Climate Change: The Move to Action
(AOSS 480 // NRE 480)

Richard B. Rood
Cell: 301-526-8572
2525 Space Research Building (North Campus)
rbrood@umich.edu
http://aoss.engin.umich.edu/people/rbrood

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Class News

• Ctools site: AOSS 480 001 W10
• On Line: 2008 Class
  – Reference list from course
• Rood Blog Data Base
Surprise Presentation!

• Climategate(s) The Past, Present, and Future of Climate Data


   Paul N. Edwards UM-School of Information
   Tuesday, 20 April 2010
   4:00–5:30 pm
   1014 Tisch
   Department of History
Projects

• Final presentation discussion;
  – April 22, 12:00 – 4:00, Place 1024 Dana (Our classroom)
  – Lunch at 12:00, presentations start promptly at 12:30. Usually arrives a little early.
  – Presentation order:
    • Near-term solutions
  – Write, call, meet before presentation.
Seeking Project Happiness

Time April 22\textsuperscript{nd}: 12:30-4:00. Lunch at 12:00. 1024 Dana

Presentation: Total time for presentation:
   30 minutes / Aim for 20 & 10

My goal, here, is something like a real world experience. Therefore, first get the presentation “right.”

Paper: There should be an accompanying narrative to the presentation. This should include references.
   Minimally: Narrative is description of the presentation.
   Target: Narrative in the spirit of executive summary, or “white paper” that the receiver of the presentation can take away and “carry forward.”
   Needs Abstract.
   10 pages is a good target. If longer than 10 pages\textrightarrow Executive Summary Narrative Summary Due April 29

If you want to write more it is fine. You should feel like you have done a good job, in the time that you have.
More Project Guidelines

• This is
  – Different from a traditional research paper
  – Needs to be integrated
• What I will look for in assessing the quality of the reports:
  – Review / inventory. Have you done a good job of reviewing the state of knowledge of the problem? Have you hit key references? Do you provide additional references that allows deeper entry into the field.
  – Separating knowledge / conjecture / belief. Have you done an objective evaluation of the information that you have gathered from different sources? Have you considered the quality and nature of your sources?
  – Identify externalities. Have you identified those issues which impact the ability of you to “solve” your problem. Have you prioritized which of these are important and require more attention. Which are unimportant or unmanageable.
  – Clear synthesis and analysis. Can you rationalize contradictions and differing priorities that are represented in your problem?
  – Recommendations and conclusions. Can you tie the pieces together well enough to represent a course of action, or an evaluation of several courses of action.
Today’s Lecture

- Making the argument and addressing the political arguments that fuel selective doubt
  - Scientific method
  - Conservation principle
  - Climate Science in Six Viewgraphs
  - Observational Evidence / Attribution
  - Response Space
    - What do we do?
Science – Scientific Method 1

• Elements of the scientific method
  – Observations of some phenomenon
  – Identification of patterns, relationships and the generation of suppositions, followed by hypotheses
  – In principle, hypotheses are testable:
    • Experiments: cause and effect
    • Prediction instead of experiments?
  – Development of constructs, theory, which follow from successful hypothesis.
    • Predict behavior, what the next observation might look like?
  – Development of tests, experiments that challenge the hypotheses and predictions.
    • Validate or refute theory and elements from which the theory is constructed.
Science – Scientific Method 2

• Science is a process of investigation
  – The results of scientific investigation are the generation of
    • Knowledge within a prescribed levels of constraints
    • Uncertainty: How sure are we about that knowledge?
      – Quantitative and Qualitative
  – Science does not generate a systematic exposition of facts
    • Facts are, perhaps knowledge, whose uncertainty is so low, that we feel certain.
    • Theories develop out of tested hypotheses.
      – Theory is NOT conjecture
      – Theory is subject to change, due to testable challenges
  – Science requires validation
    • Requires that hypotheses and theories are testable
    • Requires transparency so that independent investigators can repeat tests and develop new tests.
Conservation Principle

- Idea that certain quantities are conserved.
  - We consider, primarily, energy and carbon dioxide
  - Need to be careful about defining our system

How a quantity changes with time = Production of the quantity - Loss of the quantity + Exchanges of the quantity

It’s a counting problem. Think of money
Balance of Energy

Changes in the sun

Things that change reflection

Things that change absorption

If something can transport energy DOWN from the surface.
Balance: An important concept

• When we talk about climate and climate change we are talking about a system in balance. What we are concerned with is how does this balance change when something is changed in the system.
  – Does it return to same balance - negative feed back $\rightarrow$ sort of biological, Gaia ....
  – Does it go to a different state – positive feed back $\rightarrow$ perhaps a different balance $\rightarrow$ runaway?

