THE GREENHOUSE EFFECT

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The Greenhouse Effect

Solar radiation passes through the clear atmosphere.

Some solar radiation is reflected by the Earth and the atmosphere.

Most radiation is absorbed by the Earth's surface and warms it.

Some of the infrared radiation passes through the atmosphere, and some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.

Infrared radiation is emitted from the Earth's surface.
THE GREENHOUSE EFFECT

THE EARTH’S ENERGY BUDGET: A DELICATE BALANCE

- Sunlight heats the Earth.
- The warm Earth radiates energy (in the form of infrared radiation, or heat) back out to space.
- Some of this infrared radiation is trapped in the atmosphere, giving Earth its temperate climate.

This is the greenhouse effect. Without it, the Earth’s climate would be like the moon’s, harsh and severe.
GLOBAL ENERGY BALANCE
Global and annual average energy fluxes in watts per square meter

\[ \frac{1}{4} S_0 (1 - \alpha) = \sigma T^4 \]

\[ \alpha = 31\% \]

\[ 69\% = 1 - \alpha \]

\[ \frac{1}{4} S_0 \approx 254K \]

\[ 343 - 237 = 106 \]

\[ 237 \approx 288K \]

\[ 390 - 327 = 63 \]

\[ 327 - 237 = 90 \]

\[ 90 - 68 = 22 \]

\[ 68 \]

\[ 169 \]

\[ 169 \]

\[ 16 \]

\[ H_2O, CO_2, CH_4... \]

Schwartz, 1996, modified from Ramanathan, 1987
ATMOSPHERIC RADIATION

Energy per area per time

Power per area

Unit: Watt per square meter $W \text{ m}^{-2}$
Everybody talks about the weather —

But nobody does anything about it.

– Mark Twain

Now with the greenhouse effect,
we ARE doing something about it.
What are we doing?
RADIATIVE FORCING

A *change* in a component of the Earth’s radiation budget.
Global carbon dioxide concentration over the last thousand years
ATMOSPHERIC CARBON DIOXIDE IS INCREASING

Global carbon dioxide concentration and infrared radiative forcing over the last thousand years.
Northern Hemisphere temperature trend (1000-1998), from tree-ring, coral, and ice-core proxy records As calibrated by instrumental measurements.  

*Mann et al., Geophysical Research Letters, 1999*
GLOBAL AVERAGE TEMPERATURE TREND
1856-2002
Temperature Anomaly Relative to Base Period 1961-1990

Climate Research Unit, East Anglia UK
INDICATIONS OF SYSTEMATIC WARMING IN RECENT YEARS

The 1990s were the **warmest decade** in the instrumental record.

The **warmest two years** of the entire instrumental record have been 1998 and 2002.

The **nine warmest years** globally have now occurred in the 1990s and 2000s.
Global warming over the past millennium

Very rapidly we have entered uncharted territory — what some call the *anthropocene* climate regime. Over the 20th century, human population quadrupled and energy consumption increased sixteenfold. Near the end of the last century, we crossed a critical threshold, and global warming from the fossil fuel greenhouse became a major, and increasingly dominant, factor in climate change. Global mean surface temperature is higher today than it’s been for at least a millennium.

*Martin Hoffert, NYU*
GREENHOUSE GAS MIXING RATIOS OVER THE INDUSTRIAL PERIOD

**CO₂**
- Ice core (↓)
- In situ (→)

**CH₄**
- Ice core (↓)
- Greenland (↓)
- Antarctica (↑)

**N₂O**
- Ice core (↓)

**CFCs**
- CFC-11
- CFC-12
- Other trace gas forcing converted to CFC-11 amount

Hansen *et al.*, PNAS. 1998
WHERE IS ALL THIS CO$_2$ COMING FROM?

WHO IS RESPONSIBLE?
ATMOSPHERIC CARBON DIOXIDE
Time series 1700 - 2003

- Law Dome (Antarctica)
- Siple (Antarctica)
- Mauna Loa (Hawaii)

Law - Etheridge et al.
Siple - Friedli et al.
Mauna Loa - Keeling
ATMOSPHERIC CO\textsubscript{2} EMISSIONS

Time series 1700 - 2003

Fossil Fuel Emissions

Fossil Fuel - Marland
ATMOSPHERIC CARBON DIOXIDE
Time series 1700 - 2003

Carbon dioxide mixing ratio, ppm

- Law Dome (Antarctica)
- Siple (Antarctica)
- Mauna Loa (Hawaii)

Fossil Fuel Cumulative Emissions

Law - Etheridge et al.
Siple - Friedli et al.
Mauna Loa - Keeling
Fossil Fuel - Marland
Carbon flux estimated as land area times carbon emissions associated with land clearing or afforestation (uptake). United States dominates emissions before 1900 and uptake after 1940.
Prior to 1910 CO₂ emissions from land use changes were dominant.

