

Climate Change: Simple, Serious, Solvable



Scott Denning
Director of Education, CMMAP
Atmospheric Science, CSU

Email Scott.Denning@ColoState.edu for a copy of this presentation

Simple

Weather vs Climate what's the difference?

- If you don't like the **weather**:
 - *Wait five minutes!*
- If you don't like the **climate**:
 - *Move!*

Climate is Place *Location! Location! Location!*

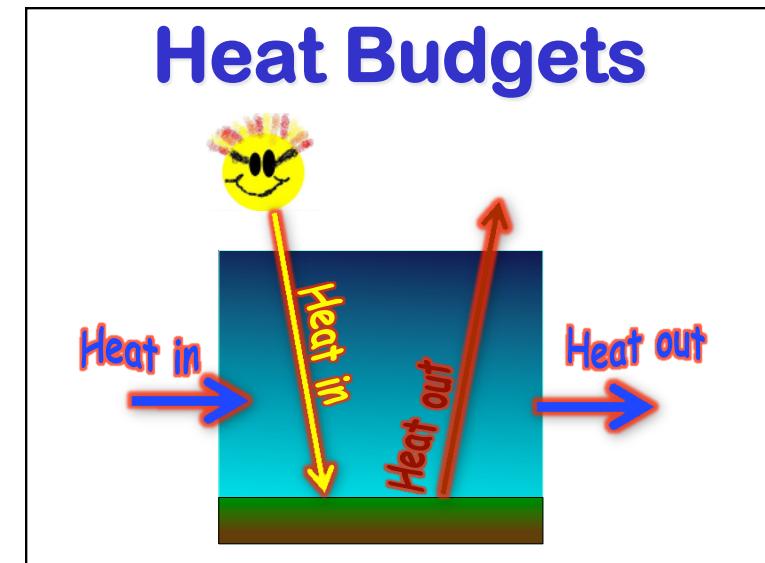
- Depends on **where you live**:
 - Latitude!
 - Altitude (mountains vs valley)
 - What's upwind (ocean vs land)
- **Changes very slowly**
- **Very predictable**
- We can *predict that Phoenix is warmer than Fargo* for precisely the **same reasons** that we can predict a **warmer future!**



Ever Wonder Why?

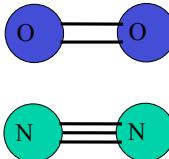


- Day is warmer than night
- Summer is warmer than winter
- Phoenix is warmer than Fargo



Dancing Molecules and Heat Rays!

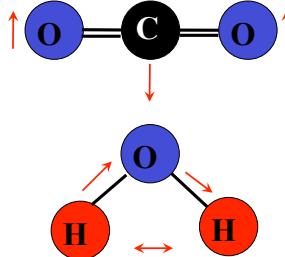
- Nearly all of the air is made of oxygen (O_2) and nitrogen (N_2) in which **two atoms of the same element share electrons**
- Infrared (heat) **energy radiated up from the surface can be absorbed by these molecules, but not very well**



Diatomeric molecules can vibrate back and forth like balls on a spring, but the ends are identical

