OUR BURNING PATH: ACTION OR DENIAL ON GLOBAL WARMING?

"If climatic change makes our country uninhabitable, we will march with our wet feet into your living rooms."

- Atiq Rahman,
Bangladesh climate negotiator
Berlin, 1995

A BRIEFING PAPER ON CLIMATE CHANGE
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Summary

Our planet now faces a looming climate catastrophe caused by human action. Scientifically, there is no longer any doubt that pollutants from the combustion of fossil fuels and other human activities are accumulating in the atmosphere, trapping radiation, and warming the earth. There remains some uncertainty about the precise timing and magnitude of the warming, and about the impacts that will result from it, but this is due as much to uncertainties about the human story line – what the global economy will do in the 21st century, and how much we will continue to pollute – as to scientific uncertainties. Many types of geophysical impact are clearly predictable and some are likely already under way: changes in precipitation and soil moisture; increased incidence of extreme weather events like droughts, floods, and hurricanes; sea level rise; the melting of polar ice and glaciers. Ecological and human impacts resulting from these changes are expected to include desertification, loss of tropical forests and coral reefs, declines in agricultural productivity, extinction of species, water shortages, growing casualties from natural disasters, and the spread of tropical diseases. Whether the magnitude of these impacts comes to constitute merely a further incremental degradation of the quality of life on earth, or a truly catastrophic collapse that leads to starvation, massive migration, and resource wars, will depend on human action during the next several decades, and on the possibility of dangerous surprises ("non-linearities") in the response of the climate system to increasing temperatures and greenhouse gas concentrations.

Human response to the climate threat so far gives only modest cause for hope. The creation of the Kyoto Protocol in 1997 symbolizes both widespread global concern about the threat, and widespread scientific consensus on the origins of the problem and the basic nature of the solutions required. Yet, the path to action has been halting and strewn with obstacles, in particular the opposition of the fossil fuel industry and the United States government. Kyoto envisages the broad outlines of a solution: the setting of internationally-agreed emission targets, and the creation of economically efficient mechanisms for achieving these targets, which will entail rebuilding the planetary infrastructure in a way that reduces the emissions of greenhouse gases by at least two-thirds over the next century. The eventual bill for this massive development and deployment of new technologies for power generation, transportation, and agriculture -- not only in the rich nations of the global North but in the poor nations of the global South, whose total emissions will soon exceed those of the North – will likely be trillions of dollars. The ultimate question is whether the North is willing to pay this bill, and the U.S. answer so far is "no". U.S. attempts to scuttle Kyoto altogether have so far been thwarted by a shaky alliance between Europe and developing countries, which share an acceptance of the principle that rich countries must in the end pay for the sustainable development of the South in order to avert a climate catastrophe.

Whether it is Kyoto or some other, better agreement, meaningful collective action on climate will eventually require the willing participation of the U.S. From the present perspective that would seem possible only in the case of a profound transformation, both of the domestic politics of the U.S. that have installed a unilateralist regime deeply embedded in fossil fuel interests, and also of the structural trends of the global political

economy for the past two decades (expressed in free trade agreements, deregulation, investment rules, and structural adjustment policies, abetted by the ascendancy of market ideologies and right wing governments) that have resulted in the growing independence of private capital and movement away from the kinds of social control over capital that could produce the necessary investment. While it is possible for the present to keep Kyoto on life support, to continue to improve scientific understanding and develop potential technical solutions, and to negotiate in theory over the complex principles and institutions of governance that will eventually be required, these efforts are likely to prove sterile without a significant political transformation, within the United States and in its geopolitical relationships. The strategies and tactics of climate protection forces should be developed not to pander to present U.S. pathologies, but rather in ways that help to promote the necessary political transformation.

CLIMATE CHANGE: THE PHYSICAL PROBLEM

FUNDAMENTALS

Some of the solar radiation that strikes the earth's surface each day is absorbed and then re-radiated back toward space in the form of infrared radiation. The *"greenhouse effect"* occurs when certain gases in the atmosphere, known as *greenhouse gase*s (GHGs), trap a portion of this infrared radiation, warming the earth. The existence of the greenhouse effect is undeniable – in fact, it is what warms the earth sufficiently to make it habitable. However, human activities in the industrial age have added GHGs – principally carbon dioxide, but also methane, nitrous oxide, and various fluorocarbons -- faster than natural processes can eliminate them. This has led to a significant increase in GHG concentrations. The pre-industrial concentration of CO_2 in the atmosphere was 275 parts per million by volume (ppm). It is now 370 ppm and rising rapidly.

According to the Intergovernmental Panel on Climate Change (IPCC), the international scientific body under U.N. auspices that coordinates and synthesizes the work of thousands of climate scientists around the world, it is highly likely that the anthropogenic increase in GHGs has already raised the earth's average surface temperature by 0.6 degrees Celsius (1° F) during the last century. Prediction and verification of human impacts on climate are based on sophisticated computer models called *Global Circulation Models* (GCMs) and a wide array of empirical evidence ranging from satellite sensing to ice cores and pollen records from the distant past. Using these methods, the IPCC attempts to rigorously quantify in turn the global *emissions* of GHGs from all *sources*, the *concentrations* that result after various processes of removal (*"sinks")* occur, the *radiative forcing* that results from a certain concentration, and the *sensitivity* of the climate – how much the earth's average surface temperature changes as a result of a certain change in radiative forcing. The sum of all of these efforts is IPCC's prediction that if atmospheric CO_2 concentrations are doubled, to 550 ppm, that it will lead to a change in earth's average surface temperature of 1.5 to 4.5° C, in the absence of major surprises (*"nonlinearities"*) in the climate system. The most recent evidence (not yet officially endorsed by IPCC) indicates that the most likely response to a CO_2 doubling will be in the range of a 3.5° C increase. By comparison, since the peak of the last ice age 17,000 years ago, earth has warmed by a total 5° C.