• Analogy to market economies - and businesses
  – Often how things change on the margins, rather than whether or not the change is large in an absolute sense.
    • $\text{CO}_2$ is a “small” change in an absolute sense, and the surface energy change from $\text{CO}_2$ is also small in an absolute sense
Climate Science in Six Slides - Approximately
But the Earth’s surface temperature is observed to be, on average, about 15 C (~59 F). Due to primarily water and carbon dioxide.

*This greenhouse effect is not controversial.*

Based on conservation of energy: If the Earth did NOT have an atmosphere, then, the temperature at the surface of the Earth would be about -18 C (~0 F).

This surface temperature, which is higher than expected from simple conservation of energy, is due to the atmosphere. The atmosphere distributes the energy vertically; making the surface warmer, and the upper atmosphere cooler, which maintains energy conservation. We are making the atmosphere “thicker.”

The Greenhouse Effect

Spencer Weart’s *The Discovery of Global Warming*
Increase of Atmospheric Carbon Dioxide (CO$_2$) (Keeling et al., 1996)

Primary increase comes from burning fossil fuels – coal, oil, natural gas

Data and more information
Web links to some CO2 data

- NOAA/ESRL Global Monitoring Division
  - Carbon Cycle Greenhouse Gas
  - Mauna Loa Carbon Dioxide
- Carbon Dioxide Information Analysis Center
  - Recent Greenhouse Gas Concentrations
- NOAA/PMEL CO2 and Ocean
Bubbles of gas trapped in layers of ice give a measure of temperature and carbon dioxide at Vostok, Antarctica ice cores.

350,000 years of Surface Temperature and Carbon Dioxide (CO₂) at Vostok, Antarctica ice cores.

- During this period, temperature and CO₂ are closely related to each other.
- It’s been about 20,000 years since the end of the last ice age.
- There has been less than 10,000 years of history “recorded” by humans (and it has been relatively warm).

Some References:
- Vostok and CO₂
- Role of Ocean in Reversal

PA4:

![Graph showing temperature and CO₂ concentration over time.]

- CO₂ 2010: 390 ppm
- CO₂ 2100: 460 ppm
Let’s look at just the last 1000 years

Surface temperature and CO₂ data from the past 1000 years. Temperature is a northern hemisphere average. Temperature from several types of measurements are consistent in temporal behavior.

- Medieval warm period
- “Little ice age”
- Temperature starts to follow CO₂ as CO₂ increases beyond approximately 300 ppm, the value seen in the previous graph as the upper range of variability in the past 350,000 years.
How do we test our models? How do we attribute observed warming to the industry of humans?

One thing we do is make “predictions” (simulations, hindcasts) of the observations of past behavior.

Natural Forcing: Solar variability, volcanoes, “pre-industrial” CO2

Anthropogenic Forcing: Industrial CO2, Changes in Land Use, Other Greenhouse Gases (N2O, CH4, CFCs)

It is only when anthropogenic forcing is calculated can we explain the warming observed to begin in the late 20th century.

Some References
- Intergovernmental Panel on Climate Change
- Fourth Assessment Report
Projections for the next 100 years.

Intergovernmental Panel on Climate Change Fourth Assessment Report
Conclusions from the Scientific Investigation of the Physical Climate

• The Earth has warmed, and most of that warming is due to the enterprise of humans.
• The Earth will continue to warm.
• Sea level will rise.
• The weather will change.

Let’s remember the ozone “smoking gun.” Is there a “smoking gun” for climate change? Is there some impact of climate change that raises urgency and accelerates action?
Observational Evidence

• Keep returning to the observations
• Coherent and convergent evidence
Observed Temperature Anomaly in 2008

http://data.giss.nasa.gov/gistemp/2008/

See Also: Osborn et al., The Spatial Extent of 20th-Century Warmth in the Context of the Past 1200 Years, Science, 311, 841-844, 2006
IPCC 2007: The last ~100 years
UNIVERSITY OF MICHIGAN
IPCC Ice Sheet Accumulation

Jump to attribution
Jump to ecosystems
20m Borehole Temperature Trends in Alaska

Hinzman et al 2005
Changes in planting zones

Jump to attribution
Length of Growing Season

From Ranga B. Myneni, Boston University
Changes in the Amplitude of the Keeling Curve (Keeling et al, 1996)

Amplitude has increased 40% in Alaska, Canada

Amplitude has increased 20% in Hawaii

The phase, start of the decrease, start of the growing season, has moved forward 7 days.
Attribution

• Coherent and convergent observation evidence.
• Spatial, temporal, and correlated behavior as predicted by theory and models.
Predictions of the 20th Century

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Fingerprint detection explained pictorially….