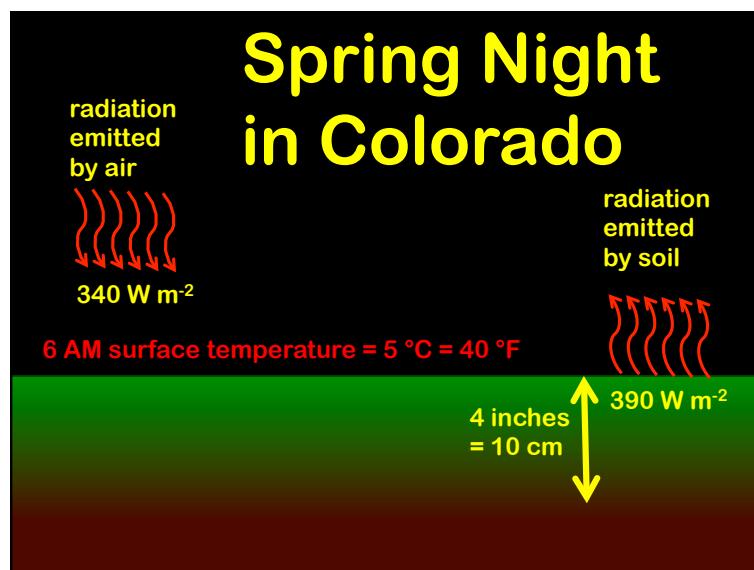
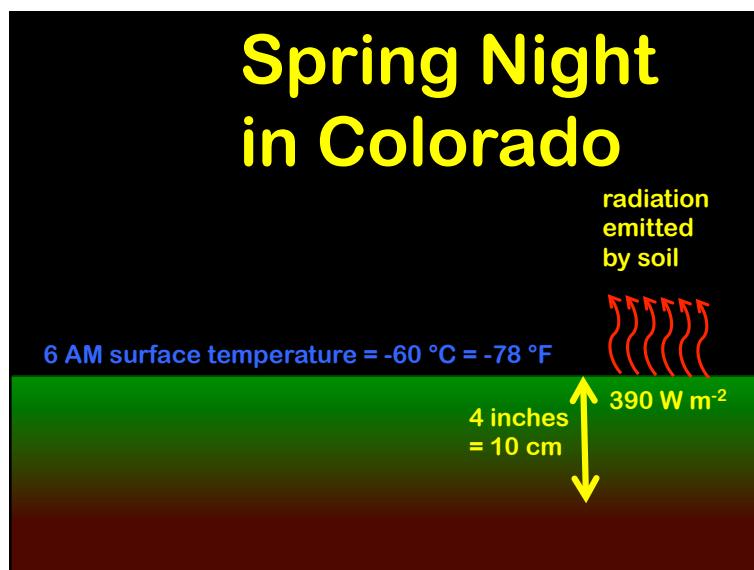
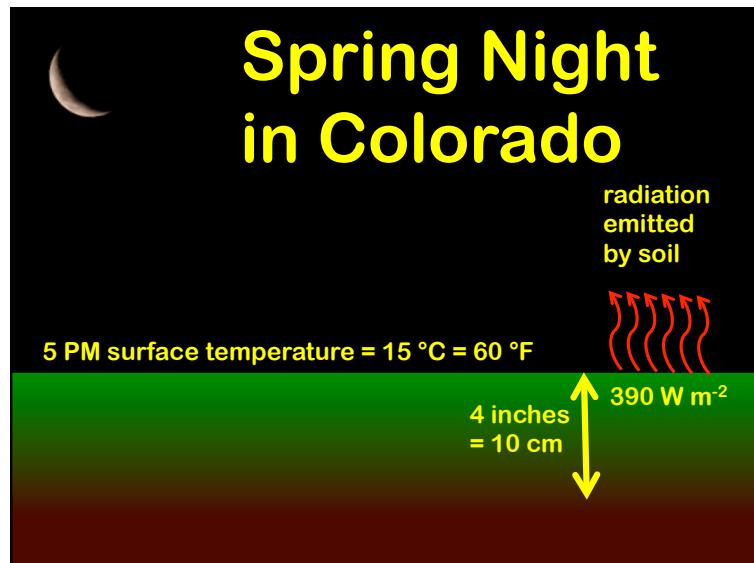
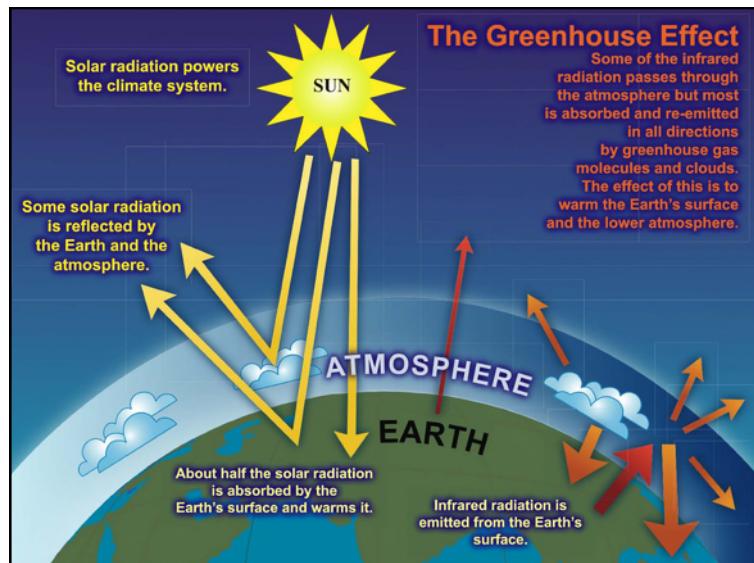
Dancing Molecules and Heat Rays!

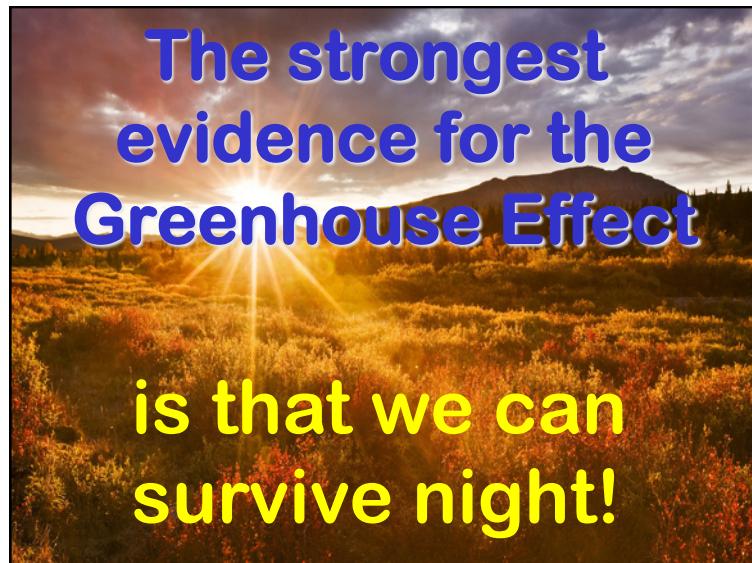
- Carbon dioxide (CO_2) and water vapor (H_2O) are different!
- They have **many more ways to vibrate and rotate, so they are very good at absorbing and emitting infrared (heat) radiation**



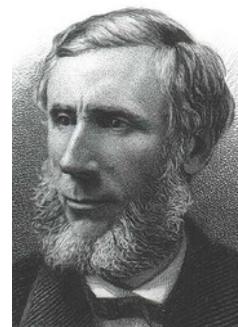
Molecules that have many ways to wiggle are called "Greenhouse" molecules

Absorption spectrum of CO_2 was measured by John Tyndall in 1863





Common Sense



John Tyndall, January 1863

- Doubling CO₂ would add **4 watts to every square meter** of the surface of the Earth, **24/7**
- Doing that would make the surface **warmer**
- This was known before light bulbs were invented!