Changes in surface temperature in turn set off a cascade of interlinked geophysical, biogeochemical, and ecological effects that the IPCC attempts to measure, model, and predict: changes in precipitation, cloud formation, sea level, ice and snow cover, prevailing winds, ocean circulation, weather variability, ecosystem health, soil fertility, agricultural productivity, disease vectors, and species survival. Uncertainties about these effects are large, including the extent to which they will constitute direct and indirect *feedbacks* to the climate system, raising or lowering the temperature change that would otherwise occur. Ultimately, however, the largest uncertainty in the human behavior-to-ecological impacts chain of events is human behavior itself: how much humanity does or does not continue to pollute the atmosphere.

CAUSES

Human Activities Leading to Climate Change

The principal types of human activities that result in increased radiative forcing of the atmosphere and therefore are driving changes in the climate are the following, in descending order of current importance:

- electricity generation
- transportation
- agriculture – especially livestock raising, the use of nitrogen fertilizer, and the growing of crops in flooded fields
- land use changes – especially deforestation and other forms of habitat conversion
- cement manufacturing

Underlying Societal Variables

The basic social, political, and economic variables that determine the actual magnitude of the climate forcing (caused by the types of human activities listed above) include:

- the rate of global economic growth
- the distribution of economic growth
- the energy intensity of future economies
- population growth
- consumption
- social and political commitment to solving the climate problem

Predictable Physical Driving Variables

Among the actual physical variables that increase radiative forcing and drive climate change, the most predictable – in the sense that they are likely to change in predictable ways as a function of the activities that produce them – are anthropogenic emissions of GHGs, listed here in decreasing order of current importance.

- CO_2 emissions from fossil fuel combustion for electricity generation
- CO_2 emissions from fossil fuel combustion for transportation
- CO_2 emissions from cement manufacturing
- CH_4 emissions from landfills, livestock enteric fermentation, and manure management
- N_2O emissions from fertilizer application in agriculture
- emissions of fluorocarbons used as substitutes for ozone-depleting substances

(Once emissions are known, there is still a degree of uncertainty in the resulting atmospheric concentration – which depends on uncertain sinks as well as uncertain sources – and in the magnitude of the resulting climate forcing.)

Less Predictable Physical Driving Variables

The most important physical driving variables affecting climate that are not readily predictable as a function of human activities – in terms of current scientific understanding and uncertainty – are likely to include the following (although due to the complex feedback and potential non-linearity of the climate system it is possible that other phenomena not on this list will prove to be of even greater significance):

- CO_2 emissions from land-use changes, such as forest burning to clear land
- “ice-albedo feedback” , meaning the additional warming effect due to reduced ice and snow cover, which causes less reflection and more absorption of sunlight
- “cloud formation feedback” , meaning changes in absorption and reflection of sunlight as a function of changes in cloud height, locations, and type
- the role of aerosols and particulates, which as a function of type, abundance, and location can have a warming effect, a cooling effect, or an effect on precipitation by serving as cloud condensation nuclei
- “fertilization effect”, in which plants absorb more CO_2 in a CO_2-rich atmosphere
- increased CO_2 emissions from enhanced rates of soil organic matter (SOM) decomposition due to warming
- ocean sinks and sources of CO_2 – changes in ocean uptake of CO_2 and deep burial of carbonate minerals as a function of atmosphere-ocean gas exchange; changes in ocean circulation that bring deep cold CO_2-rich water up to the surface and increase outgassing

Current Rates of Change of Physical Driving Variables

The rates of change of emissions and atmospheric accumulation are different for different GHGs. Among the most important current trends are the following:

- emission of CO_2 from fossil fuels is accelerating
- tropical deforestation is accelerating
- emission of fluorocarbons used as substitutes for ozone-depleting substances is accelerating, and they have no short-term sink
- emission of N_2O is not accelerating but has no short-term sink
- emission of CH_4 is not accelerating

Key Interactions Among Activities and Driving Variables

In addition to the direct emissions described earlier, the most important interactions among human activities and physical driving variables are the following:

- fossil fuel combustion emits CO_2 but also releases sulfate aerosols which tend to cool; when sulfates (a major health hazard) are reduced in order to improve urban air quality, warming will tend to increase

- biomass burning emits CO_2 and also releases aerosols (black carbon) which tend to increase warming
- land use changes can cause both positive and negative changes in flux of CH_4, CO_2, and N_2O
- the greater GHG emissions, the greater the warming; the greater the warming, the more likely are ice-albedo, cloud, and biosphere feedbacks that will tend to cause further warming

IMPACTS

Impacts on Climate

The principal direct geophysical impacts of increased radiative forcing on the global climate are expected to include the following:

- warmer average temperatures, with the greatest changes at high latitudes
- sea level rise, due primarily to thermal expansion of seawater
- accelerated hydrologic cycles
- drier soils in many places
- increased frequency of extreme weather events

Impacts on Humans and Ecosystems

The principal direct impacts of climate change on human society are expected to include the following:

- changes in fresh water resources, including decreases in some areas already experiencing water shortages
- increased incidence of floods, fires, hurricanes, severe storms
- disturbance of ecosystem function and productivity, including agricultural and forest ecosystems
- loss of biodiversity and genetic diversity
- spreading of diseases currently kept in check by cold weather
- direct effect of temperature on human health (*a la* France summer 2003 heat wave)

Interactions with Other Global Changes

Climate change will interact with other human-induced global changes resulting from increased population and consumption, and from the spread of certain patterns of development. The human and ecological impacts from many of these interactions are expected to be greater than those of climate change by itself. Some of the most important global change interactions are expected to include the following:

- interaction of increased human withdrawals of available freshwater with climate-change induced changes in amount and timing of precipitation, potentially leading to severe water shortages in many densely populated regions, and further loss of water available for natural ecosystems
- interaction of increased demand on agricultural ecosystems and soils with climate-change induced changes in soil moisture and fertility, potentially leading to reductions in production of food and fiber
- interaction of human land use changes, conversion of natural ecosystems, and habitat fragmentation with climate pressure on ecosystems, leading to further loss of habitat, biodiversity, genetic diversity, and ecosystem functions essential to human well-

being, such as water and air filtering and sources of genetic material for pharmaceuticals and other industrial uses
- interaction of human-introduced invasive species and diseases with climate pressure on ecosystems, leading to loss of native species, establishment of non-native species and diseases, and erosion of ecosystem and human health
- interaction of increasing human settlement of coastal areas and flood plains with climate change-induced sea level rise and increased frequency of extreme weather events, resulting in increased flood damage and loss of life in "natural disasters"

Distributional Impacts

Climate change impacts on human society are likely to be distributed unevenly, between global regions, among countries, and within a given country among sub-national regions and social classes. Some of the possible types of impacts include:

- Poor people generally stand to be more adversely affected than affluent people because they have fewer resources with which to mitigate the impacts of climate change, and because many (such as subsistence farmers) are more directly dependent on the normal functioning of climate and ecosystems for their livelihood
- Agriculture in boreal regions such as Canada and Siberia could benefit from longer growing seasons, while tropical and temperate agriculture could suffer losses due to higher temperature extremes, drought, floods, and loss of soil fertility
- Indigenous people and others with a strong dependence on ecosystem resources and functions, such as farmers and fishermen, could experience loss of livelihood
- People living in already water-stressed areas such as North China, Sub-Saharan Africa, and parts of South Asia could experience more severe water stress and negative health consequences
- People living in low-lying areas – islands and coastal regions – may experience submersion or increased flooding of their homelands, or be required to make major investments in order to prevent these, involving substantial opportunity costs

Surprise / Non-Linear / Qualitative Impacts

It is possible for geophysical, biogeochemical, ecological, and human impacts to accumulate to a point at which incremental changes end and qualitatively different phenomena begin, due to the crossing of some cumulative quantitative threshold (for example, species extinction, or the loss of an entire sub-population) or the activation of some non-linear effect. Some scientists refer to this category of effect as "surprise." Such effects are somewhat speculative by nature, but some that have been more rigorously studied and are considered scientifically plausible include:

- changes in the thermohaline circulation of the ocean, which could result in changes in the magnitude and direction of major ocean currents, such as the Gulf Stream – which could, in turn, have a severe adverse effect on climate and agriculture in Europe
- changes in ocean circulation could also create a positive feedback that makes global warming much more severe due to increased upwelling of deep CO_2-rich water

- prevailing areas of high and low pressure could change, resulting in entirely new climatic patterns in some regions of the world, to which ecosystems and human populations are not adapted
- the melting of ice caps and the breakup of Antarctic ice sheets
- major changes in global ecosystem type driven by changes in hydrology, soils, fire regime, new conditions supporting invasive species, loss of substantial biodiversity and genetic diversity
- diseases (for example, malaria and dengue fever) spreading to new places where they currently don’t exist, such as more northern or higher elevation areas
- runaway greenhouse effect, triggering a major global climate transition to something never experienced since homo sapiens has been on the planet

PREDICTIONS

Scientific Understanding Of Climate Change

Scientific concern with the influence of GHGs on climate is not a recent development. The role of the greenhouse effect in earth's climate and the potential for human-induced climate perturbations were first described scientifically in 1896 by the Swedish chemist Svante Arhennius, who made a number of predictions that are in general agreement with today's models and observations: that a doubling of atmospheric CO_2 would raise global mean surface temperature by approximately 5° C, and that the warming effects would be most acute in the upper latitudes. The first official report to a U.S. president on potential climate threats and the need to monitor atmospheric CO_2 concentrations came was produced in 1965.

Today, the state of scientific knowledge on the causes and effects of global warming is assessed and synthesized every few years by the Intergovernmental Panel on Climate Change (IPCC), established by the United Nations Environment Program and the World Meteorological Organization in 1988, and now the official scientific arm of the Kyoto Protocol. IPCC has produced three major assessment reports, in 1990, 1995, and 2001, that most climate scientists worldwide consider to be authoritative. IPCC's three scientific working groups – on climate science, human and ecological impacts, and mitigation/prevention – consist of many of the world's top scientists in their respective fields. In addition to the assessment reports, the IPCC produces numerous technical reports and is responsible for the collection of GHG inventory data from every country in the world, which forms the basis on which the Kyoto Protocol is to be implemented.

The character of scientific knowledge regarding climate change is for the most part extremely open and non-proprietary. IPCC reports and the scholarly research that underlies it belong to the public domain. Empirical data, model results, and emissions scenarios are highly transparent and subject to rigorous scrutiny and testing according to the norms of the scientific community. A possible exception to the general rule of transparency involves the reporting of GHG inventory data by national governments, which carries potentially significant economic implications; however, the potential for erroneous reporting is constrained by various possible methods of cross-checking of reported data.

Models

The most important job of climate scientists in practical terms is to provide data that helps the international community prevent or reduce disruptive climate change by setting appropriate targets for maximum emissions levels. Since there is no way of knowing *a priori* the precise effects of a given level of GHG emissions on climate at a future time, these must be modeled mathematically using sophisticated computer programs. There are numerous kinds of models, operating at different scales – from microphysics models that incorporate the fundamentals of biogeochemical and physical processes at a small scale, to mesoscale models that incorporate local and regional processes and data, to

GCMs, which model global atmospheric and oceanic transport of mass and energy within grid cells representing areas of 1° by 1° of the earth's surface. There are now five principal GCMs in use, which give generally consistent results using somewhat different methods.