Thanks to Ben Santer for Content!
Searching for fingerprints of human activities in the world’s oceans

- Initial work by Syd Levitus and colleagues showed an increase in the heat content of the oceans over the second half of the 20th century (Levitus et al., 2001, Science)

- Subsequent research by Tim Barnett and colleagues identified a human fingerprint in the observed ocean heat content changes (Barnett et al., 2001, Science)

Thanks to Ben Santer for Content!
“Fingerprinting” in the ocean: Warming of the North Atlantic over 1955-99

Thanks to Ben Santer for Content!

“Fingerprinting” in the ocean: Warming of the world’s oceans over 1955-99

Red = Observed  Green = Parallel Climate Model (PCM)  Blue = PCM control run

North Indian

North Pacific

North Atlantic

South Indian

South Pacific

South Atlantic

Thanks to Ben Santer for Content!

Human-caused fingerprints have been identified in many different aspects of the climate system.

Thanks to Ben Santer for Content!
Response

- Mitigation
- Adaptation
- Geoengineering
Mitigation is controlling the amount of CO₂ we put in the atmosphere.

Adaptation is responding to changes that might occur from added CO₂.
Stabilization

• Controlling emissions to stabilize the concentration of CO2 in the atmosphere at some value.
• Conclusion: Need to act soon.
Basic constraint on carbon policy

Atmospheric Stabilization Emissions Paths

- Business As Usual
- 750 ppm ceiling
- 550 ppm ceiling = 2 X Pre-Industrial CO
- 350 ppm ceiling

1990 by 2020
Let’s visit the wedges

- **Mignone: Stabilization and Policy Timing**
  - If start in 2008 at 1% per year reduction, then we will limit CO$_2$ to ~ 475 ppm
  - Each year delayed is an increase of 9 ppm.
Impacts

• An important place to remember that we are looking at a system that is in “balance”
  – Climate
  – Ecosystems
  – Humans

• Agriculture, public health, water resources, etc.
Remember this curve

Temperature
(other environmental parameter)

GOOD

BAD
Carry away from impact?

- Existing problem with existing system to address the problem
  - Some good, some bad
- Highly localized
- Strongly dependent on extreme events, not the average
  - Hence want to know how extreme events will change
- Technological and engineering solutions usually evident
  - or technological development is feasible
- Not clearly and distinctly addressed by efforts to mitigate greenhouse gas emissions
  - Motivator for “Kyoto like” policy?
Practical Response Space
Past Emissions

Princeton Carbon Mitigation Initiative

The Stabilization Triangle

Historical emissions

Currently projected path = “ramp”

Interim Goal

The Wedge Concept

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.

Total = 25 Gigatons carbon

1 GtC/yr

50 years
Stabilization

Fill the Stabilization Triangle with Seven Wedges

Princeton Carbon Mitigation Initiative
Stabilization wedges update


- Avoided 180 Pg C (7 wedges)
- Allowable 350 Pg C

Pacala & Socolow (2004) updated

- Avoided 250 Pg C (10 wedges)
- Allowable 350 Pg C

Worst case scenario (no CO₂ fertilization)

- Avoided 375 Pg C (15 wedges)
- Allowable 225 Pg C
Global cost curve for greenhouse gas abatement measures beyond ‘business as usual’: greenhouse gases measured in GtCO₂e¹

Approximate abatement required beyond ‘business as usual,’ 2030

- Carbon capture and storage (CCS); new coal
- Medium-cost forestation
- Cofiring biomass
- Wind; low penetration
- Industrial feedstock substitution
- CCS, enhanced oil recovery, new coal
- Low-cost forestation
- Livestock
- Nuclear
- Industrial non-CO₂
- Standby losses
- Sugarcane biofuel
- Fuel efficiency in vehicles
- Water heating
- Air-conditioning
- Lighting systems
- Fuel efficiency in commercial vehicles
- Building insulation

