Climate-Change Risks & Opportunities:
Recent Developments, Available Strategies, New Technologies

JOHN P. HOLDREN

Teresa & John Heinz Professor and Director
Program on Science, Technology, and Public Policy

John F. Kennedy School of Government

HARVARD UNIVERSITY

Co-Chair

NATIONAL COMMISSION ON ENERGY POLOICY

2005 Institutional Investor Summit on Climate Risk

United Nations • New York • 21 April 2005

Introduction: the problem in a nutshell

- The problem of disruption of global climate by human-produced greenhouse gases (GHG) in the atmosphere is coming to be understood as the most dangerous and intractable of all the environmental problems caused by human activity.
- It is the most dangerous because climate is the "envelope" within which all other environmental conditions and processes operate.

  Distortions of this envelope of the magnitude that are in prospect are likely to so badly disrupt these conditions and processes as to impact adversely every dimension of human well-being that is tied to environment.

The problem in a nutshell (continued)

- The problem is highly intractable because the dominant cause of the disruption – emission of carbon dioxide from fossil-fuel combustion – arises from the process that currently supplies nearly 80 percent of civilization's energy.
  - The energy technologies involved represent a huge capital investment (~$12 trillion worldwide), and they turn over slowly (~30-40 years).
  - Thus there is no "quick fix". If the energy system is to look much different in 2050 than today, a major push to change it must start now.
  - So far, this isn't happening.

The problem in a nutshell (concluded)

- Most current policies & practices of governments, firms, consumers, & investors are
  - actively contributing to driving up the risks we face from human-induced climate change
  - or, if aimed at abating those risks, are falling far short of what would be needed to reduce the risks significantly.
- Publics, investors, & policymakers alike will be looking for damage-limiting options as the magnitude of climate disruption becomes increasingly apparent.
  - Strategies & technologies for coping at manageable cost exist; but insight, initiative, & resolve will be needed to get them deployed in time.
  - The countries & companies that develop & exploit the needed strategies & technologies first will benefit, and the laggards will suffer.

Points to be covered in elaboration

- What climate change means & what it puts at risk
- Recent developments in climate-change science
  - evidence of causation, magnitude, & peril becoming overwhelming
  - “dangerous anthropogenic interference” can’t be avoided; avoiding unmanageable damage will be harder than previously thought.
- Locating the leverage for risk reduction
  - CO_2 as the principal culprit
  - the option space for addressing CO_2
  - strategies & technologies for fashioning a response
  - what should be done (including recommendations of the National Commission on Energy Policy

What climate change means

Climate consists of averages and extremes of

- hot & cold
- wet & dry
- snowpack & snowmelt
- winds & storm tracks
- ocean currents & upwellings

…how much, where, and when

Global-average surface temperature (T_{avg}) is an index of the "state" of the climate – the set of patterns of all the above. Differences of a few degrees in T_{avg} correspond to <u>large</u> differences in climatic state.

An ice age and an interglacial (as now) differ by only ~5°C in T_{avg}.

What climate change puts at risk

Climate governs (so climate change affects)

- productivity of farms, forests, & fisheries
- geography of disease
- livability of cities in summer
- damages from storms, floods, wildfires
- property losses from sea-level rise
- expenditures on engineered environments
- distribution & abundance of species

The strengthening signal of disruption

- Historic temperature highs continue.
  - 2004 was the 4th hottest year in the 140+ years of thermometer records; 2003 was 3rd hottest; 2002 2nd hottest; 2001 5th hottest; 1998 the hottest.
  - Recent studies of glaciers, boreholes, corals all indicate we're in the warmest period in 1000+ years.
- Multi-decade ocean temperature measurements now confirm ocean is storing excess heat trapped by anthropogenic greenhouse gases.
  - Newly measured heat storage in ocean accounts perfectly for calculated energy imbalance from known green-house-gas buildup.
  - Ocean heat storage means a further 0.6°C increase in T_{avg} is in store from <u>today's</u> GHG concentrations.

The strengthening signal (continued)

- Newest climate models match observations with much-improved fidelity (in both temporal and spatial patterns of change) when “driven” by known anthropogenic & natural forcings.

  The excellent “fit” between observations & predicted consequences of the measured increases in green-house gases is a “fingerprint” -- proving beyond reasonable doubt that anthropogenic GHG are the principal culprit behind observed climate change.