In terms of policy implications, it is important to realize that it is impossible to use models to predict climate in, say, the year 2100, without knowing a great deal about the driving variables. Therefore, IPCC publishes its predictions in the form of *scenarios*, which are based on different sets of assumptions about changes in emission levels over a certain period of time – say the next 20 years, or the next century. Fundamentally, all these scenarios start with certain assumptions about future levels of population, economic growth, and technology, on which basis future emissions are estimated. These are then used, along with scientific knowledge of sources, sinks, and greenhouse warming potential, to calculate radiative forcing. Then, making further assumptions regarding climate sensitivity to radiative forcing, future temperature and precipitation for the different scenarios are calculated. IPCC is scrupulous to note uncertainties in all of its scenarios, both those resulting from scientific uncertainty and those resulting from uncertainty about human factors.

Targets

Since model predictions are uncertain, and since judgment of what constitutes unacceptable climate impacts is to a considerable extent political and subjective, IPCC does not itself issue emission targets; this is the function of the international community under the auspices of the Kyoto Protocol – if ratified. Nonetheless IPCC scenarios are highly instructive regarding the types of inputs to be expected for given emissions pathways, and it is on the basis of these scenarios that most of the policy discussions of acceptable limits and emissions targets take place.

At the current time, many governments and NGOs have converged on the idea of a 2° C warming as the maximum that is likely acceptable in terms of predicted ecological and human impacts. Based on a middle-of-the road estimate of climate sensitivity to radiative forcing and the assumption of no major surprises in the climate system, a 2° C warming implies in turn a maximum atmospheric concentration of 450 ppm CO_2-equivalent. In turn, this implies total carbon-equivalent emissions of 550 Gt (C), with an uncertainty of ± 200 Gt, over the course of the 21st century. With present emissions of 8 Gt/yr and rising, a frequently cited trajectory for achieving the 2° C level has global emissions leveling off until about 2020, followed by a steady decline in emissions until they reach about 3 Gt/yr in 2100, or roughly one-third the current level. (See Figure Y)

Understanding the implications of this scenario is sobering. To begin with, assumptions that a 2° C warming is relatively "safe", that a 450 ppm atmosphere will produce only a 2° warming, and that a 550 Gt trajectory of the sort described will produce only a 450 ppm atmospheric concentration may all be optimistic. But what is of greatest concern is the economic reality it implies: how can GHG emissions be cut by two-thirds during a century in which global population is expected to double and the global economy to increase at least by a factor of ten? It is this question that underlies the climate policy problem.

CLIMATE CHANGE: THE POLICY PROBLEM

THE BIG ISSUES

Current Trajectory

- global net CO_2 emissions are rising, not falling, despite Kyoto
- under business as usual, annual global emissions will probably double and could easily triple by 2100
- under business as usual, average temperatures could increase by as much as 5.5° C (~10° F) by 2100
- the outcome could well be catastrophic, with severe risk of surprise / runaway feedbacks

Targets

- 2° C warming upper limit has broad support among scientists and NGOs
- 450 ppm is thought to lead to a 2° C warming, using middle of the road estimates of climate sensitivity to radiative forcing
- CAUTION: Impacts of a 2° C warming are still uncertain, could turn out to be unacceptably severe
- CAUTION: Climate sensitivity is uncertain, 450 ppm could lead to more than a 2° C warming
- CAUTION: Waiting for absolute certainty on the magnitude of climate threat before setting targets – especially if certainty means having demonstrable anecdotal evidence to convince the most obstinate opponents, such as the calving of a major ice sheet in Antarctica or a major change in the Gulf Stream -- would probably mean waiting far too long to avert truly catastrophic climate changes.

450 ppm

- To reach 450 ppm, cumulative emissions in the 21st century would have to be reduced by about one-half relative to most likely business as usual scenario (~600 Gt in 450 ppm pathway, versus ~ 1200 Gt in most likely business as usual)
- Actual emissions in 2100 would have to be roughly 1/3 of our current level, despite expected many-fold increase in global GDP (~3 Gt in 2100, versus ~8 Gt in 2000)
- In the 450 ppm pathway, emissions should reach a peak in 2015, fall to half their current level by 2050, and to one-third by 2100
- In contrast, the most likely business as usual scenario breaks through the 450 ppm pathway in 2005, and uses up all the available climate space before mid-century

North and South

- Inequitable use of climate space – ability of atmosphere to absorb GHGs
- North has historically used atmosphere as open access resource, essential to own industrial development based on fossil fuel, without paying for it or taking care of it
- US has 5% of world population, 25% of emissions
- Total Southern emissions have been climbing rapidly, now about equal to total Northern emissions (about 4 Gt/year each)

- Southern per capita emissions are much lower than Northern. In 2000, Northern per capita emissions = 2.8 tonnes (C)/year, Southern per capita emissions = 0.8 tonnes (C)/year. (Based on Northern population of ~ 1.5 billion, Southern population of ~ 4.5 billion)
- Southern emissions are expected to cross 450 ppm pathway by themselves – no matter what Northern emissions do -- by about 2020. Even then Southern emissions will still be much lower on a per capita basis

The Big Questions

- What constitutes an acceptable tradeoff between the need for greater certainty – about the imminence, magnitude, and precise characteristics of climate change -- and the risk of inaction to protect climate?
- How can global political will be mobilized for immediate, aggressive, committed preventive action?
- What technical solutions exist, or will have to be invented, for climate protection at the 2° C warming level?
- What is the source of massive financial investment required for a sweeping energy infrastructure transition -- including in the poor south?
- How can economic growth be maintained to support increased population and improve of living standards in the south while the global economy is decarbonized?
- What international governance institutions would have to be created, with what ultimate source of authority, to oversee massive transfers of wealth from north to south and to police financial mechanisms and climate protection activities?
- How could such institutions be structured to respond flexibly to changed conditions and new scientific evidence, without being vulnerable to manipulation and loss of resolve?
- What are the intersections of global warming and climate protection with other global trends in the 21st century?
- Is the most effective locus of political action and consciousness raising for climate protection at the popular/democratic level, or at the elite level?
- Is the Kyoto Protocol the best hope currently existing for climate protection? If Kyoto is not ratified, then what must be done?
- What can be done about the United States?