Abatement beyond ‘business as usual,’ GtCO₂e¹ per year in 2030

- 550 ppm⁴
- 450 ppm⁴
- 400 ppm⁴

Marginal cost, £ per tCO₂e²

- ~25
- ~40
- ~50

¹GtCO₂e = gigaton of carbon dioxide equivalent; “business as usual” based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.
²tCO₂e = ton of carbon dioxide equivalent.
³Measures costing more than £40 a ton were not the focus of this study.
⁴Atmospheric concentration of all greenhouse gases recalculated into CO₂ equivalents; ppm = parts per million.
⁵Marginal cost of avoiding emissions of 1 ton of CO₂ equivalents in each abatement demand scenario.
Policy Response Space
Elements of environmental pollutant market

\[
\frac{\Delta [CO_2]}{\Delta t} = P_{CO_2} - L_{CO_2}
\]

GDP

ENERGY PRODUCTION

FUEL SOURCES

\[ F_1^A \quad F_2^A \quad F_i^A \]

\[ F_1^c \quad F_2^c \quad F_i^c \]

ABATEMENT

\[ A_1 \quad A_2 \quad A_i \]

SHARES OF POLLUTANT CREDITS

COST GAP

efficiency
The abatement that we talk about

- Terrestrial sink?
  - This is fragile, limited, and there is growing evidence that it does not “grow” to address the problem.
    - That is “carbon fertilization” is less effective than posed.
- Oceanic sink?
  - Evidence of ocean “taking up less.”
Abatement

• What are the forms of abatement?

• Sequestration to keep carbon dioxide out of the atmosphere.

• Some engineered way to remove carbon dioxide from the atmosphere.
  – Think about the energy of this requires something “biological” to use the Sun.
Policy response space

- Must put a cost on carbon dioxide pollution
- Must value efficiency
An integrated picture?
Towards an integrated picture

**ECONOMIC ANALYSIS**

**CLIMATE SCIENCE**

**ENERGY**

**CONSUMPTION**

**POPULATION**

**UNCERTAINTY**

**KNOWLEDGE**

**IMPACTS**

**LAW**

**INTEGRATED IMPACTS**

PROMOTES / CONVERGENCE

OPPOSES / DIVERGENCE

Fragmented Policy

?
Need for a portfolio of solutions
What is short-term and long-term?

Pose that time scales for addressing climate change as a society are best defined by human dimensions. Length of infrastructure investment, accumulation of wealth over a lifetime, ...

There are short-term issues important to climate change.
We arrive at levels of granularity

Need to introduce spatial scales as well

Small scales inform large scales.
Large scales inform small scales.

Sandvik: Wealth and Climate Change
Projects

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    • Near-term solutions
  – Write, call, meet before presentation.
Thank You: Fill out online evaluation forms
PA1: Just a Theory

• A common statement is that greenhouse gas is just a theory, equating theory with conjecture.
  – Theory is not conjecture, it is testable.
    • Theory suggests some amount of cause and effect – a physical system, governed by quantitative conservation equations.
  – Theory is not fact, it can and will change.
  – Need to consider the uncertainty, and the plausibility that the theory might be wrong.

• Often it is stated in this discussion that gravity is only a theory.
  – True, and the theory of gravity is a very useful theory, one put forth by Newton.
  – True, we don’t exactly understand the true nature of the force of gravity, there are “why” questions.
  – Formally, Newton’s theory of gravity is incorrect – that’s what Einstein did.
    • Still, it is a very useful and very accurate theory, that allows us, for example, to always fall down and never fall up – and go to the Moon with some confidence.
PA2: Greenhouse Effect

• This is generally not a strongly argued point. Warming of the surface due to greenhouse gases make the planet habitable.
  – Habitable? Water exists in all three phases?
• Water and carbon dioxide and methane are most important natural greenhouse gases.
• Often a point of argument that water is the “dominant” gas, so traces of CO2 cannot be important.
  – Water is dominant … often said 2/3 rds of warming. Because there is so much water in the ocean, the amount of water vapor in the atmosphere is largely determined by temperature. (The relative humidity.)
  – This is where it is important to remember the idea of balance, the climate is in balance, and it is differences from this balance which we have co-evolved with that are important.
    • Burning fossil fuels is taking us away from this balance. It is like opening or closing a crack in the window … it makes a big difference.
PA3: What happens to this CO₂

- A “new” political argument: CO₂ from fossil fuels is small compared to what comes from trees and ocean. True. But a lot goes into trees and oceans as well. So it is the excess CO₂, the CO₂ on the margin that comes from fossil fuel burning. Not all of this goes into the trees and oceans, and it accumulates in the atmosphere.

