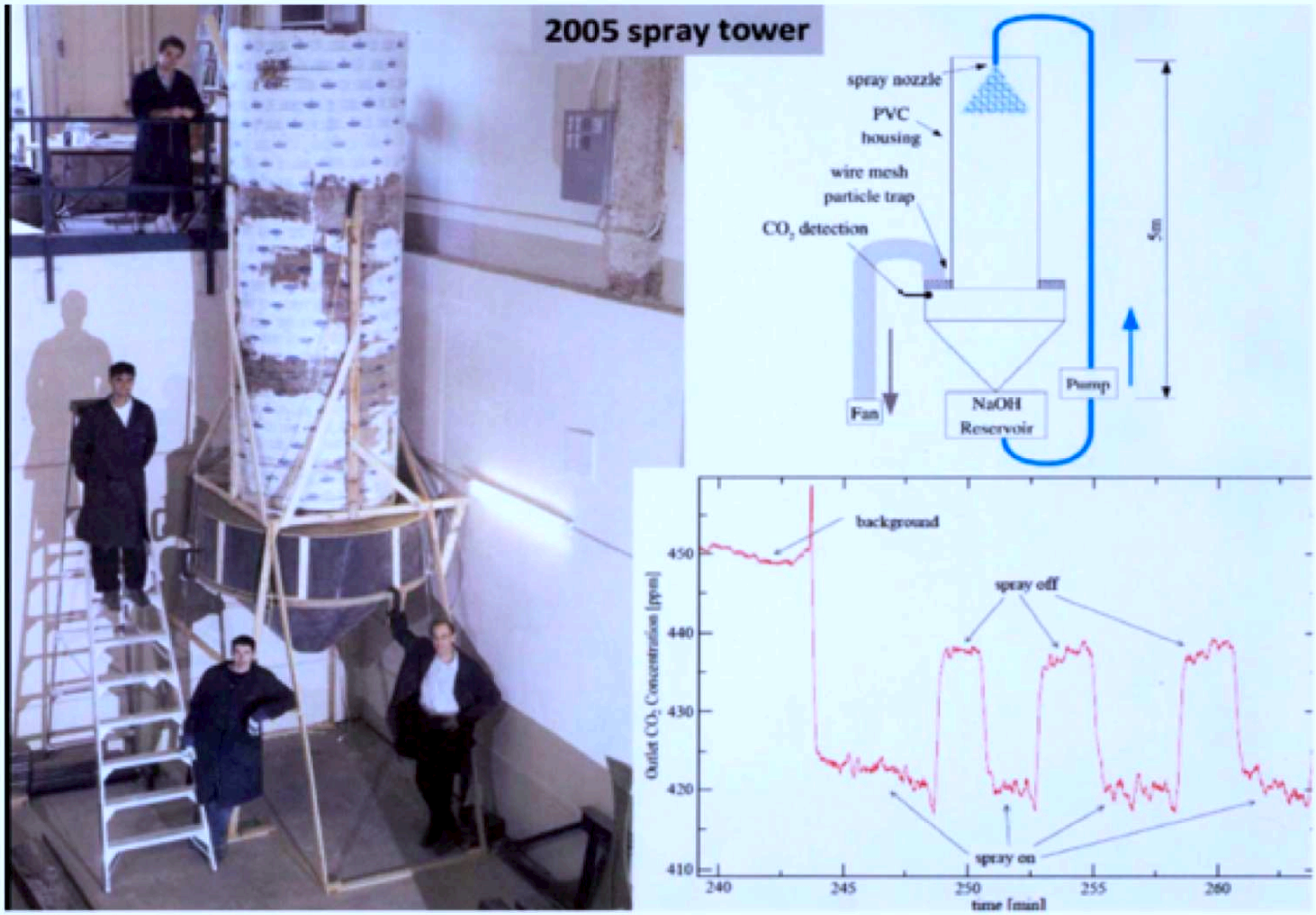
2) Increase ocean CO_2 uptake by promoting photosynthesis and thus remove CO_2 from the atmosphere

3) Carbon Capture and Sequestration – take carbon from the smokestack and move somewhere else

4) Add negative radiative forcing intentionally to the atmosphere (Geoengineering – discussed Thurs)

5) Mitigation - Don't emit in the first place. Use renewables.

Take CO_2 out of the air (from anywhere)