Common Myth #1

"Scientists expect a warmer future because it's been warming up recently"



Cause and Effect

Forcing → Response
Watts per square meter degrees Celsius or F

$$\text{Sensitivity} = \frac{\text{Response}}{\text{Forcing}}$$

degrees per Watt m⁻²

Learning from the Past

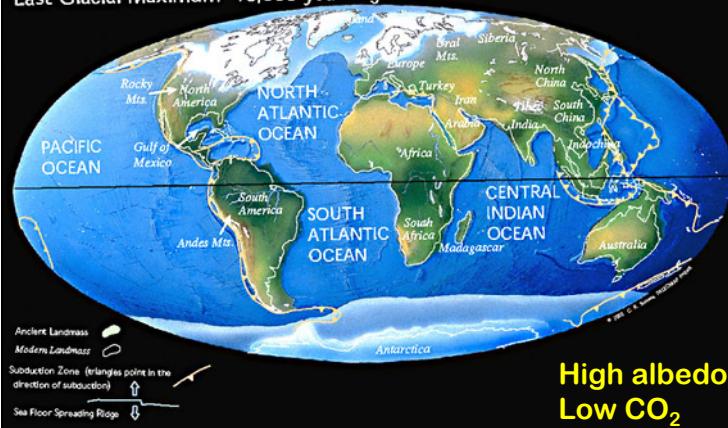
1. Geologic past
(100's of millions of years)
2. Deglaciation analog
(18,000 years ago to preindustrial time)
3. Last Millennium analog
(Medieval Warm Period to Little Ice Age)
4. Modern Climate Record
(20th Century changes)



The further back we go, the less data we have to work with.
Using modern data, we have only brief transients to study.

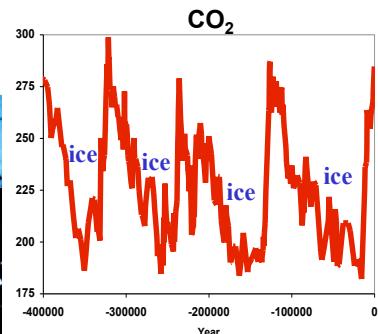
Ice Age World

Last Glacial Maximum 18,000 years ago



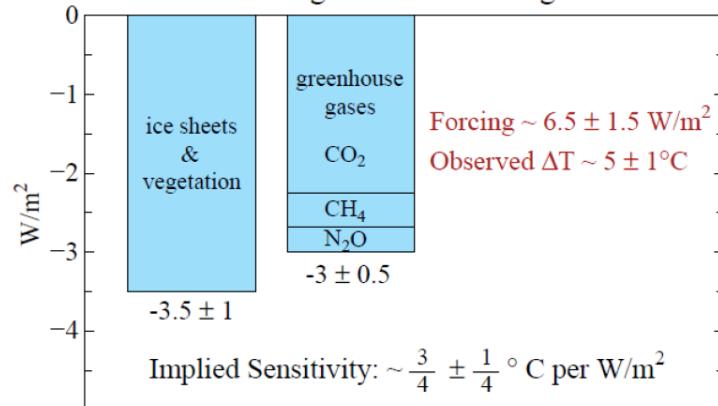
CO₂ and the Ice Ages

- Over the past 420,000 years atmospheric CO₂ has varied between 180 and 280 ppm, beating in time with the last four glacial cycles



Climate Forcing

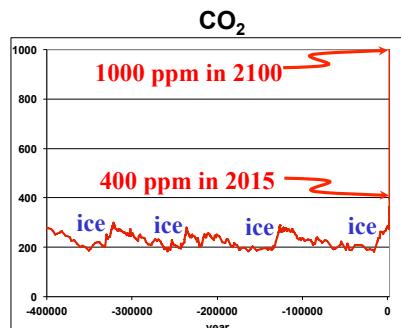
Ice Age Climate Forcings



Source: Hansen and Sato (2011)

CO₂ and the Future

- Over the past 420,000 years atmospheric CO₂ has varied between 180 and 280 parts per million, beating in time with the last four glacial cycles
- Since the Industrial Revolution, CO₂ has risen very rapidly
- If China & India develop using 19th Century technology, CO₂ will reach 1000 ppm in this century



You ain't seen nothing yet!

Climate Forcing

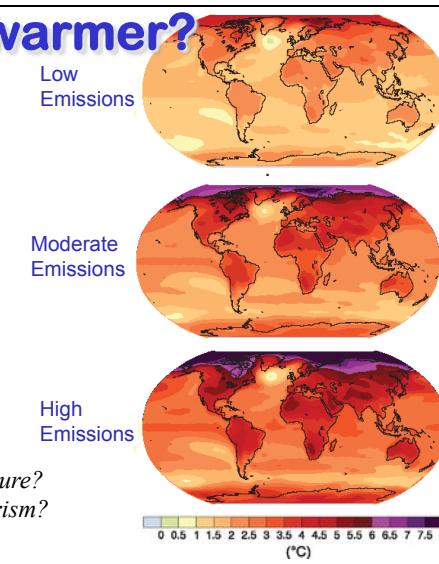
- If developing countries build modern economies based on coal ...
- Earth will gain more heat in 21st Century than it did when warming after Last Ice Age!
- ... but warming after Ice Age took 100 Centuries