- Parallel efforts in modeling, statistical analysis of observations, and study of past climates have led to strengthened consensus that “sensitivity” to a CO_2 doubling is ~3°C.

  The last refuge of “contrarians” (the idea that human disruption, though real, will be small) is vanishing.

Growing evidence of adverse impacts

Since the IPCC Third Assessment Report (2001), evidence has grown concerning the links between GHG-induced climate disruption and…

- deadly heat-waves
- increased intensity of major storms
- increased frequency & intensity of droughts
- increased frequency of great floods
- impacts on species ranges & behavior
- increased frequency & extent of wildfires
- greater adverse than beneficial impacts on agricultural productivity

Adverse impacts (continued)

- deadly heat-waves

  "[P]resent-day heat waves over Europe and North America coincide with a specific atmospheric circulation pattern that is intensified by ongoing increases in greenhouse gases, indicating that it will produce more severe heat waves in those regions in the future." (*Science*, 13 August 2004, p 994)

- increased intensity of major storms

  "Current hurricane potential intensity theories, applied to the climate-model environments, yield an average increase of intensity of 8% to 16% for the high-CO2 environments. Convective available potential energy is 21% higher on the average in the high-CO2 environments." (*Journal of Climate*, 15 September 2004).

Adverse impacts (continued)

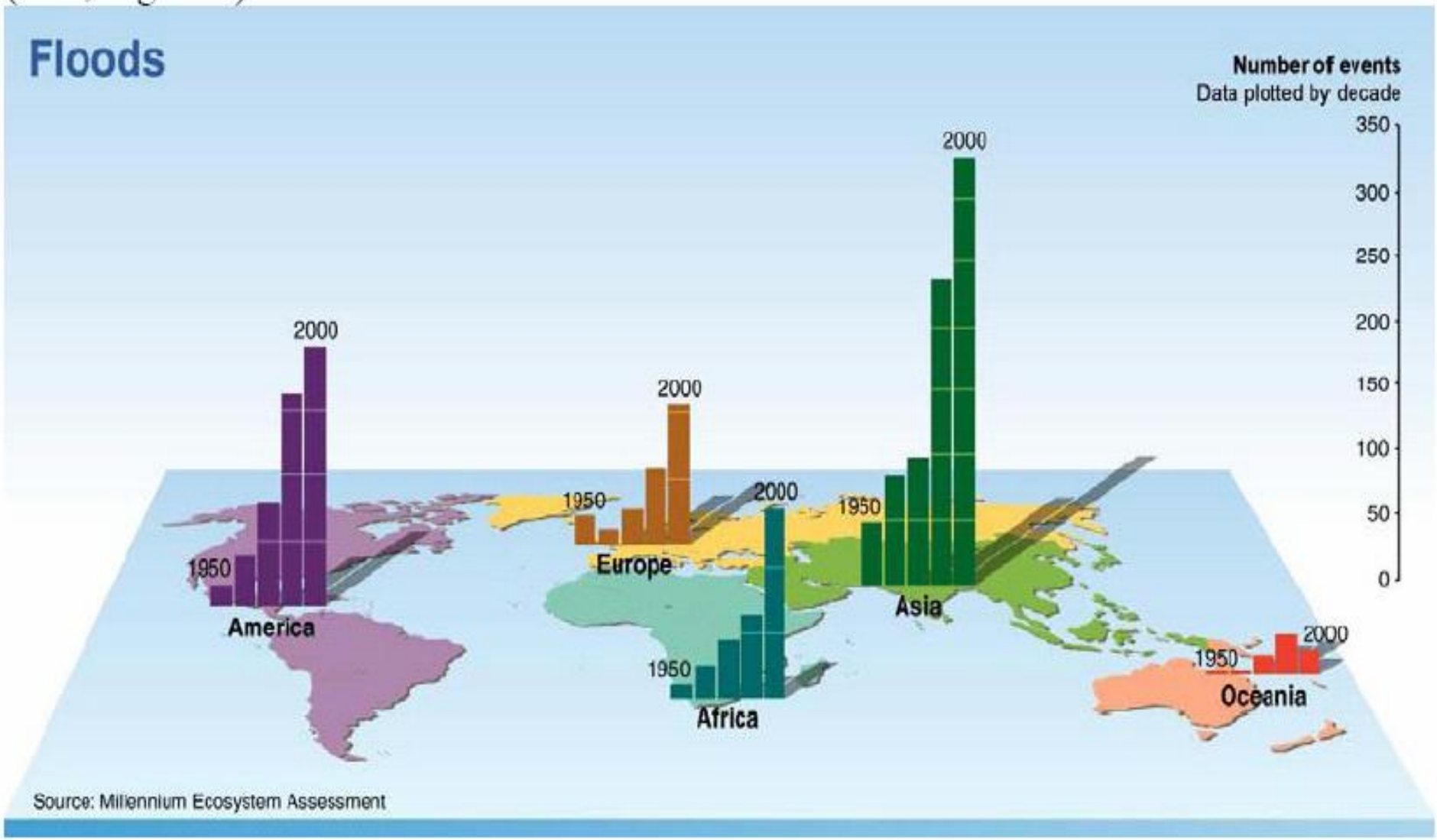
- increased frequency & intensity of droughts