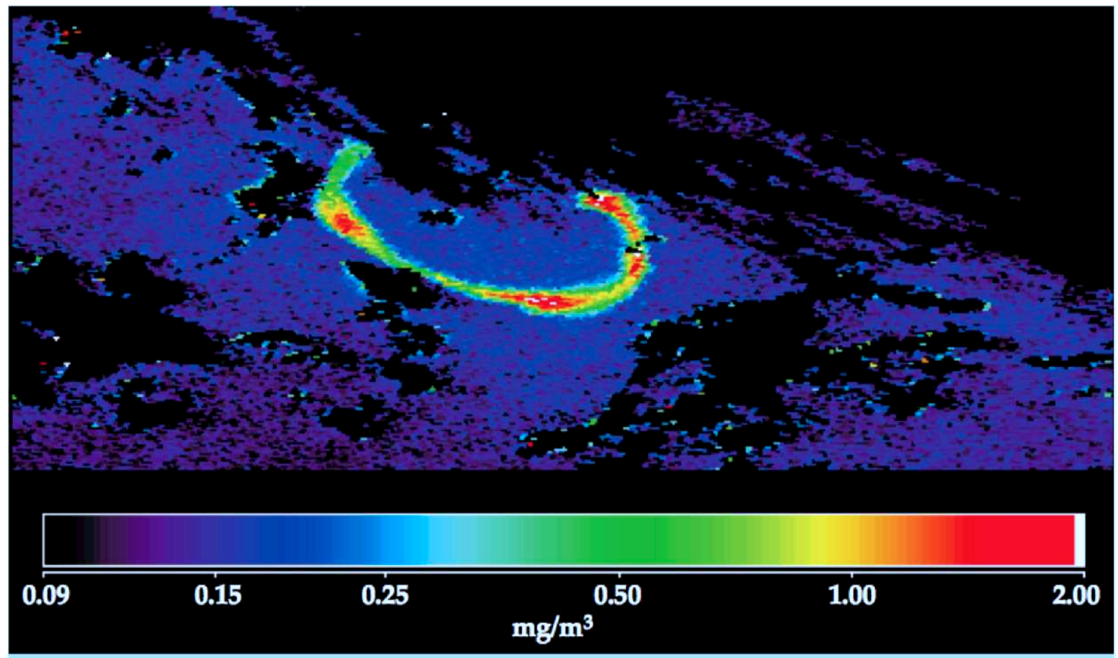
Source: David Keith, MIT talk, Sept. 16, 2008

Currently few ways to do this. None have left the prototype stage. All are projected to be astoundingly expensive.

Promote Photosynthesis by Fertilizing the Ocean

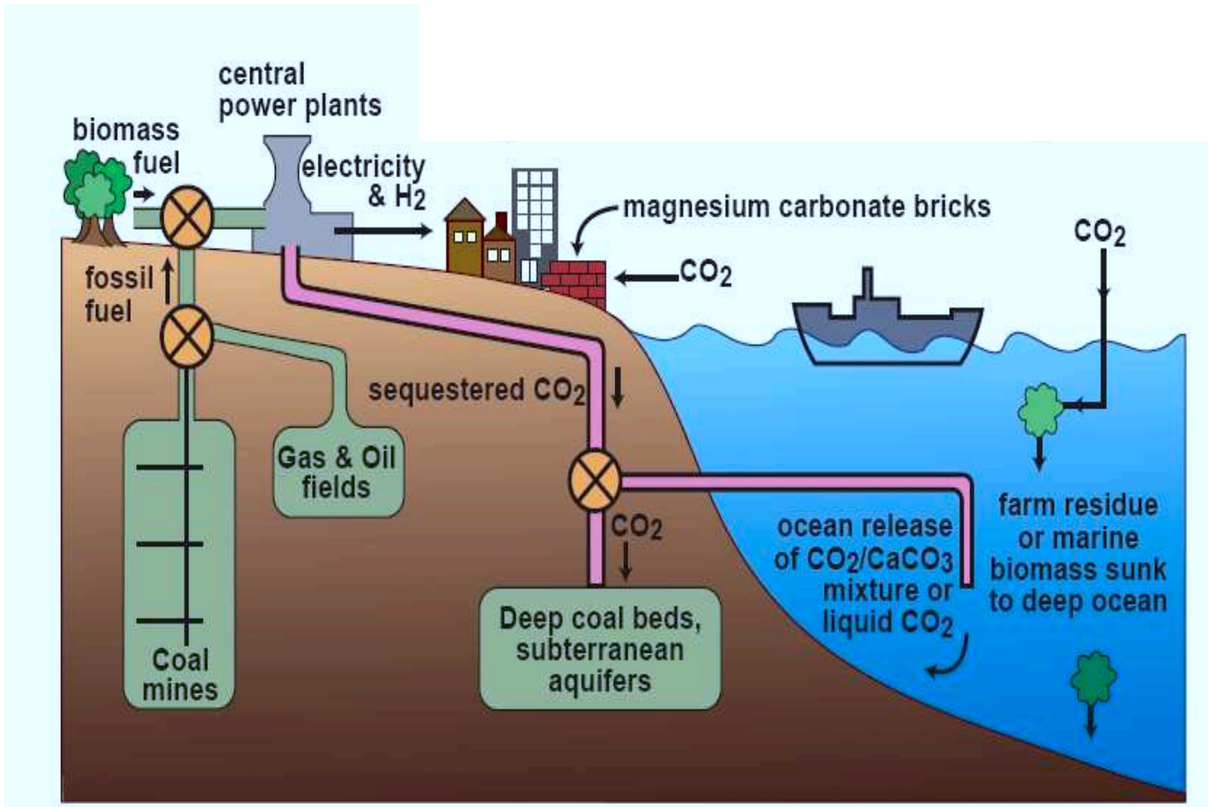
- Fertilize the ocean with iron (a limiting nutrient) to promote photosynthesis and thus remove CO_2 from the atmosphere

- Downsides:
  - Studies show after the phytoplankton bloom, most carbon goes right back into the atmosphere
  - Major disruption to the base of the marine food chain



Phytoplankton bloom following an iron-fertilization experiment in the Southern Ocean. The area covered spans about 1 degree of latitude and 2 degrees of longitude. Color scale indicates the mass of chlorophyll per cubic meter of seawater, mostly contained in phytoplankton. (Image provided by the NASA Goddard Earth Sciences Data and Information Services Center.)