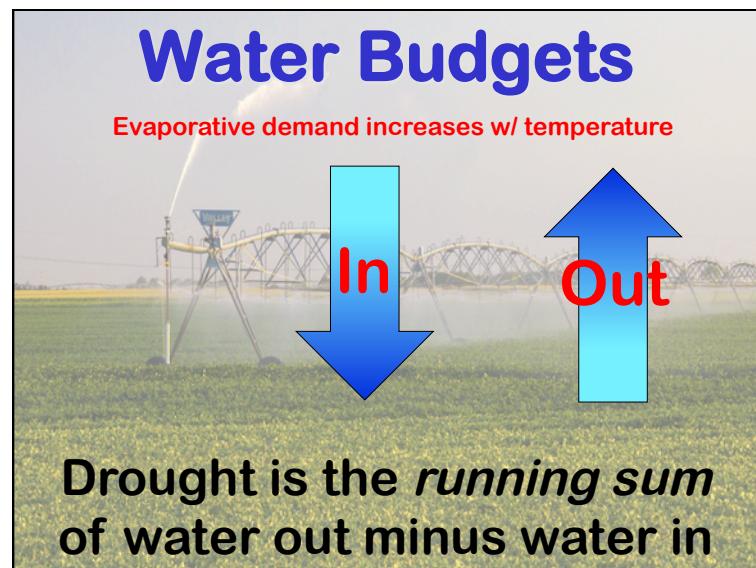
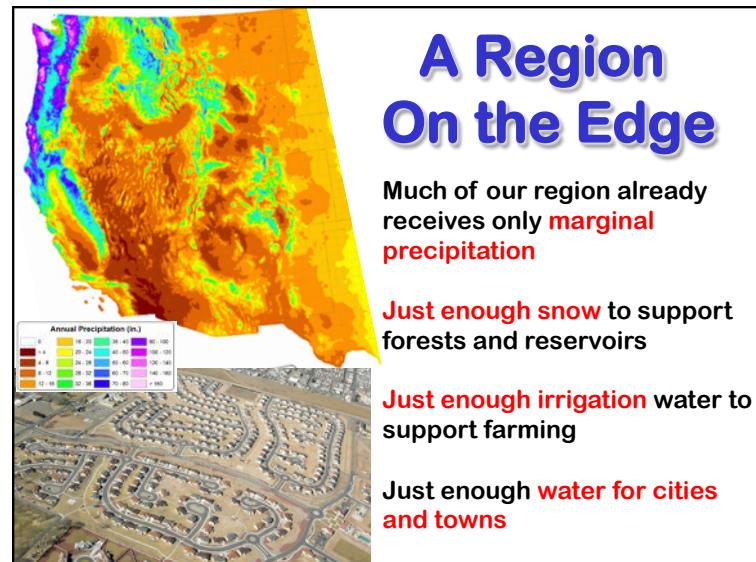
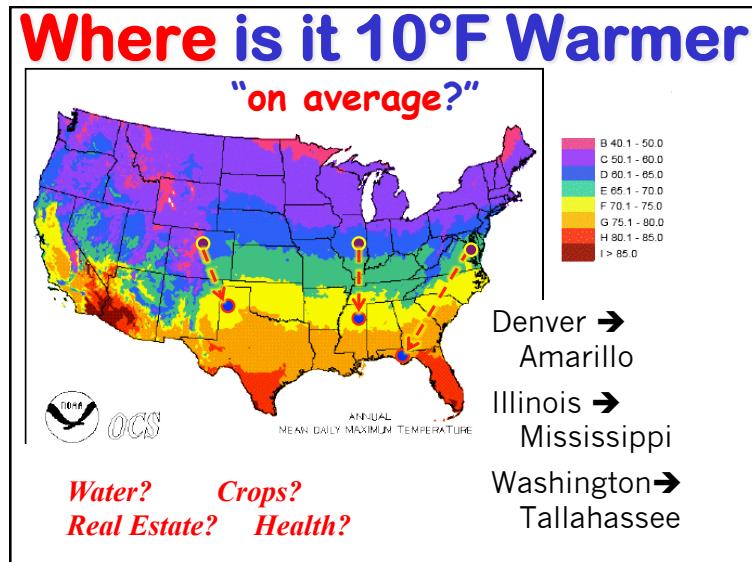


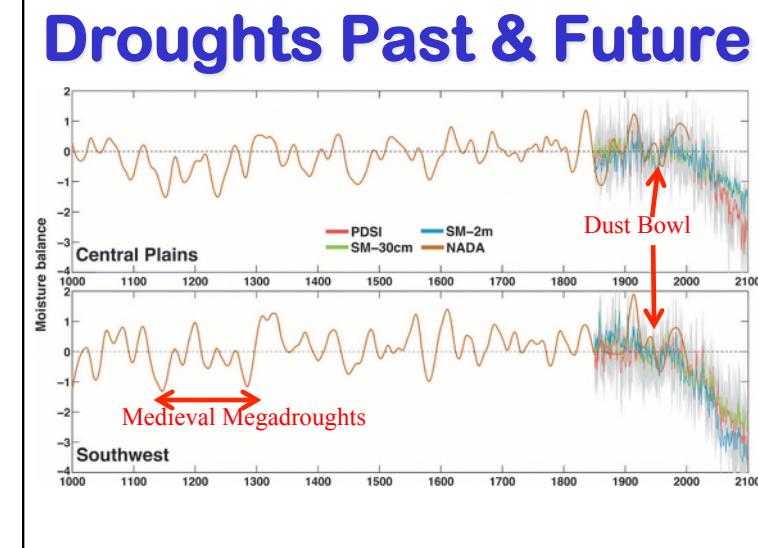
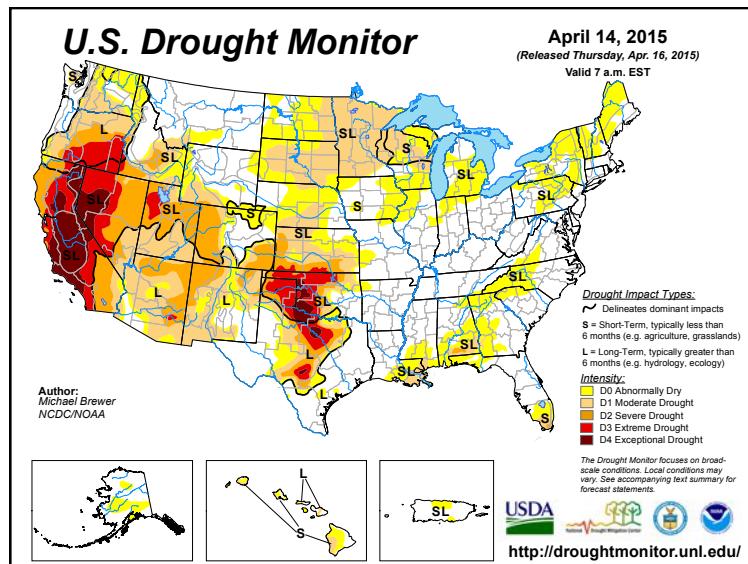
Serious

