Meeting the Climate-Change Challenge

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Main messages

• “Global warming” is a misnomer; we should be calling it “global climatic disruption”.

• The disruption & its impacts are now growing more rapidly than was expected just a few years ago.

• The world is already experiencing “dangerous anthropogenic interference in the climate system”. The question now is whether we can avoid catastrophic interference.

• Our options are mitigation, adaptation, & suffering. If we do less mitigation & adaptation, we’ll do more suffering.

• In mitigation and adaptation, there is a lot of “low-hanging fruit”, but it’s not enough. We need a price on GHG emissions to motivate reaching higher in the tree, as well as R&D to bring more fruit into reach.

• The United States must switch from laggard to leader – and sooner rather than later – if the world is to act in time.
What climate is & what climate change means

Climate is the **pattern** of weather, meaning averages, extremes, timing, spatial distribution of...

- hot & cold
- cloudy & clear
- humid & dry
- drizzles & downpours
- snowfall, snowpack, & snowmelt
- zephyrs, blizzards, tornadoes, & typhoons

Climate change means **altered patterns**.

Global average temperature is just an **index** of the state of the global climate as expressed in these patterns. Small changes in the index → big changes in the patterns.
What climate change puts at risk

Climate governs (so climate change affects)

• availability of water
• productivity of farms, forests, & fisheries
• prevalence of oppressive heat & humidity
• formation & dispersion of air pollutants
• geography of disease
• damages from storms, floods, droughts, wildfires
• property losses from sea-level rise
• expenditures on engineered environments
• distribution & abundance of species
The Earth is getting hotter.

Green bars show 95% confidence intervals.

2005 was the hottest year on record; the 14 hottest all occurred since 1990, 24 out of the 25 hottest since 1980.

http://data.giss.nasa.gov/gistemp/graphs/
What’s happening reverses a long cooling trend

“Proxy” temperature reconstructions + 125-yR thermometer record

T leveled off ~1600, started to rise after 1700 & more sharply after 1800.
We know why: Human vs natural influences 1750-2005 (watts/m²)

Human emissions leading to increases in:
- atmospheric carbon dioxide + 1.7
- methane, nitrous oxide, CFCs + 1.0
- net ozone (troposphere↑, stratosphere↓) + 0.3
- absorptive particles (soot) + 0.3
- reflective particles (sulfates, etc.) - 0.7
- indirect (cloud forming) effect of particles - 0.7

Human land-use change increasing reflectivity - 0.2

Natural changes in sunlight reaching Earth + 0.1

The warming influence of anthropogenic GHG and absorbing particles is ~30x the warming influence of the estimated change in input from the Sun.

IPCC AR4, WG1 SPM, 2007
The key greenhouse-gas increases were caused by human activities.

Compared to natural changes over the past 10,000 years, the spike in concentrations of CO$_2$ & CH$_4$ in the past 250 years is extraordinary.

We know humans are responsible for the CO$_2$ spike because fossil CO$_2$ lacks carbon-14, and the drop in atmospheric C-14 from the fossil-CO$_2$ additions is measurable.

IPCC AR4, WG1 SPM, 2007
The smoking gun for human influence


Bottom panel shows that state-of-the-art climate model, fed these forcings, reproduces almost perfectly the last 125 years of observed temperatures.

The current heating is not uniform geographically

Average T for 2001-2005 compared to 1951-80, degrees C
Circulation patterns are changing

Weakening of the East Asia Monsoon is an example

Chinese studies conclude that this phenomenon is indeed a result of greenhouse-gas-driven global climatic change.
Evaporation & precipitation are increasing

Effect is not uniform; most places getting wetter, some getting drier.
Permafrost is thawing

Average ground temperature near Fairbanks, Alaska, degrees C

Permafrost thaws when $T \geq 0^\circ$C

ACIA 2004
Arctic summer sea ice is disappearing

September 2005

September 2007

US National Snow & Ice Data Center, 2007
Surface melting on Greenland is expanding

In 1992 scientists measured this amount of melting in Greenland as indicated by red areas on the map.

Ten years later, in 2002, the melting was much worse.

And in 2005, it accelerated dramatically yet again.

Source: ACIA, 2004 and CIRES, 2005
Sea-level is rising

1993-2003 ≈ 30 mm = 3.0 mm/yr; compare 1910-1990 = 1.5±0.5 mm/yr.

ACIA, 2004
There’s a consistent 50-year upward trend in every region except Oceania.
Harm is already occurring (continued)

Wildfires in the Western USA have increased 4-fold in the last 30 years.