Carbon Capture and Storage



- Works for CO_2 emitted from coal, but not applicable to non-point sources (e.g., CO_2 emitted from tailpipes)
- Makes energy from coal expensive compared to many other sources, including renewables.
- Risky if CO_2 escapes from storage

“Clean Coal” is not the same thing as Carbon Capture and Storage

May include among the following

- Wash coal to remove harmful chemical
- Gasify coal by heating it to release and capture SO_2, some CO_2 is released and often pumped into depleted oil and gas fields to create pressure
- Produce Synfuels, which are burnt later (releasing CO_2 later)

This term is used by the coal industry but they offer no analysis to show it lowers CO_2 emissions

“Why did I have to give bad kids all that coal?”

Mitigation

Renewable = energy generated from natural sources such as solar, wind, tidal, geothermal, and hydro.

Nuclear is not renewable. but it also doesn't emit CO_2

Over half of the world's renewable energy is produced in Germany. Their energy is nearly 100% renewable today.

Can the U.S. do the same?

Useful Facts about Energy

U.S. Energy sources (2007):

- Oil 40%,
- Coal 23%,
- Gas 22%,
- nuclear 8%,
- renewables:7%

(U.S. Electricity Sources coal, nuclear and renewables dominate)

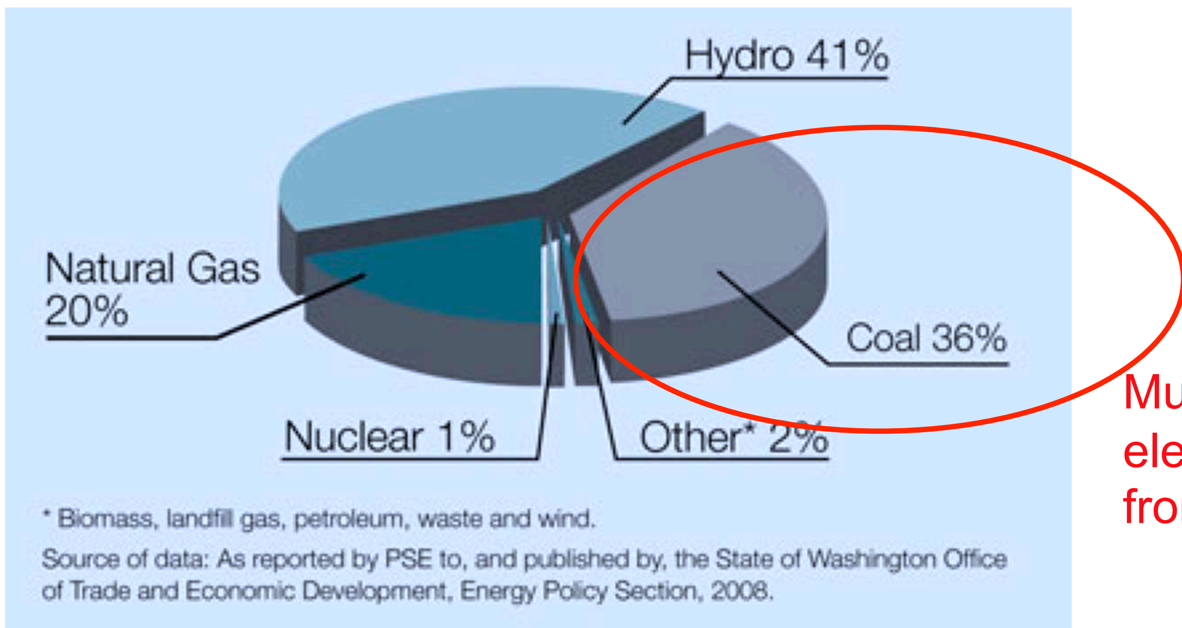
Useful Facts about CO2

- Energy per CO_2 emitted:
  - gas compared to coal 1.7,   oil compared to coal: 1.3
  - Coal is a 'dirty fuel'

- 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
- 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.



Much of our electricity comes from coal

Puget Sound Energy Electricity Portfolio

Total worldwide energy use is 15 terawatts = 15×10^{12} W

How does this compare to the sun's radiation reaching the surface of Earth?

$200\ W/m^2$ average solar flux reaching surface
$\times\ 0.5 \times 10^{15}\ m^2$ area of Earth's surface

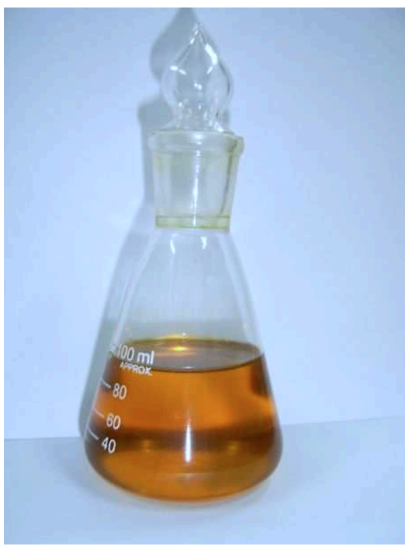
$= 100 \times 10^{15}$ W

~7000 times more energy from the sun reaches surface

At this point in history, we have no real substitutes for oil in global transport…

We are working on some (e.g. hydrogen), but they are still years away.

Biofuels are likely to only be a temporary measure



Biodiesel

What is Ethanol?

- Ethyl Alcohol (the drinkable kind of alcohol, unless it is denatured)
- Produced from carbohydrates and yeast
- Sweet, simple carbohydrates ferment most easily (cane sugar is best wood pulp is harder)

What is Biodiesel?