How much warmer?

- Land vs ocean!
 - North vs South
 - Global mean warming of 2° to 5° C
 - North American warming of 3° to 6° C
 - = 5° to 11° F
 - Arctic warming of 8° to 14° F
- Rainfall? Agriculture?
Water demand? Tourism?
Mass immigration?







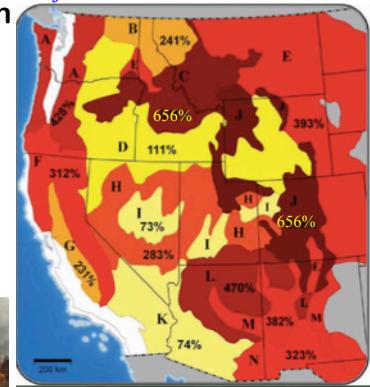


Warming Promotes Wildfire

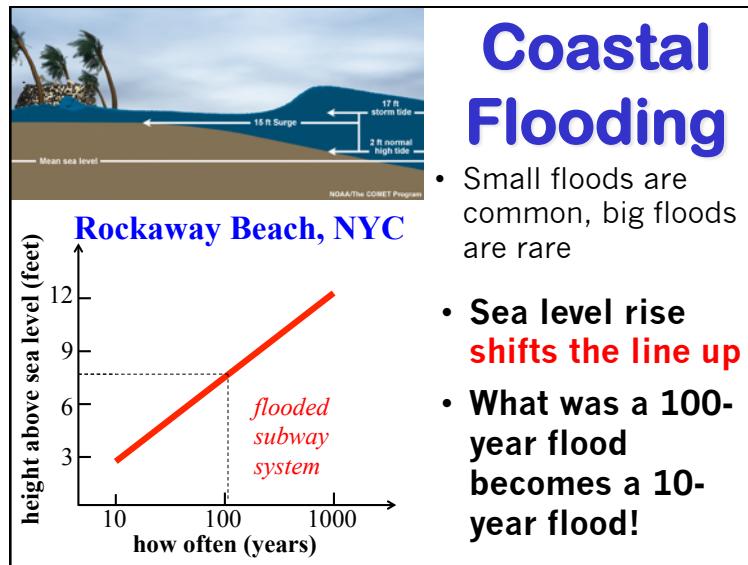
1. Warmer air increases evaporative demand on forests
2. Longer warm season depletes soil moisture
3. More frequent extremely hot, dry, windy days when fires are uncontrollable



Projected Increase in Area Burned



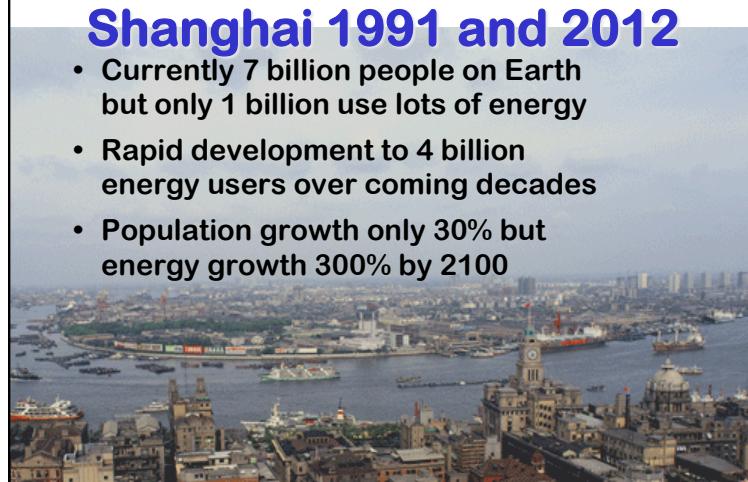
NRC 2011



Billions and Billions

Shanghai 1991 and 2012

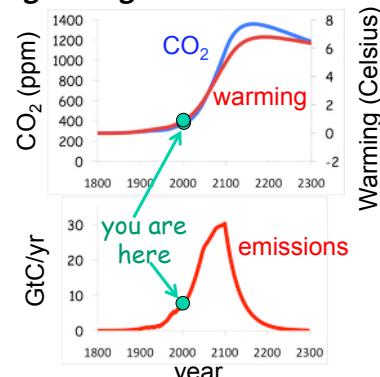
- Currently 7 billion people on Earth but only 1 billion use lots of energy
- Rapid development to 4 billion energy users over coming decades
- Population growth only 30% but energy growth 300% by 2100