Subsequently fossil fuel CO₂ has been dominant and rapidly increasing!
ATtribution of increase in atmospheric CO₂

Comparison of cumulative CO₂ emissions from fossil fuel combustion and land use changes with measured increases in atmospheric CO₂.

Prior to 1970 the increase in atmospheric CO₂ was dominated by emissions from land use changes, not fossil fuel combustion.
HOW MUCH CARBON IS IN A GALLON OF GASOLINE?

1 lb?

2 lbs?

3 lbs!?

5 lbs!?!?

All of this carbon goes into the atmosphere as carbon dioxide when you burn the gasoline in your car.
THE MOST EFFECTIVE WAY TO DOUBLE THE FUEL ECONOMY OF A CAR . . .

IS TO PUT TWO PEOPLE IN IT!
YOUR FAMILY’S CONTRIBUTION TO THE GREENHOUSE EFFECT

CARBON DIOXIDE EMISSIONS FROM ELECTRIC ENERGY PRODUCTION (1990's Technology)

A typical household using 1000 kilowatt hours of electricity per month is responsible for emission of 3 tons of carbon a year in the form of carbon dioxide. How much does your household contribute?
At half a pound of carbon per KWH, the average household is responsible for emission of 500 pounds of carbon a month.
Suffolk County Limits CO₂ Emissions

Breath of Fresh Air

Gaffney signs bill to limit greenhouse gas emissions

July 25, 2001

By Emi Endo

Suffolk County Executive Robert Gaffney yesterday signed into law a bill aimed at limiting greenhouse gas emissions locally, although critics questioned how much it would actually reduce the emissions.

Beginning in March, for every 100 megawatts of new generation added in the county, the emissions rate must be reduced by 1 percent, until a 20-percent reduction is achieved. Power plants that exceed the standard would face fines.

During negotiations, Fisher raised the emissions limit from less than 1,500 pounds to 1,800 pounds of carbon dioxide per megawatt hour and cut the penalties from $5 for each ton of carbon dioxide emissions exceeding the limit to $2.

0.49 lbs Carbon per KWH
WHERE DOES YOUR ELECTRIC ENERGY COME FROM?

SOURCES OF ELECTRIC ENERGY IN THE UNITED STATES

Annual Total 3.71 Trillion KWH

On Long Island most electric energy derives from combustion of oil.
WHAT COUNTRY USES THE MOST ELECTRIC POWER?
WHAT COUNTRY USES THE MOST ELECTRIC POWER?

ANNUAL ENERGY CONSUMPTION

Total Global Consumption 382 Quadrillion BTU

Selected Countries

Percent of Total

No surprise. It's the United States.
WHAT COUNTRY USES THE MOST ELECTRIC POWER \textit{PER CAPITA}?
WHAT COUNTRY USES THE MOST ELECTRIC POWER PER CAPITA?

No surprise. It's the United States again.
WHERE IS THIS CARBON DIOXIDE COMING FROM?
WE ARE ALL RESPONSIBLE.

Burning a gallon of gasoline in your car puts 5 pounds of carbon in the atmosphere as carbon dioxide (CO$_2$), and it will stay there for decades — maybe a century!

Other sources are home heating and electric power production.
Looking to the Future . . .
Prediction is difficult, especially about the future.

– Niels Bohr
THE “BIBLE” OF CLIMATE CHANGE RESEARCH

CLIMATE CHANGE 2001
The Scientific Basis

Cambridge University Press, 2001

http://www.grida.no/climate/ipcc_tar/wg1/
THE BIBLE OF CLIMATE CHANGE

It's big and thick.
Every household should have one.
No one reads it from cover to cover.
You can open it up on any page and find something interesting.

It was written by a committee.
It is full of internal contradictions.
It deals with cataclysmic events such as floods and droughts.
It has its true believers and its rabid skeptics.
FUTURE CLIMATE IS HIGHLY UNCERTAIN

Contributors to uncertainty include emissions, concentrations, and Earth's climate sensitivity.
Global Atmosphere, Global Warming

QUESTIONS ABOUT GLOBAL WARMING

- Is it real?
- Is it important?
- What is it due to?
- How much more can we expect?
- Are we seeing just the tip of the iceberg?

Research at Brookhaven National Laboratory is helping to answer these questions.