- Methyl or ethyl esters
- Formed by *transesterfication*:

  alcohol + oil --> less alcohol + biodiesel + fertilizer + glycerin

- Oil source: soybean oil, canola oil, restaurant grease

  biodiesel smells like french fries… because…

  esters are aromatic! (think bananas, apples, dirty socks…)

The Biofuel Cycle

CO_2

Is this C cycle closed or is there a ‘leak’ of C to the atmosphere?

Fermentation and/or transesterfication

Biodiesel

oil, alcohol

Biofuel Use Today

in 2008, Americans consumed 9.6 billion gallons of ethanol, which reduced gasoline consumption by less than 5%

Most gasoline has some ethanol in it

E10 is Gasoline with 10% ethanol content by volume. E85 is 85% ethanol and 15% gasoline, and it is mostly sold in the Midwest.

The energy content of ethanol is about 33% less than “pure” gasoline So your vehicle mileage may decrease by up to 3.3% when using E10.

Currently, you must have a “flex-fuel” vehicle to use gasoline with an ethanol content greater than 10% because ethanol takes more energy to vaporize. Can be hard to start in the cold

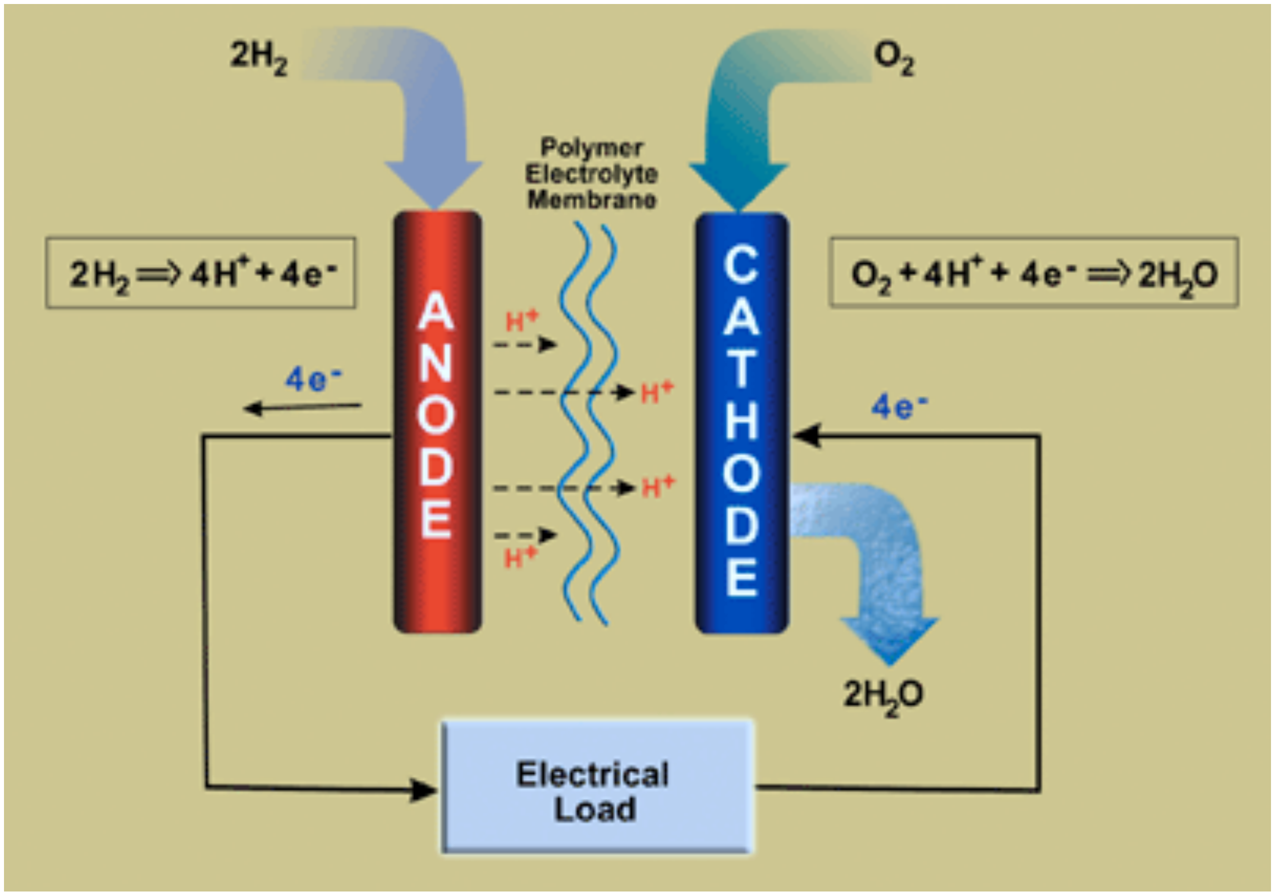
Pros

- Reduces NET CO_2 emissions
- Better for human health reduced carbon monoxide and particulate emissions.
- Less smog potential reduced unburned hydrocarbon emissions
- Reduced acid rain potential no sulfate emissions
- Energy independence

Cons

- May be worse for human health in some ways via ozone and NO_X emissions
- Expensive
- Less land for food production people compete with machines for food
- Pure/high ethanol is not approved for most cars okay as an additive

Hydrogen Fuel Cells – make electricity



No moving parts, so combustion is unlikely
Needs a steady supply of the fuel, which is H_2

How does it work?

$$2H_2 + O_2 \text{ --> } 2H_2O + \text{energy}$$

Sounds GREAT! Nothing bad in that equation!