- There are 8.6 Petagrams C per year emitted
  - 3.5 Pg C stay in atmosphere
  - 2.3 Pg C go into the ocean
  - 3.0 Pg C go into the terrestrial ecosystems
    - Terrestrial ecosystems sink needs far better quantification

- It’s a counting problem! One of our easier ones.
PA4: Cycles

• Some say that there are cycles, they are natural, they are inevitable, they show that human have no influence.
  – Cycles? yes → natural? Yes
    • Inevitable → There are forces beyond our control
  – We can determine what causes cycle; they are not supernatural
    • Greenhouse gases change
    • “Life” is involved → ocean and land biology
    • Humans are life → This is the time humans release CO₂
PA4: Cycles → CO₂ and T

- At the turn around of the ice ages, temperature starts to go up before CO₂; hence, T increase is unrelated to CO₂
  - Need to think about time and balance here …
  - There are sources of T and CO₂ variability other than the radiative greenhouse gas effect.
    - If CO₂ increases in the atmosphere, there will be enhanced surface warming, but is the increase large enough to change temperature beyond other sources of variability?
    - If T increases, there could be CO₂ increases associated with, for instance, release from solution in the ocean
    - CO₂ increases could come from burning fossil fuels, massive die off of trees, volcanoes → have to count, know the balance.
In 1975 scientists were predicting an ice age. Now warming. You have no credibility, why should we believe you now.

- In 1975, small number of papers got a lot of press attention.
- 2010 → Think scientific method
  - Observations, observations, observations
  - Improved theory, predictions, cause and effect
  - Results reproduced my many investigators, using many independent sources of observations
  - Consistency of theory, prediction, and observations
  - Probability of alternative description is very small.
PA5: Hockey Stick

• This is the “hockey stick” figure and it is very controversial. Quality of data, presentation, manipulation, messaging.
  – Rood blog
  – Nature on Hockey Stick Controversy

• There are some issues with data, messaging, emotions of scientists here, but the data are, fundamentally, correct.
PA5: Hockey Stick: Science

• But place the surface temperature record of the hockey stick in context using the scientific method.
  – Reproduction of results by independent researchers, through independent analyses
  – Verification of results in other types of observations → sea level rise, ocean heat content, earlier start of spring
  – Consistency of signals with theory → upper tropospheric cooling
  – Evaluation of alternative hypotheses

Return to last 1000 years
There has developed a discussion between those who believe in surface temperature data and those who believe in satellite data. Scientifically, it should not be a matter of belief, but validation. Each system has strengths and weaknesses. Differences should be reconciled, not held as proof of one over the other.

- Surface: Issues of how sited, representative, urban heat island
  - If ignored (wrong), then data flawed
  - If taken into account (right), then data are manipulated
- Satellite data objective and accurate?
  - Read the literature! Took years to get useful temperature. Every satellite is different, calibrated with non-satellite data

And ultimately: Scientific method
- Reproduction of results by independent researchers, through independent analyses
- Verification of results in other types of observations
- Consistency of signals with theory
- Evaluation of alternative hypotheses
Some Geoengineering figures
Geoengineering Schematic

Schematic representation of various climate-engineering proposals (courtesy B. Matthews).

Keith Geoengineering Nature 2001
Anthropogenic Climate Modification

Energy balance

Short-wave (albedo)
- Space-based scatterers
- Atmospheric scatterers
- Land surface albedo modification

Long-wave (emissivity)
- Ocean fertilization
- Terrestrial ecosystem carbon capture
- Geochemical sequestration
- Ecosystem productivity enhancement by genetic modification

Energy transport

Ocean
- Large dams: Gibraltar or Bering straits
- Iceberg transport

Atmosphere & Land Surface
- Chemical or physical control of evaporation
- Hydrological engineering
- Weather control
- Modification of surface roughness

Inadvertent Climate Modification

- Sulphuric and carbonaceous aerosols: Direct and indirect effects
- Surface albedo change: Clearing forests
- Built structures: Cities & roads...