SOLUTIONS

Premises

- The severity of climate change depends fundamentally on the amount of GHG emissions by human beings. Impacts may not be something that humanity can predict with absolute certainty, but emissions are something that humanity absolutely can control.
- Prevention is preferable to mitigation. It is likely that there is still sufficient time for technical solutions to be implemented to avoid the worst climate consequences. Mitigation after the fact may exacerbate other global problems (such as water shortages) and protect only the wealthy.
- The technology and infrastructure to prevent catastrophic climate change can be created if the money and political will exists. The goal is to reduce GHG emissions to a tolerable level while still permitting sustained economic growth, especially in poor countries.
- The economic cost of climate protection will be on the order of several trillion dollars (estimated as being between US$1 trillion and US$8 trillion in current dollars in IPCC Third Assessment Report). This does not take into the economic benefits.
- Resolving the governance problem is at least as important as resolving the technical problem. Climate protection will require a global governance regime with unprecedented legitimacy, authority, and competence, to provide the far-sighted, flexible, equitable, and resolute creation and policing of the financial and administrative mechanisms needed for climate protection.
- Climate protection faces adamant opposition from the world's most powerful government and most powerful industry. The political problem must be solved in order for technical, policy, and governance solutions to proceed.
- Major changes in the international political economy may be required to achieve the necessary level of international cooperation. The current relationships – financial, economic, military, diplomatic – between the global North and global South may have to change dramatically for climate protection to proceed.
- Equity may be the only path forward with a chance of success. Major cash flows from North to South may be required.

Technical Solutions

- General improvement of energy efficiency
    - Minimize energy intensity of production processes, maximize energy efficiency of consumption and end-use
- General decarbonization and dematerialization
    - Reduce unsustainable consumption by system-level design of production, consumption, patterns of settlement
    - Design products and processes with cradle-to-grave, closed-loop material cycles
    - Reduce carbon intensity of all energy production and consumption
- Low CO_2 electricity
    - Maximize electricity end-use efficiency in industrial equipment, lighting, and appliances

  - Develop and expand generation that uses CO_2 –free primary energy sources, such as solar, wind, geothermal, and nuclear, or carbon-neutral sources such as biomass
- Low CO_2 transportation
  - (Re)design urban development patterns and transportation infrastructure to maximize mass transit and human-powered transportation
  - Maximize vehicle fuel efficiency in short term with hybrids and high mileage internal combustion engines
  - Develop and expand use of non-fossil fuel vehicles, including electric vehicles charged by CO_2 –free electricity, fuel cell vehicles using hydrogen or hydride fuels from CO_2 –free sources, and internal combustion vehicles using biomass fuels that are inherently carbon-neutral
- Low-N_2O agriculture
  - efficient fertilizer management – precision application of fertilizer at optimal time for plant uptake
  - maintain aerobic conditions in soil
- Climate-friendly land use practices
  - stop deforestation and expand forest regrowth
  - design urban areas to minimize urban heat island effect and decrease air conditioning demand
- Low-CH_4 agriculture
  - expand adoption of vegetarian or low-meat diet
  - improve manure management and methane capture
  - reduce methane emissions from rice-growing
- Carbon sequestration
  - Improve ability to capture CO_2 from combustion, secondary fuel production (such as hydrogen reforming of fossil fuels), and cement production
  - Develop deep geologic storage for captured carbon
- Better substitutes for ozone-depleting substances
  - Further develop and deploy low- and zero- greenhouse-potential substitutes for CFCs and other ozone-depleting substances used in refrigeration, industrial cleaning, packaging, fire prevention

Prefigurative Technological Opportunities

In the Table below, the technical solutions listed above are cross-referenced with converging bio, nano, and information technologies that are at varying stages of research and development. Here, we will expand on two of the possible applications of these emerging technologies to technical solutions, noting that other limiting conditions need to be overcome for climatically benign outcomes to be realized.

The first are applications of nanotechnology to renewable energy supplies. Shell, for example, incorporates such new technologies its energy scenarios for 2050, written in 2001. Shell foresees in *Dynamics as Usual* that the share of renewable energy will rise quickly until 2020, then stagnate, and then accelerate again after 2030. They suggest that renewables could account for 22 percent of energy supply (leaving aside biofuels) in 2050. In their *The Spirit of the Coming Age*, Shell suggests that the hydrogen fuel cycle based on carbon nanotechnology could be the basis of a new renewably powered energy economy by 2050.

Of course, many technological obstacles remain to be overcome. Thin film solar cells based on nanotechnology, for example, convert energy less efficiently than crystalline silicon cells. According to BP Solar, thin film PV manufacture is still hamstrung on the fact that large-scale industrial production of thin film cells is still not feasible. However, Grätzel organic dye solar cells are now moving into production and may demonstrate that organic solar cells are commercially feasible in the future (see www.mansolar.nl).

Other nanotechnology innovations may be applicable to the climate change problem. RAND, for example, has suggested that cheap catalytic air "nanoscrubbing" might be released into the atmosphere to capture airborne carbon and thereby reduce climate change.

Based on rapidly advancing computational capacity and access to computers, the “extended Internet” that combines wireless connectivity, devolved communications, global positioning satellites, and sensors may achieve more efficient coordination and control of manipulated mass and energy flows—whether the system be a national electric grid, the global “just-in-time” production-consumption cycle of an agile company, or the delivery of cement, as already occurs with the Mexican company, CEMEX.

CEMEX, for example, uses GPS to track where all its delivery trucks are located, and based on real-time monitoring of traffic conditions, re-routes trucks to deliver cement in Mexico City. Using extended net technology, CEMEX has cut delivery time to twenty minutes, allowing it to reduce its truck fleet by 35 percent, saving it $100 million annual in costs, and avoiding substantial greenhouse gas emissions from fuel use.