Is there a catch?

The Catches

- Where do you get H_2?
  - not naturally occurring in large quantities
- H_2 can be generated via electrolysis
  - $2H_2O$ + energy --> $H_2 + 2O_2$
  - Where do we get THIS energy?
- H_2 can be generated from “fossil fuel reformer”
  - reacts steam at high temperatures with methane.
  - requires energy and produces CO_2
- How is H_2 stored? it takes up a lot of space

Hydrogen is a carrier of energy, not a source

At this point in history, we do have alternative sources of electicity

Nuclear
Wind
Solar
Hydropower
Geothermal
Wave/tidal
etc

Nuclear Power

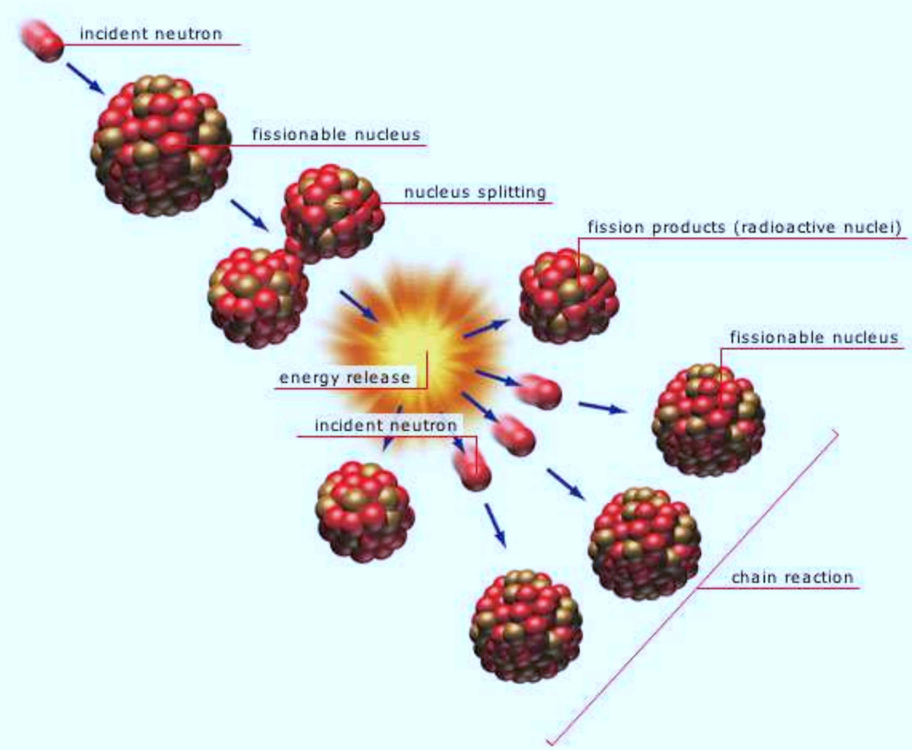
How is Nuclear Power Generated?

One way to capture this energy is to:

1) heat water

2) which makes steam

3) which can turn a turbine.



Pros

- Produces no greenhouse gasses
- Available 24 hrs/day
- Possibly Cheap
- Plenty of Uranium in US

Cons

- Storage of extremely hazardous radioactive wastes
- Uses enormous amount of concrete to build
- Meltdowns, reactor leaks
- Relationship to weapons
- Replaces Big Oil with another big company

Wind Power

How is Wind Power Generated?

wind blows past a turbine (like a propeller)

turbine is turned --> energy

power produced is proportional to (wind velocity) ^{3}

<u>example:</u>

average wind speed = 5 m/s

case 1: range of 4 to 6 m/s

average power ~ $1/2*4^3 + 1/2*6^3 = 140$ units

case 2: range of 1 to 9 m/s

average power ~ $1/2*1^3 + 1/2*9^3 = 365$ units

Wild Horse Wind Farm

Location – 18 miles east of Ellensburg, Kittitas County; 127 miles southeast of Seattle

Land area – 9,000 acres

Start-up – December 2006

Turbines – 127

Power output – 229 MW at peak capacity; 642,000 MWh annual output (est.), enough to meet the total power needs of about 55,000 households

1 MW needed for 1 Wal Mart store
or 250 houses

Winds – must be at least 9 mph, peak capacity reached at 30 mph

Produce electricity ¾ of the time at Wild Horse

Turbines - 351 feet tall from the ground to the tip of a vertical rotor blade; 223 tons total weight

Tower foundation – buried 25 to 32 feet (depending on bedrock depth) in up to 260 cubic yards of concrete;

Generators –each produces up to 1.8 MW of power

Capacity – peak power capability if winds are optimal (wind), river flow is optimal (hydro), coal is burning constantly, etc. Still ignoring waste heat.