Source: Westerling et al. 2006
Harm is already occurring (continued)
Total power released by tropical cyclones (green) has increased along with sea surface temperatures (blue).

Kerry Emanuel, MIT, 2006
Harm is already occurring (continued)

Weakening East-Asia monsoon has meant less moisture flow South to North, producing increased flooding in South, drought in North

Qi Ye, Tsinghua University, May 2006
Harm is already occurring (continued) The Amazon is drying & burning

Drying results from combined effects of altered regional atmospheric circulation linked to global climate change and local influence of deforestation itself.

Nepstad et al., Forest Ecology & Management 154, 2001
Harm is already occurring (concluded)

WHO estimates climate change already causing ≥150,000 premature deaths/yr in 2000
Bigger disruption is coming: IPCC 2007 scenarios

Last time T was 2°C above 1900 level was 130,000 yr BP, with sea level 4-6 m higher than today.

Last time T was 3°C above 1900 level was ~30 million yr BP, with sea level 20-30 m higher than today.

Note: Shaded bands denote 1 standard deviation from mean in ensembles of model runs.

EU target $\Delta T \leq 2^\circ$C

IPCC 2007
Where we’re headed: Heat waves

Extreme heat waves in Europe, already 2X more frequent because of global warming, will be “normal” in mid-range scenario by 2050

Black lines are observed temps, smoothed & unsmoothed; red, blue, & green lines are Hadley Centre simulations w natural & anthropogenic forcing; yellow is natural only.

Asterisk and inset show 2003 heat wave that killed 35,000.

Higher temperatures also mean more smog

Our Changing Climate: Assessing the Risks to California (2006),
www.climatechange.ca.gov. Source: Air Resources Board, 2000
Where we’re headed: Agriculture in the tropics

Crop yields in tropics start dropping at local $\Delta T \geq 1-1.5^\circ$C

Figure 1. Corn and Rice yields versus temperature increase in the tropics averaged across 13 crop modeling studies. All studies assumed a positive change in precipitation. CO$_2$ direct effects were included in all studies.

Easterling and Apps, 2005
Temperate-zone crop yields start dropping at local $\Delta T \geq 1-2^\circ C$.

Drops are more gradual than in tropics, but still significant.

Figure 2. Corn and Wheat yields versus temperature increase in the temperate zone averaged across 30 crop modeling studies. All studies assumed a positive change in precipitation. CO$_2$ direct effects were included in all studies.

Easterling and Apps, 2005
Where we’re headed: droughts

Drought projections for IPCC’s A1B scenario

Percentage change in average duration of longest dry period, 30-year average for 2071-2100 compared to that for 1961-1990.
Where we’re headed: Oceans acidifying as well as warming

pH history and “business as usual” projection

Surface ocean pH has already fallen by 0.1 pH unit. Projected additional changes are likely to have large impacts on corals and other ocean organisms that make skeletons/shells from calcium carbonate.

Red line is global annual average; blue lines show ocean-to-ocean and seasonal variation.
Where we’re headed: sea level

Melting the Greenland and Antarctic Ice Sheets would raise sea level up to 70 meters.

This would probably take 1000s of years, but rates of 2-5 m per century are possible.

GIS = Greenland Ice Sheet
WAIS = West Antarctic Ice Sheet
EAIS = East Antarctic Ice Sheet

Dr. Richard Alley, 2005
Facing the dangers from climate change…

…there are only three options:

• **Mitigation**, meaning measures to reduce the pace & magnitude of the changes in global climate being caused by human activities.

• **Adaptation**, meaning measures to reduce the adverse impacts on human well-being resulting from the changes in climate that do occur.

• **Suffering** the adverse impacts that are not avoided by either mitigation or adaptation.
Concerning the three options…

• We’re already doing some of each.

• What’s up for grabs is the future mix.

• Minimizing the amount of suffering in that mix can only be achieved by doing a lot of mitigation and a lot of adaptation.
  – Mitigation alone won’t work because climate change is already occurring & can’t be stopped quickly.
  – Adaptation alone won’t work because adaptation gets costlier & less effective as climate change grows.
  – We need enough mitigation to avoid the unmanageable, enough adaptation to manage the unavoidable.
Mitigation leverage: The sources of GHG emissions

- Energy supply: 25.9%
- Residential and commercial buildings: 7.9%
- Industry: 19.4%
- Agriculture: 13.5%
- Transport: 13.1%
- Forestry: 17.4%
- Waste and wastewater: 2.8%

2004

IPCC WG3, 2007
Mitigation possibilities include...