Climate Change Applications of Converging Technological Innovation

	Biotech	Nanotech	Infotech
Energy Efficiency			
Positive Impact		nanomotors; reduced mass; sensors	precision automated control
Negative Impact			
System Decarbonization			
Positive Impact	biomaterials vs petroleum based	dematerialization; reduced mass; sensors	planning tools; precision control of production processes
Negative Impact			IT infrastructure electricity demand
Electricity Decarbonization			
Positive Impact	hydrogen production	versatile multi-junction PV; microturbines; fuel cells	precision control of grid & end-use devices; real time pricing
Negative Impact			
Transportation Decarbonization			
Positive Impact	biofuels; hydrogen production	reduced mass; fuel cells; motors;	
Negative Impact			
Low N2O Agriculture			
Positive Impact	lower fertilizer demand, increase uptake	sense soil conditions	precision control of fertilizer application
Negative Impact	increase fertilizer demand		
Land Use			
Positive Impact	improved low-water crops, cover crops	environmental sensors; reduced gross materials requirements	global high resolution GIS; climate-land use models
Negative Impact	increased land coversion for agriculture in marginal areas		
Low CH4 Agriculture			
Positive Impact	low CH4 crop varieties; reduce CH4 from ruminants	storage of methane hydrides; sense soil conditions	precision control of water
Negative Impact	high CH4 varieties		
Carbon Sequestration			
Positive Impact	GMOs with enhanced carbon storage; GMOs in deserts	carbon nanostorage; creation of nanofibers from stored carbon	precision monitoring and control of carbon reservoirs
Negative Impact	GMO "outbreak" in altered conditions		
Ozone Depleting Substitutes			
Positive Impact		create specialized, short-lived materials for ODS functions	
Negative Impact	GMOs require more ODS (e.g. methyl bromide)	use of ODS in nanotech industry	

Policy Solutions

- must win the enduring trust and cooperation of most countries in the world in order to succeed
- must produce a scientifically rigorous, economically achievable plan to decarbonize the global infrastructure over the next century
- must ensure transformation begins before existing technologies, development patterns, and consumption trends become locked in
- must encourage, not inhibit, the economic development of the global South, while encouraging it along a sustainable low-GHG path
- must require the global North to drastically reduce its own emissions, and not create mechanisms that can be used opportunistically to shift the primary burden to the South
- must mobilize several trillion dollars to accomplish the technical and infrastructure transformation required of both North and South, including providing transition support for populations that stand to be adversely affected (such as coal miners)
- must create efficient, transparent, and fair financial mechanisms that ensure that money actually goes to clean development and is not captured by narrow interests
- must establish governance institutions with global responsibility and authority to create and enforce policy and eliminate cheating and free riding, and also the flexibility to respond to new developments and new scientific understanding
- must provide funding and leadership for scientific, technical, and policy R&D
- must create climate protection solutions that do not contribute to adverse trends in non-climate aspects of global change

KYOTO

Kyoto Protocol

- Created in 1997 under auspices of U.N. Framework Convention on Climate Change
- Requires the ratification (by their own governments) of a sufficient number of countries to constitute 55% of 1990 emissions in order to go into effect
- Sets 1990 as the base year against which future emissions will be compared
- Creates a governance framework (still weak and without enforcement power) to allow international coordination and cooperation
- Is not a comprehensive solution, but establishes a key set of first-phase principles and goals on which future solutions can be based:
    - Industrialized countries must take the lead by reducing GHG emissions to 5% below 1990 levels by 2010, while developing countries are exempt
    - The emission of carbon is a right that must be paid for at prices established by an open international process
    - Agreements are subject to alteration based on authoritative new scientific evidence (a principle established in the 1987 Montreal Protocol on ozone-depleting substances) as certified by the IPCC

Kyoto State of Play

- Kyoto ratification has not yet occurred. It will occur if Russia or certain combinations of other fence-sitting countries ratify, even if the U.S. does not
- U.S. officially refuses to ratify the Kyoto Protocol (per the 1998 Byrd-Hagel Act passed 95-0 in the U.S. Senate) unless developing countries also required to reduce emissions.
- Kyoto was saved from a U.S. attempt to scuttle it at a Conference of the Parties in Berlin in 2001 by a coalition between the European Union and developing countries, united on the principle of the responsibility of industrialized countries to take the lead in reducing emissions.
- Russia has a large potential allotment of unused potential emission credits because emissions have fallen dramatically since the collapse of the Soviet Union and subsequent industrial decline; many believe that Russia has delayed its ratification in order to drive up the potential price of carbon
- Negotiation and controversy continue over the concrete goals and methods of climate protection, with an eye to the 2nd commitment period starting in 2012, during which developing countries are expected to begin making reductions

Points of Contention

- Equity. How should the historic overuse of the atmosphere by industrialized countries be reflected in responsibility for climate protection?
- "Flexibility mechanisms" that allow (industrialized) countries to receive emission reduction credits for financing projects that reduce emissions in other (developing) countries. Are these an efficient market device, or a way for the rich to shirk their responsibility?
- Emissions "baselines" and methodologies for emissions accounting, including sinks as well as sources

- Emissions credits for forest regrowth
- Tradeable emissions permits
- Financing mechanisms, including carbon taxes, Tobin taxes, development funds, and emission rights
- Strategy regarding U.S. participation: Appease U.S. conservatives with non-threatening requirements in order to entice U.S. ratification, or ignore the U.S. for now and focus on an agreement among the rest of the world that gains the willing participation of developing countries?