Wild Horse wind farm averages 33%
Coal 80%
Hydropower at 50%

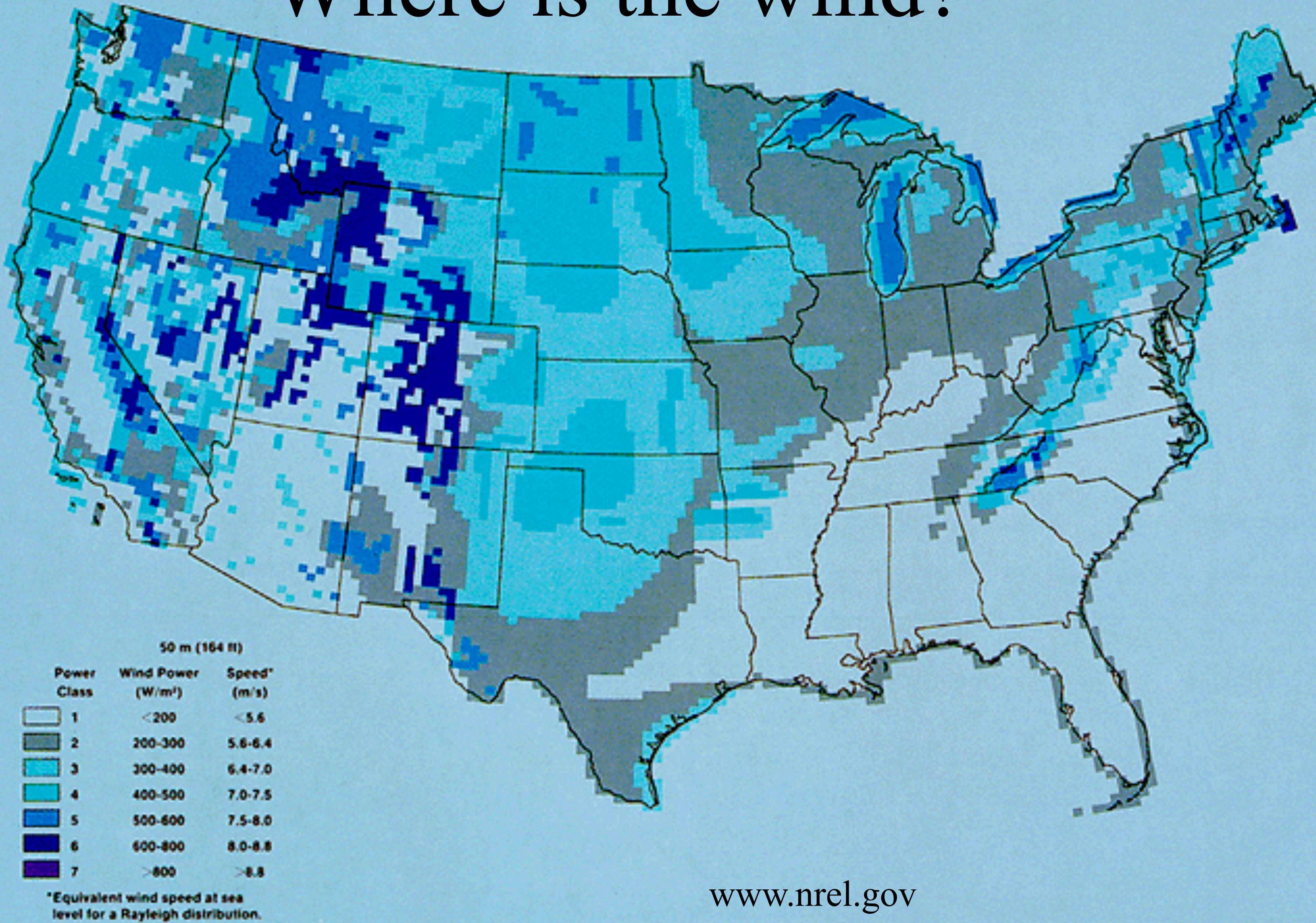
Which power source can be most easily varied to meet demand?

Hydropower by varying sluice gates (water input to turbine)

What does this mean?

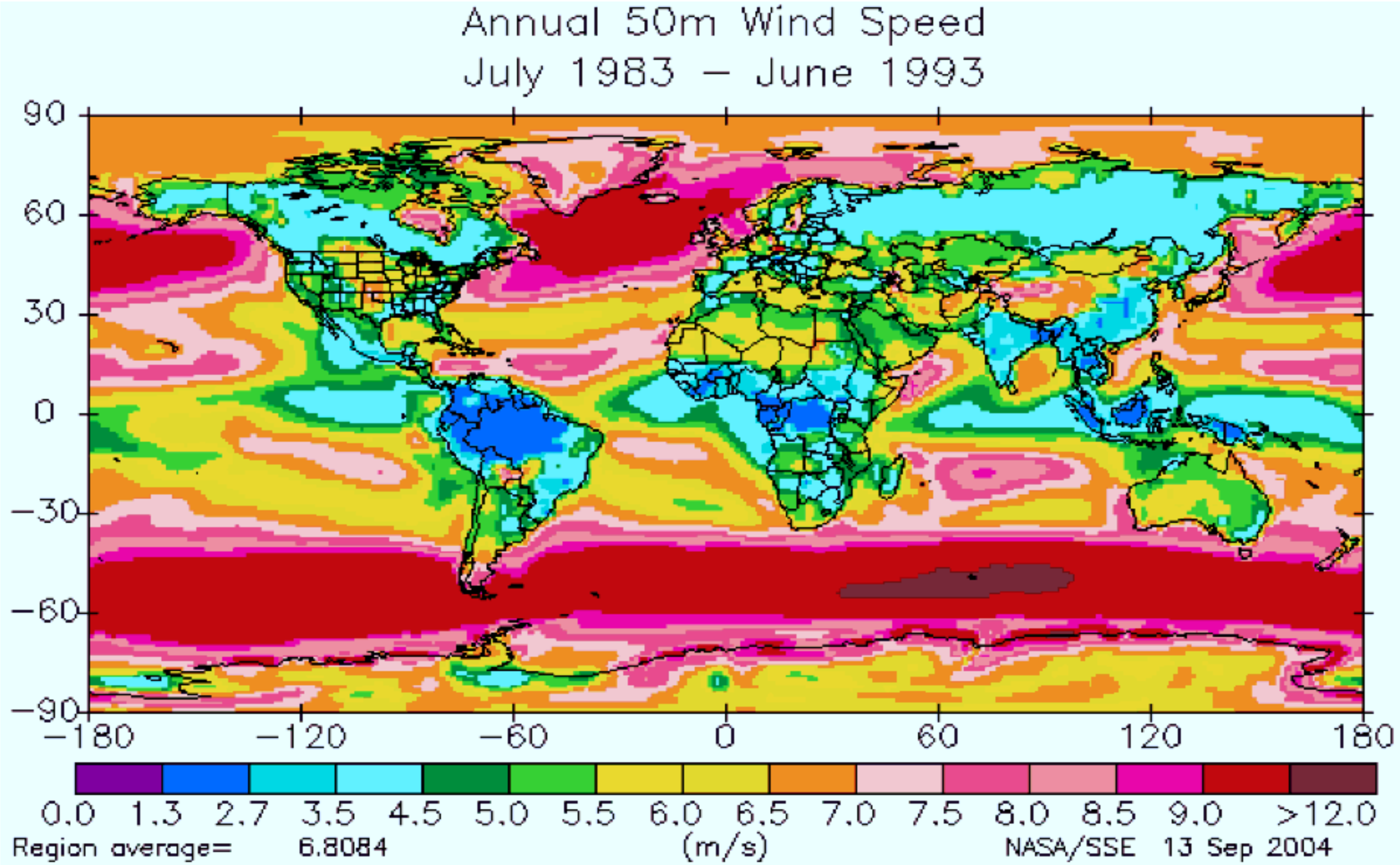
Coal plant stays fired most of the time while often some hydropower capacity is reserved for high demand periods