(CERTAINLY)

• Reduce emissions of greenhouse gases & soot from the energy sector

• Reduce deforestation; increase reforestation & afforestation

• Modify agricultural practices to reduce emissions of greenhouse gases & build up soil carbon

(POSSIBLY)

• “Scrub” greenhouse gases from the atmosphere technologically

• “Geo-engineering” to create cooling effects offsetting greenhouse heating
How much mitigation is needed, how soon?

• The UN Framework Convention on Climate Change of 1992 is “the law of the land” in 191 countries (including the United States).

• It calls for

  “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”.

• But there was no formal consensus in 1992 as to what constitutes “dangerous anthropogenic interference” or what level of GHG concentrations will produce it.
How much, how soon? (continued)

• There’s still no “official” consensus, but by any reasonable definition the current level of interference is dangerous.

• Can we avoid catastrophic interference?
  – $T_{\text{avg}}$ would rise $0.6^\circ\text{C}$ more (to $1.4^\circ\text{C}$ above pre-industrial) even if concentrations were stabilized today.
  – Chance of a tipping point into catastrophic change grows rapidly for $T_{\text{avg}}$ more than $2^\circ\text{C}$ above pre-industrial (IPCC 2007, UNSEG 2007).

• Limiting $\Delta T_{\text{avg}}$ to $\leq 2^\circ\text{C}$ is the most prudent target that still might be attainable; as a fallback, $2.5^\circ\text{C}$ gives better odds of avoiding catastrophe than $3^\circ\text{C}$. 
Key mitigation realities

• Human CO₂ emissions are the biggest piece of the problem (50% and growing)
  – 3/4 comes from burning coal, oil, & natural gas (80% of world energy)
  – 1/4 comes from deforestation & burning in the tropics

• While 60% of fossil CO₂ still came from industrialized countries in 2006, developing countries will dominate after 2015.

• Global energy system can’t be changed quickly: $15T is invested in it, w normal turnover ~40 yrs.

• Deforestation isn’t easy to change either: forces driving it are deeply embedded in the economics of food, fuel, timber, trade, & development.
Fossil CO$_2$ emissions paths: BAU versus stabilizing CO$_2$ concentration to limit $\Delta T_{avg}$

Global Energy Technology Strategy, Battelle, 2007
Leverage on fossil-fuel CO$_2$ emissions

The emissions arise from a 4-fold product…

\[
C = P \times \frac{GDP}{P} \times \frac{E}{GDP} \times \frac{C}{E}
\]

where \(C\) = carbon content of emitted CO$_2$ (kilograms), and the four contributing factors are

- \(P\) = population, persons
- \(\frac{GDP}{P}\) = economic activity per person, $/pers
- \(\frac{E}{GDP}\) = energy intensity of economic activity, GJ/$
- \(\frac{C}{E}\) = carbon intensity of energy supply, kg/GJ

For example, in the year 2005, the world figures were…

\[
6.4 \times 10^9 \text{ pers} \times 6500/\text{pers} \times 0.012 \text{ GJ}$/\text{pers} \times 15 \text{ kgC/GJ} \\
= 7.5 \times 10^{12} \text{ kgC} = 7.5 \text{ billion tonnes C}
\]
Options for reductions

Reduce growth of energy use by…

• reducing population growth
• reducing growth of GDP/person
• reducing E/GDP ratio by
  – increasing efficiency of conversion to end-use forms
  – increasing technical efficiency of energy end-use
  – changing mix of economic activities

Reduce CO$_2$/E ratio by…

• substituting natural gas for oil & coal
• replacing fossil fuels with renewables
• replacing fossil fuels with nuclear energy
• capturing & sequestering CO$_2$ from fossil-fuel use
There is no panacea

All of the options have limitations & liabilities.

- **limiting population**: social & political sensitivities
- **slowing GDP/person**: economic aspirations
- **expanding natural gas**: resource size & distribution
- **wind**: intermittency, siting (NIMBY→BANANA)
- **biofuels**: net energy, land, food/ecosystem impacts
- **photovoltaics**: intermittency, cost, toxics
- **nuclear fission**: cost, waste, safety, proliferation
- **nuclear fusion**: doesn’t work yet
- **CO₂ capture/sequestration**: cost, scale, complexity
- **end-use efficiency**: education, other barriers

Note: H₂ is not an energy source; it comes from other sources
Big problem & lack of panacea mean…

• We’ll need a portfolio of approaches
  – Not just one or two, but many;
  – although not necessarily everything on the menu, as
devolving the better options to their full potential may
allow foregoing some that prove very costly or risky.