Common Myth #2

"When we reduce or stop burning fossil fuel, CO₂ will go away and things will go back to normal"

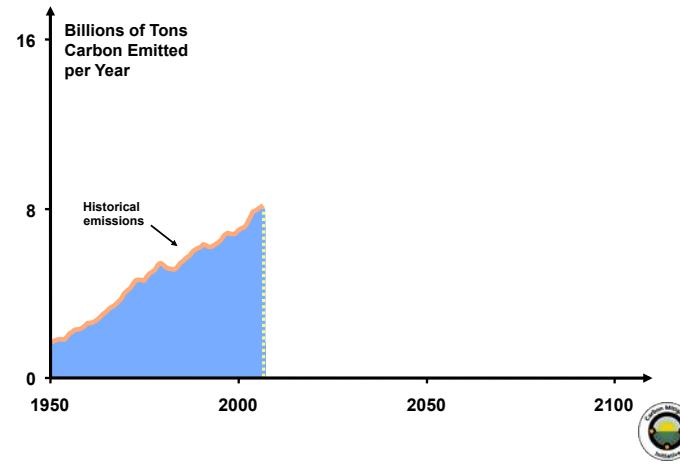
- If developing countries industrialize with coal, CO₂ will rise to **5x preindustrial**
- Extra CO₂ will last for **millennia after coal is gone**



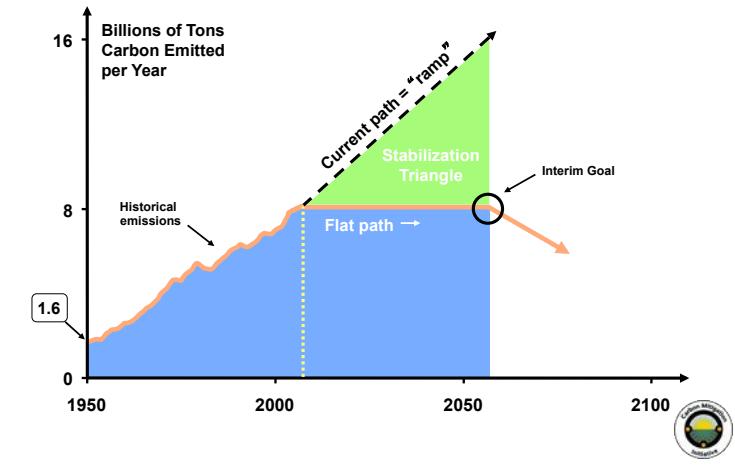
Not just Polar Bears ... what would that do to farmers?

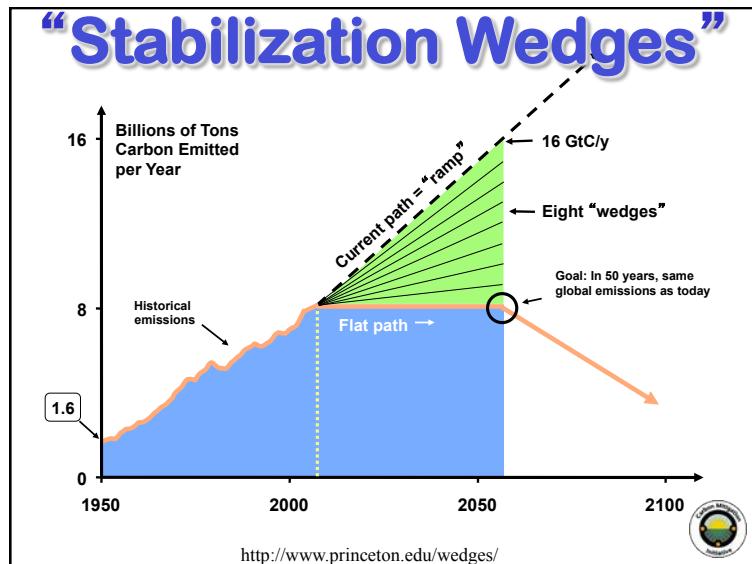
Solvable

Historical Emissions



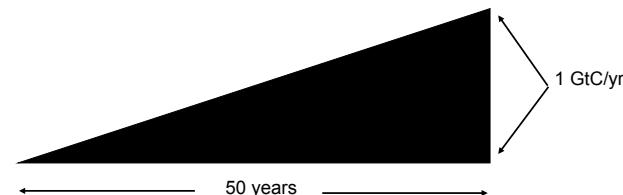
The “Stabilization Triangle”





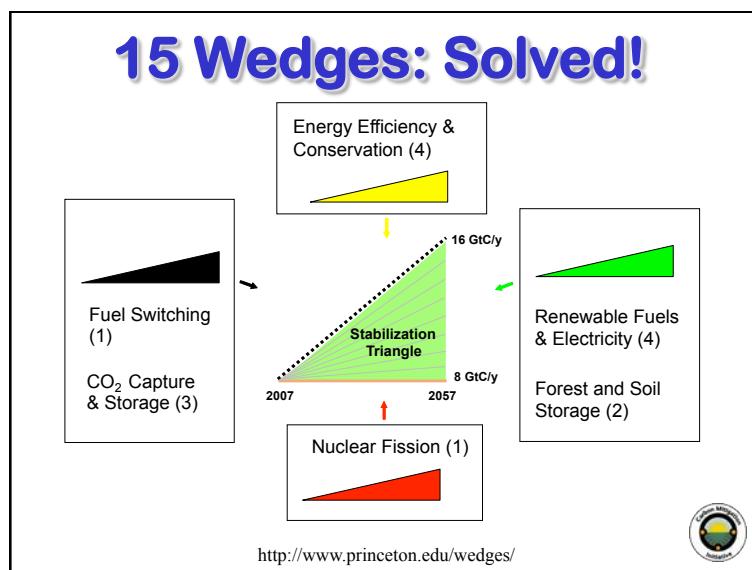
What is a “Wedge”?