Where is the wind?



www.nrel.gov

Where is the wind? Part 2



www.ocean.udel.edu

Pros

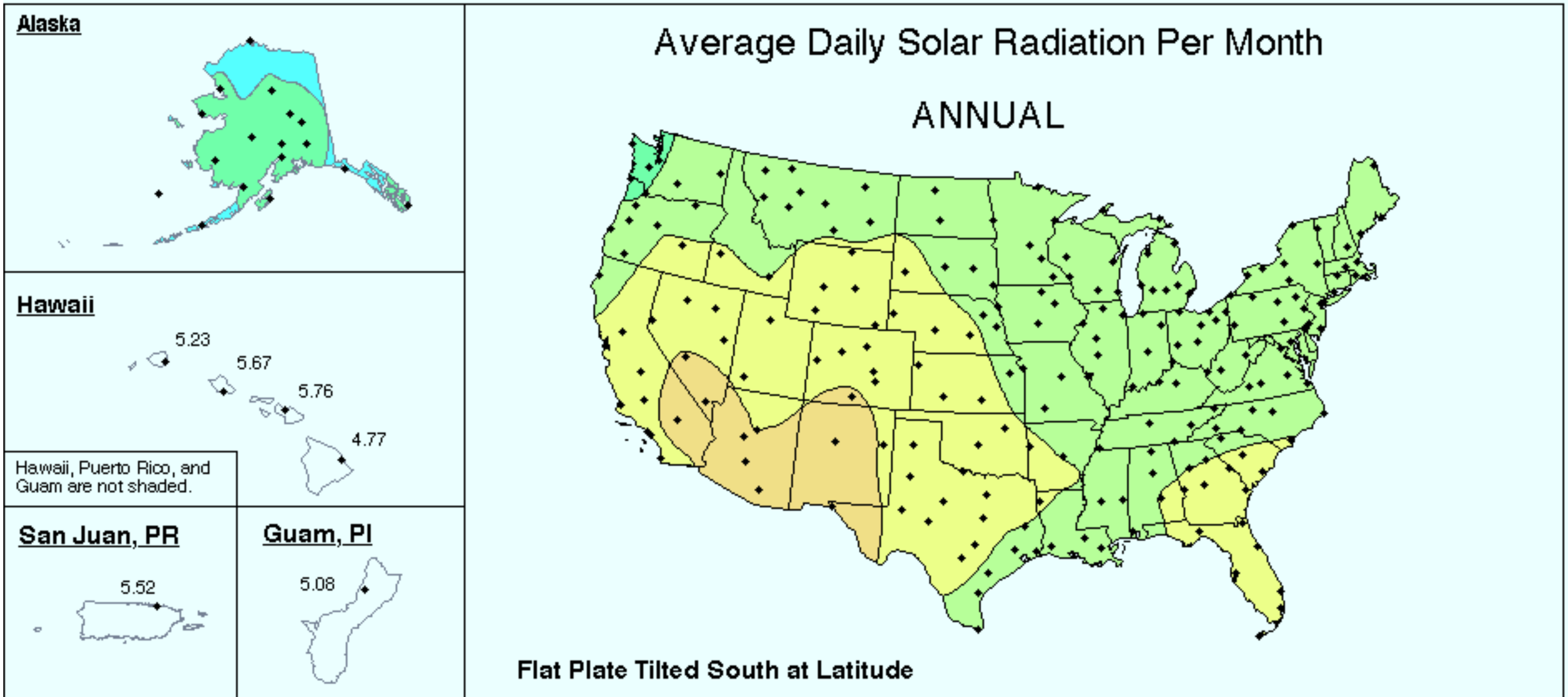
- Produces no greenhouse gases after windmill is constructed
- Decentralized production
- Moderately priced in the long term compared to fossil fuel

Cons

- Intermittent
- Not available everywhere
- Obstructs views/noise paranoia
- Requires large area

Solar Power


Solar power is harnessed through two principal means:
(1) Solar thermal collectors, which can produce hot water and warm air for homes and industrial applications.
(2) Solar photovoltaic cells, shown here, which generate pollution-free electricity directly from sunlight.