  The amount of land suffering from severe drought has more than doubled in the last 30 years. Almost half of the increase is due to rising temperatures rather than decreases in rainfall or snowfall. (NCAR researchers in the *Journal of Hydrometeorology*, December 2004)

- increased frequency of great floods

  "[T]he frequency of great floods increased substantially during the 20th century. The recent emergence of a statistically significant trend in the risk of great floods is consistent with results from the climate model, and the model suggests that the trend will continue." (*Nature*, 31 Jan 2002, p 514)

Appendix Figure A.7. Number of Flood Events by Continent and Decade Since 1950
(C16, Fig 16.6)



Adverse impacts (continued)

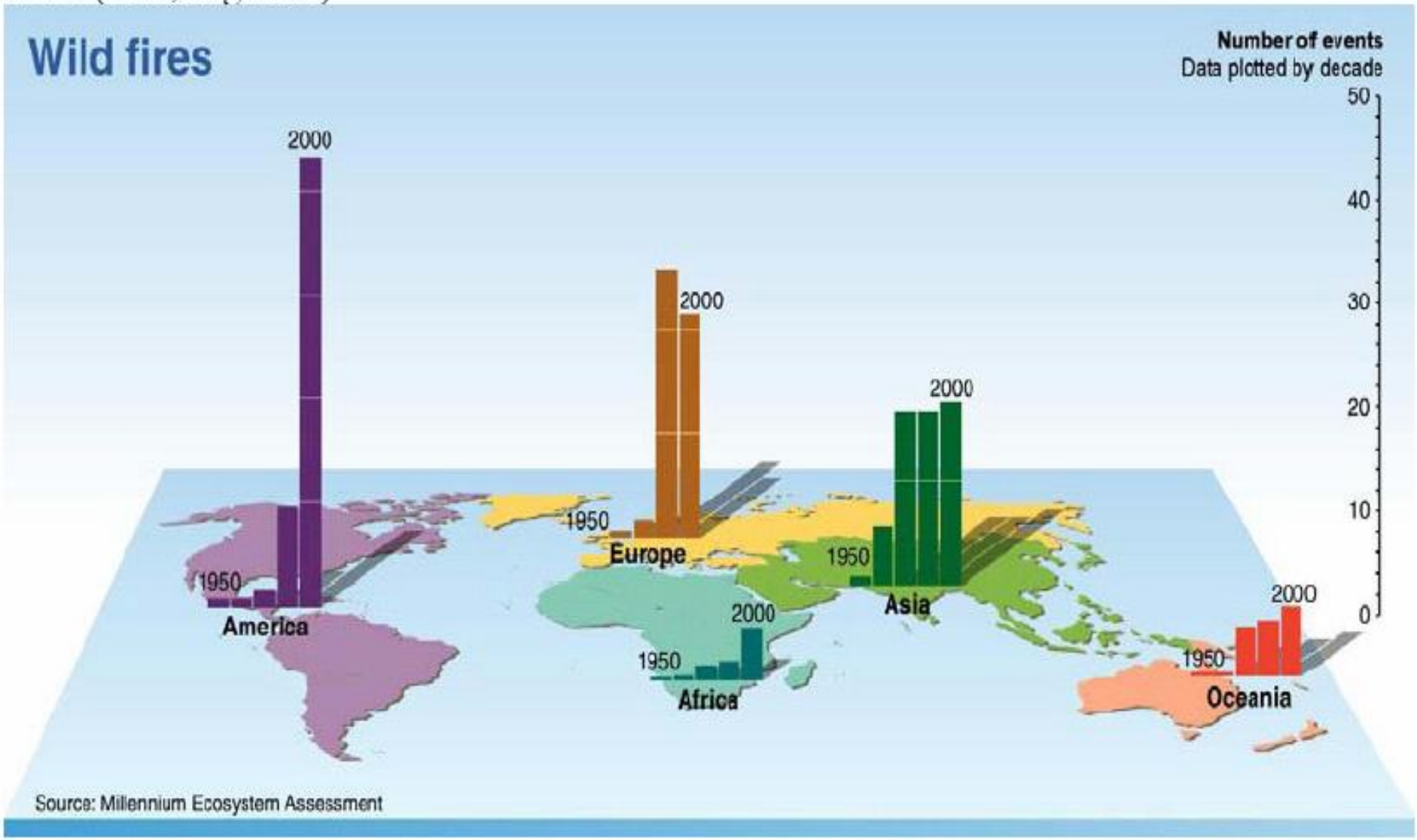
- impacts on species ranges & behavior

  "[A] clear pattern emerges of temporal and spatial sign switches in biotic trends uniquely predicted as responses to climate change. With 279 species (84% of those studied) showing predicted sign switches, this diagnostic indicator increases confidence in a climate-change fingerprint." (*Nature*, 2 Jan 2003, p 41)

- increased frequency & extent of wildfires

  Wildfires have been increasing on all continents – particularly sharply in North America – and this trend is predicted to increase under even moderate further increases in global T_{avg}. (*Millennium Ecosystem Assessment*, 2005, and *Conservation Biology*, August 2004).

Appendix Figure A.8. Number of Major Wild Fires by Continent and Decade Since 1950 (C16, Fig 16.9)



Adverse impacts (continued)

- greater adverse than beneficial impacts on agricultural productivity
  - IPCC 2001 report modeled changes in T, soil moisture, and the CO_2-fertilization effect; concluded that some regions would do better and some worse for moderate increases in T_{avg}, transitioning to net loss globally under larger increases.
  - IPCC report did <u>not</u> model the increase in pest & pathogen problems expected in a warmer, wetter world, which would make the picture more pessimistic.