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.

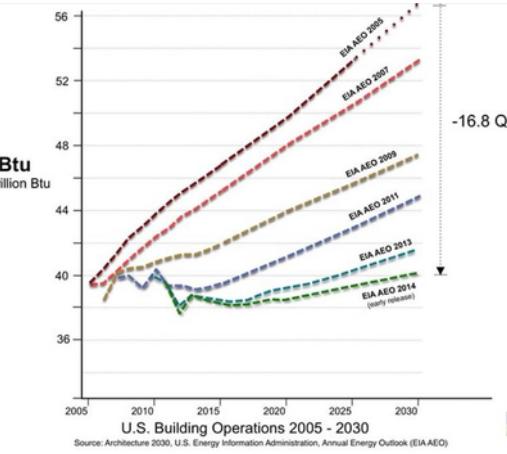


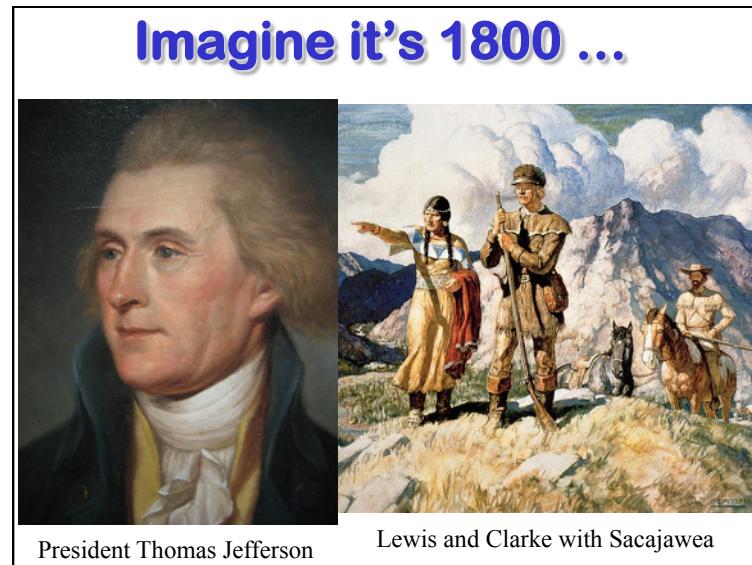
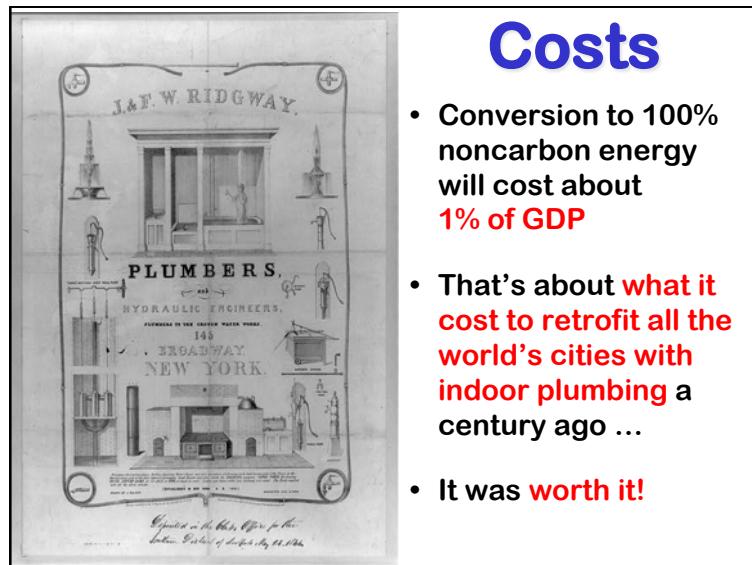
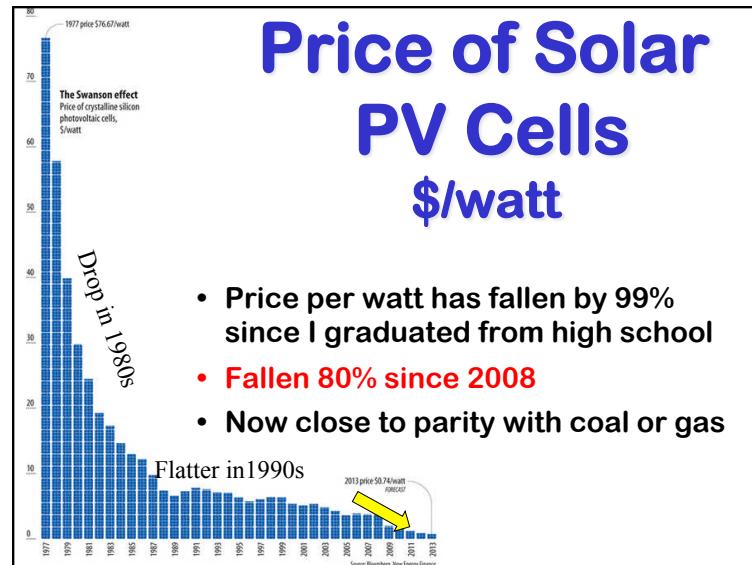
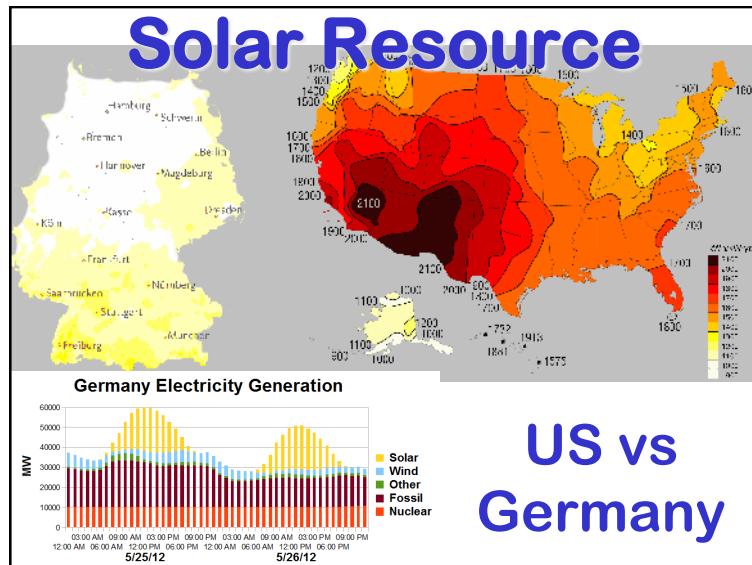
Cumulatively, a wedge redirects the flow of 25 GtC in its first 50 years. This is 2.5 trillion dollars at \$100/tC.