Collector Orientation

Flat-plate collector facing south at fixed tilt equal to the latitude of the site: Capturing the maximum amount of solar radiation throughout the year can be achieved using a tilt angle approximately equal to the site's latitude.

This map shows the general trends in the amount of solar radiation received in the United States and its territories. It is a spatial interpolation of solar radiation values derived from the 1961-1990 National Solar Radiation Data Base (NSRDB). The dots on the map represent the 239 sites of the NSRDB.

Maps of average values are produced by averaging all 30 years of data for each site. Maps of maximum and minimum values are composites of specific months and years for which each site achieved its maximum or minimum amounts of solar radiation.

Though useful for identifying general trends, this map should be used with caution for site-specific resource evaluations because variations in solar radiation not reflected in the maps can exist, introducing uncertainty into resource estimates.

Maps are not drawn to scale.

National Renewable Energy Laboratory
Resource Assessment Program

kWh/m²/day

- 10 to 14
- 8 to 10
- 7 to 8
- 6 to 7
- 5 to 6
- 4 to 5
- 3 to 4
- 2 to 3
- 0 to 2
- none

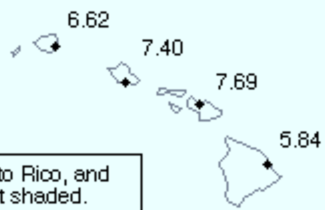
FLATA13-208

Average Daily Solar Radiation Per Month

ANNUAL

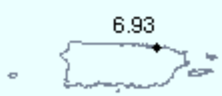
Alaska

Hawaii

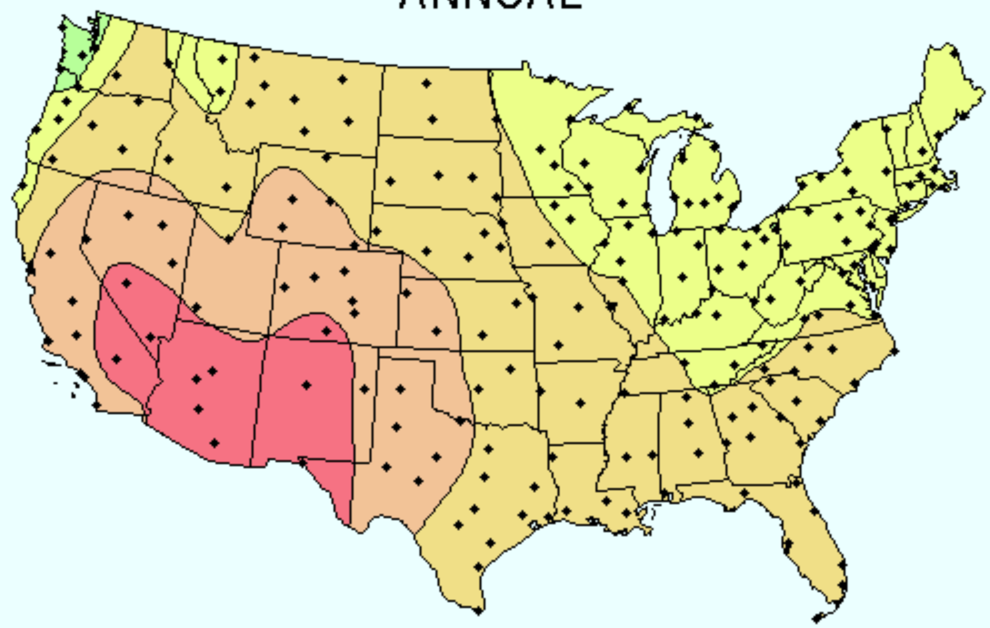


Hawaii, Puerto Rico, and Guam are not shaded.

San Juan, PR



Guam, PI



North-South Axis Tracking Flat Plate Tilted at Latitude

Collector Orientation

One-axis tracking flat-plate collector with axis oriented north-south at a tilt angle equal to the site's latitude: To achieve maximum annual solar radiation, a tilt angle approximately equal to the site's latitude is recommended.

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$kWh/m^2/day$

- 10 to 14
- 8 to 10
- 7 to 8
- 6 to 7
- 5 to 6
- 4 to 5
- 3 to 4
- 2 to 3
- 0 to 2
- none

FXLTA13-442

Pros

- Produces no greenhouse gases after panel is installed
- Unlimited
- Long lasting
- Peak production in-sync with demand
- Decentralized production

Cons

- Expensive now
- Somewhat limited by location

Geothermal Power

Pros

- Reliable supply
- Relatively simple facilities
- Inexpensive
- Small land footprint compared to wind and sola

Cons

- Regionally limited
- Releases a little CO_2 and other more harmful gases from ground
- Enhanced geothermal systems have caused seismic activity during construction

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 GHGs must level off by ~2100 to ~ 1.5 Gt/yr, or ~20% of present global emissions

  – At that time, the CO_2 ocean uptake will balance the human input (and the ocean will continue to acidify).