Per Capita Equity

Many climate equity supporters – including progressive NGOs and Southern governments – support a per capita emissions system. In this system, a formerly free access resource – the atmosphere – is transformed into a regulated global commons to which all people have an equal per capita right. The North must compensate the South for its use of the commons on this basis, making Northern funding of clean development in the South not aid, but an economic obligation. The basic mechanisms:

- Establish strict emissions targets (presumably based on 450 ppm pathway)
- Allocate emissions allowances on an equal per capita basis
- Further adjust allowances based on national circumstances, such as the present condition of the infrastructure
- Developing countries would sell underutilized allowances to industrialized countries to acquire the revenues needed for clean development
- Per capita allowances would be constantly adjusted downward to reflect the declining emissions requirements of the 450 ppm pathway

Strategy

- Turn South. Europe and Northern NGOs should engage with the South to come up with a long-term per capita climate accord that gains the willing (not grudging) participation of developing countries
- Keep the door open for the U.S. to enter Kyoto at a later time, but do not pander to U.S. conservatives by avoiding discussions of equity
- Work for the transformation of the U.S. political environment such that it is possible to achieve basic acceptance of the need to for climate protection, and of North-South equity as the means to achieve it

GLOBAL TRENDS

Intersections

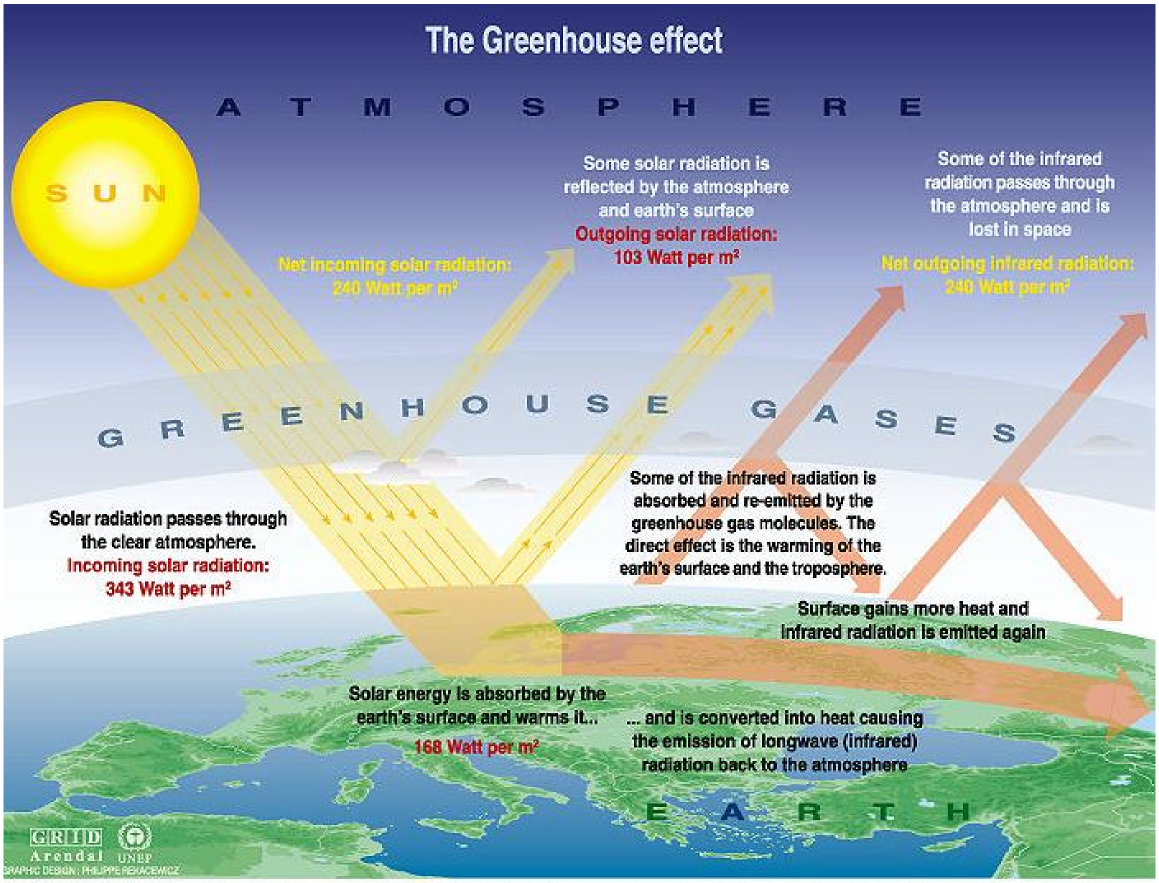
Climate change and climate protection intersect with many other global trends – social-demographic, political-economic, and technological. Unfortunately, many of the intersections reinforce negative trends -- either climate change exacerbates other problems of global change, or other global trends work against climate protection.

- Governance – dominant trends in global and U.S. politics do not favor effective global governance for climate protection
- Liberalization – liberalization, deregulation, and privatization trends in global markets and financial institutions are largely unfavorable to climate protection
- Energy – the dominant trends in the global energy sector – growth in fossil fuel consumption, privatization of electricity production, expansion of private vehicle use – are distinct threats to climate.
- Water – growing water scarcity is an alarming trend in many populous regions of the world already, affecting the poorest populations the most – reduced precipitation in water-stressed regions could have major impacts on public health and food supply, and on desertification of lands currently at the margin; on the other hand, climate mitigation effects to ensure adequate water supplies, such as building new dams and reservoirs, will have further negative consequences for riparian and aquatic ecology and biodiversity; use of conventional fuels for desalinization of sea water will increase GHG emissions
- Security – the impact of Iraq war on international diplomacy, the increased focus by the U.S. on unilateral military solutions, increased resources dedicated to defense instead of other priorities – threaten the funding and cooperation required for climate protection
- Migration – if climate change adversely impacts agriculture, hunger could drive mass migrations; existing migratory populations in disaster-prone areas, with inadequate food and shelter and little safety net, are extremely vulnerable to climate change-induced natural disasters
- Land use – current patterns of settlement and development, and modes of agriculture and forestry, make food production, habitats, ecosystem services, and biodiversity more vulnerable to climate disruptions; while deforestation contributes significantly to global warming
- New technologies – cut both ways. Biotechnology could be used to provide new fuels such as biodiesel and hydrogen, or in future carbon sequestration schemes. Nanotechnology could be used to make highly efficient motors and generators and reduce energy demand, as well as nanosensors for climate science. Information technology is essential to modeling climate and to many aspects of climate protection. At the same time, new technologies can lead to accelerating consumption and consequent GHG emissions (e.g. the growth of electrical demand associated with internet growth/server farms in the late 1990s). They can also promote a techno-optimism that makes the public and policy-makers reluctant to invest in precautionary measures.