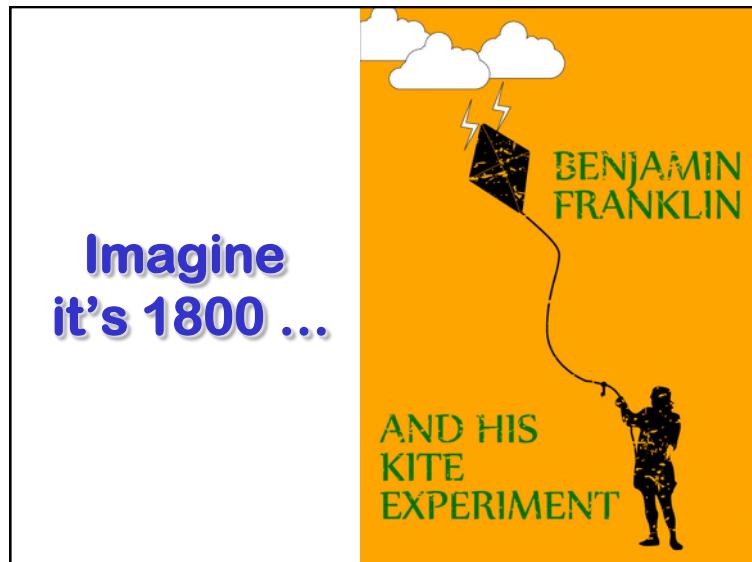
A “solution” to the CO₂ problem should provide at least one wedge.



Efficient Architects!







**Imagine
it's 1800,
and you're
in charge**
...

A portrait painting of Napoleon Bonaparte, dressed in his military general's uniform with elaborate gold embroidery and medals. He is seated, looking slightly to the left. The text "Imagine it's 1800, and you're in charge ..." is displayed in blue to the right of the portrait.

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

- ✓ Dig 8 billion tons of carbon out of the ground every year

Two small images illustrating the industrial activities mentioned: on the left, several oil derricks silhouetted against a sunset; on the right, a large open-pit coal mine with a dump truck.

A portrait painting of Napoleon Bonaparte, dressed in his military general's uniform with elaborate gold embroidery and medals. He is seated, looking slightly to the left. The text "Imagine it's 1800, and you're in charge ..." is displayed in blue to the right of the portrait.

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

- ✓ Build a system of pipelines, supertankers, railroads, highways, and trucks to deliver it to every street corner on the planet

Four small images illustrating the infrastructure mentioned: a large industrial facility with pipes; a busy highway with cars; a coal train car; and a large supertanker ship at sea.

 **Imagine it's 1800,
and you're in charge ...**

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

- ✓ Build millions of cars every year, and millions of miles of roads to drive them on



 **Imagine it's 1800,
and you're in charge ...**

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

- ✓ Generate and pipe enough electricity to every house to power lights & stereos & LCD TVs



**Imagine it's 1800,
and you're in charge ...**

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

- ✓ Dig 8 billion tons of coal out of the ground
- ✓ Build a system of railroads, ships, and trucks to deliver it to every street
- ✓ Build millions of houses, and millions of miles of roads to drive them on
- ✓ Generate and pipe enough electricity to every house to power lights & stereos & LCD TVs

... "and here's the itemized bill..."



Who Built That?

- Our ancestors built that very system
- It cost them every dime of global GDP for 200 years (now \$78T/yr)
- It created every dime too!



Now our kids get to do it again!



Choose Your Future

Many people think:

“Our well-being is based on
stuff we extract from the ground”

When we stop burning coal, will our
descendants shiver in the dark?



Choose Your Future

I prefer:

“We create our well-being through
creativity, ingenuity, and hard work”

The future is bright!