• We need increased research & development on
all of the options to try to
  – improve their performance,
  – lower their costs, and
  – reduce their adverse side effects,
so that the future menu can be better than
today’s.
Good & bad news re mitigation

• G: The cheapest, fastest, cleanest, surest source of emissions reductions is to increase the efficiency of energy use in buildings, industry, and transport.

• G: Many such approaches are “win-win”: their co-benefits in saved energy, increased energy security, reduced conventional pollution, etc., are more than worth their costs.

• G: Some supply-side mitigation options (wind, some bio-fuels) are also “win-win”, as are many adaptation options.

• B: The “win-win” approaches will not be enough. Adequate mitigation will require putting a price on emissions of GHG (via emissions tax or tradable emissions permits).
Supply curve for GHG abatement in 2030

Global cost curve for greenhouse gas abatement measures beyond 'business as usual'; greenhouse gases measured in GtCO₂e. McKinsey, 2007
Capturing CO$_2$ from power plants will be costly, but concentrations can’t be stabilized soon enough unless we do it.

TOTAL = 1,070 (billions of tons of carbon dioxide)

TOTAL = 735

All CO$_2$ emissions from 1750 to 2002

Lifetime CO$_2$ emissions from power plants built 2003-2030

LIFETIME FOSSIL-FUEL EMISSIONS from power plants projected to be built during the next quarter of a century will be comparable to all the emissions during the past 250 years.

Courtesy David Hawkins, Rob Socolow, & Scientific American
The challenge of scale

• Stabilizing at 500 ppmv CO$_2$-e means global CO$_2$ emissions must be $\sim$7 GtC/yr below BAU in 2050.

• Avoiding 1 GtC/yr requires…
  - energy use in buildings cut 20-25% below BAU in 2050, or
  - fuel economy of 2 billion cars $\sim$60 mpg instead of 30, or
  - carbon capture & storage for 800 1-GWe coal-burning power plants, or
  - 700 1-GWe nuclear plants replacing coal plants, or
  - 1 million 2-MWe(peak) wind turbines replacing coal power plants or
  - 2,000 1-GWe(peak) photovoltaic power plants replacing coal power plants

Socolow & Pacala, 2004
Some mitigation-policy realities

• In applying the costlier solutions, the industrialized nations must lead – going first, paying more of the up-front costs, offering assistance to developing countries.  
  
  This is a matter of historical responsibility, capacity, equity, and international law (the UNFCCC).

• Developing countries will need to be compensated for reducing/avoiding deforestation.

• Without a formal & binding global agreement on the allocation of emissions in the post-Kyoto period, the needed global reductions will not be achieved.

• The best basis for such an agreement in the short term is probably reductions in emission intensity (GHG/GDP); in the longer run, the only politically acceptable basis will be equal per-capita emissions rights.
Economics of mitigation

• Current global CO\(_2\) emission rate from fossil fuels + deforestation ≈ 9-10 billion tonnes of C per year.

  Paying $100/tC to avoid half of it would be $0.5 trillion/year, about 1% of the Global World Product (much of it a transfer, not money down a black hole).

• World spends 2.5% of GWP on defense; USA spends 5% of GDP on defense, 2% on environmental protection.

• More sophisticated analyses of economic impact of mitigation to stabilize at 550 ppmv CO\(_2\)e \(\rightarrow\) \(~1\)% GWP loss (range 0.5-2%) in 2100 (Stern review); mid-range IPCC 2007 estimates are \(~0.5\)% GWP loss in 2030.
Adaptation possibilities include…

• Changing cropping patterns
• Developing heat-, drought-, and salt-resistant crop varieties
• Strengthening public-health & environmental-engineering defenses against tropical diseases
• Building new water projects for flood control & drought management
• Building dikes and storm-surge barriers against sea-level rise
• Avoiding further development on flood plains & near sea level

Many of these are “win-win”.
The most important next steps

• Accelerate “win-win” mitigation and adaptation measures; integrate adaptation with development
• Put a price on GHG emissions so marketplace can work to find cheapest reductions
• Pursue a new global framework for mitigation and adaptation in the post-2012 period
• Ramp up investments in energy-technology research, development, & demonstration by 2-5X
• Expand international cooperation on deploying advanced energy technologies

The United States must lead!
Some references


Intergovernmental Panel on Climate Change, *Climate Change 2007* http://www.ipcc.ch/

KSG Belfer Center, *Energy Technology Innovation Policy website*: http://www.belfercenter.org/energy/