Timelines

- 1700 Pre-industrial CO_2 at 275 ppm
- 1896 Arhennius publishes first paper on greenhouse effect
- 1965 First report on CO_2 emissions to U.S. president
- 1988 U.N. creates IPCC
- 1990 Baseline year for emissions set by Kyoto Protocol
- 1992 United Nations Framework Convention on Climate Change
- 1997 Kyoto Protocol signed
- 1998 Byrd-Hagel Amendment, U.S. rejects Kyoto
- 2003 CO_2 at 370 ppm
- 2005 Negotiations begin on Kyoto 2^{nd} commitment period
- 2010 Industrialized countries to reduce emissions by 5% below 1990 level
- 2012 Kyoto 2^{nd} commitment period begins
- 2020 Southern emissions alone exceed 450 ppm pathway?
- 2100 Worst case business as usual -- 600 ppm, 10° F warming possible

GRAPHICS



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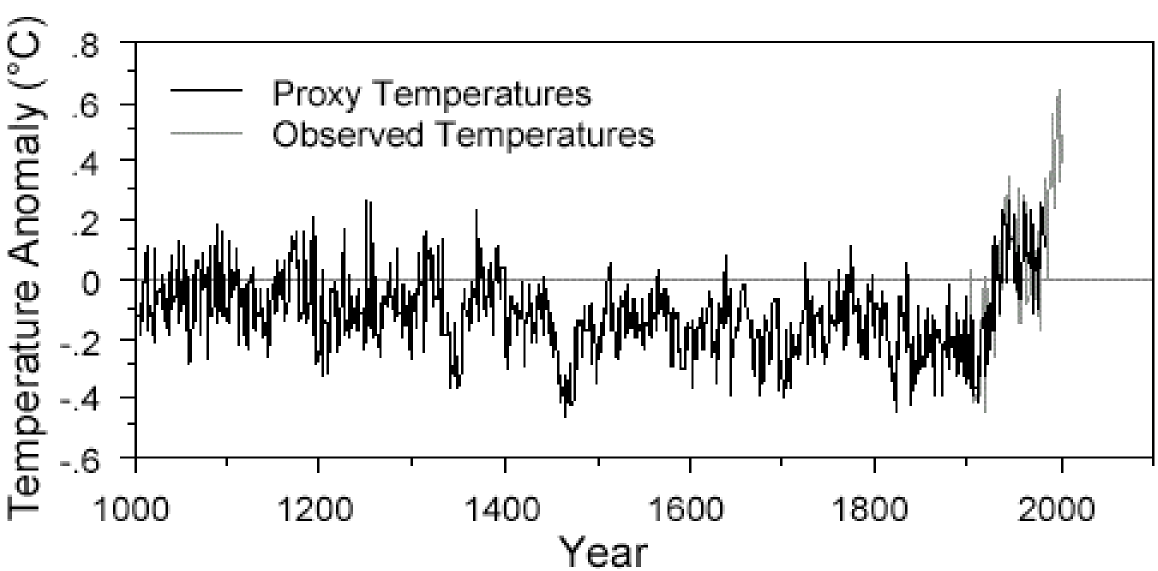

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WEB SITES

Governmental Sites

European Commission Climate Change Site
http://europa.eu.int/comm/environment/climat/home_en.htm

IGBP (International Geosphere-Biosphere Program)
http://www.igbp.kva.se/cgi-bin/php/frameset.php

IPCC (Intergovernmental Panel on Climate Change)
http://www.ipcc.ch/

Kyoto Protocol (Text)
http://unfccc.int/resource/docs/convkp/kpeng.html

Kyoto Ratification Status
http://unfccc.int/resource/kpstats.pdf

NCAR (National Center for Atmospheric Research, U.S.)
http://www.ncar.ucar.edu/ncar/

UNFCCC (United Nations Framework Convention on Climate Change)
http://unfccc.int/

U.S. Department of Energy Climate Change Site
http://www.doe.gov/engine/content.do?BT_CODE=EN_SS3

U.S. Environmental Protection Agency Global Warming Site
http://yosemite.epa.gov/oar/globalwarming.nsf/content/index.html

NGO Sites

Center for Science and the Environment (India)
http://www.cseindia.org

Climate Action Network International
http://www.climatenetwork.org/

Ecoequity (US)
http://ecoequity.org/

Environmental Justice and Climate Initiative (US)
http://www.ejcc.org/

Java Climate Model
http://www.chooseclimate.org/

Natural Resources Defense Council
http://www.nrdc.org/globalWarming/brief.asp

Pacific Institute (US)
http://www.pacinst.org/

Redefining Progress (US)
http://www.rprogress.org/programs/climatechange/

The Sky Trust (US)
http://www.usskytrust.org/

Third World Network (Malaysia)
http://www.twnside.org.sg/climate.htm

Tellus Institute (U.S.)
http://www.tellus.org/

U.S. Climate Action Network
http://www.climatenetwork.org/uscan.htm

World Council of Churches Climate Change Site
http://www.united-church.ca/jpc/climate/home.shtm

World Resources Institute (US)
http://www.wri.org/

Industry Sites

EPRI (Electric Power Research Institute) Climate Research
http://www.epri.com/globalclimate/

ExxonMobil
http://www2.exxonmobil.com/Corporate/Notebook/Climate/Corp_N_ClimateDetails.asp

Global Climate Coalition
http://www.globalclimate.org/

OPEC (Organization of Petroleum Exporting Countries) Climate Position
http://www.opec.org/

Royal Dutch / Shell
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