- Radiatively active gases: CO₂, CH₄, N₂O, etc

- Secondary effects of land use change: e.g., salinity changes in Atlantic due to increased evaporation in Mediterranean
- Ocean thermal energy conversion

- Hydrological modification
- Modification of surface roughness
An incomplete history of Geo-engineering

• Good reviews
  – Keith_Geoengineering_History_Prospect_AnnRevEneEnvir_2000
  – Spencer Weart History

• In 1905 Arrhenius discussed a “virtuous circle” in which CO$_2$ emissions would warm the climate, changing the northern limits of agriculture and enhancing productivity.

• Cloud seeding efforts started in 30s and 40s

• John Von Neumann deliberate modification of weather for civilian and military use
  – 1953 Presidents Advisory Committee on weather control with focus on “rainmaking”
  – 1955 in interview in Fortune magazine JVN speculated that “Microscopic layers of colored matter spread on an icy surface, or in the atmosphere above one, could inhibit the reflection-radiation process, melt the ice, and change the local climate

• Budyko in Soviet Union modification to improve agriculture and ocean commerce
Geoengineering history II

• By 1970s US gov spending $20M/yr on weather modification research. Substantial amounts also spent in USSR on this.
• Circa 1974, ... Budyko calculated that if global warming ever became a serious threat, we could counter it with just a few airplane flights a day in the stratosphere, burning sulfur to make aerosols that would reflect sunlight away.
• 1977, National Academy Report on Geoengineering, ...
  – "an essential precaution is to wait until a scientific system for forecasting the behavior of the natural climate... has been devised and operated successfully for, perhaps, a hundred years."
• 1992, National Academy Report on Mitigation and Adaptation
Nine Ways to Cool the Planet

**SPACE SHIELDS**
Storable micrometers-thick refractive screens could divert a portion of the sun's energy away from Earth, thus cooling the atmosphere. The screens would orbit between the sun and the Earth.
- No pollution; can be turned on or off quickly.
- Even using futuristic launching technology, the 20 million metric tons of mesh would cost US $4 trillion to deploy.

**SPACE DUST**
Reflective particles in low orbit reflect sunlight and cool the planet.
- Closer orbit and low manufacturing costs could make dust cheaper to deploy than space shields.
- Costly to deploy and would require frequent replenishment as solar radiation drives dust down to Earth.

**PARTICLES IN THE STRATOSPHERE**
Sulfate or other reflective particles injected at the equator stay aloft in the stratosphere for one or two years, reflecting sunlight and cooling the planet.
- Principle proven by volcanic eruptions; $130 billion price tag is relatively reasonable.
- Increased acid rain, ozone layer damage.

**REFLECTIVE BALLOONS**
Reflective balloons would bounce a portion of the sun's energy away from Earth before it had a chance to warm the surface or the lower atmosphere.
- Cheaper to launch than space shields or space dust.
- Would require millions of balloons that would eventually fall to Earth as trash.
Gail Geoengineering IEEE 2007

**CLOUD COVER**
Ships spray salt-water droplets that make ocean clouds more long-lasting and reflective, cooling the planet.
- **Pros**
  - Pollution free.
  - Would take some 5000 salt-water spraying ships, at $2 million to $5 million apiece, to counter a carbon dioxide doubling.

**REFLECTIVE ROOFS**
Simply painting roofs and roads white could cool populated places by reflecting sunlight.
- **Pros**
  - Paint is cheap.
  - A small effect because much of the sun’s energy is absorbed in the air before it reaches the ground; cooling is local and so could make the local weather worse.

**SEQUESTRATION**
Carbon in the atmosphere or in smokestacks is converted to a form that can be stored underground.
- **Pros**
  - Already being intensely investigated.
  - Could be expensive to deploy the technology and store the carbon; carbon reservoirs could leak.

**IRON DUST**
Iron particles spread over unproductive parts of the ocean cause photosynthetic plankton blooms. The plankton absorb carbon dioxide. When they die, they carry some carbon to the ocean bottom.
- **Pros**
  - Some experiments indicated that thousands of metric tons of carbon were absorbed per metric ton of iron.
  - Unclear how much carbon is permanently trapped; plankton blooms can poison other sea life.

**REFORESTATION**
Trees pull carbon dioxide out of the air and use it to form wood.
- **Pros**
  - Uncontroversial and already accepted under the Kyoto Protocol.
  - Most carbon uptake happens only in the early part of a forest’s growth; new forests could compete with agriculture for land and water.