  - April 2005 UK Royal Society workshop on "Food Crops in a Changing Climate" reported new work showing CO_2-fertilization effect likely to be smaller than previously estimated and effects of rising temperatures likely to be worse, meaning net negative impacts on global crops from climate change even in the near term.

New regional studies increase cause for concern

Studies modeling regional consequences show large impacts of modest increases in global T_{avg}.

- National Assessment of Climate Change Impacts on the US indicates drying out in Northwest, reduced summer soil moisture in breadbasket, large increases in summer heat index in Southeast.
- UK Meteorological Office studies & others show transformation of much of Amazon rainforest into grassland.
- Chinese and Indian studies show disruptive monsoon changes, as well as loss of mountain glaciers that feed the great rivers in those countries, portending large increases in variability (flood & drought).

New regional studies (continued)

- 8-Nation Arctic Climate Impact Assessment (ACIA, 2004)
  - "Arctic average temperature has risen at almost twice the rate as the rest of the world in the past few decades."
  - "In Alaska and western Canada, winter temperatures have increased as much 3-4°C in the past 50 years. Over the next 100 years, under a moderate emissions scenario, annual average temperatures are projected to rise 3-5°C over land and up to 7°C over the oceans.
  - Over the past 30 years, the annual average sea-ice extent has decreased by about 8%, or nearly 1 million square kilometers… Sea-ice extent in summer has declined more dramatically than the annual average, with a loss of 15-20% of late-summer ice coverage. Additional declines of 10-50% in annual average sea-ice extent are projected by 2100."
  - "The reduction in sea ice is very likely to have devastating consequences for polar bears, ice-dependent seals, and local people for whom these animals are a primary food source."

NASA photograph

Shrinking Polar Ice

Extent of Arctic summer ice in 1979 (top satellite image) and in 2003 (lower satellite image).

Greenland & Antarctic ice sheets at risk

- ACIA documented much faster melting of Greenland Sheet (GIS) than previously expected.

  "Maximum surface-melt area on the ice sheet increased on average by 16% from 1979 to 2002… The total area of surface melt on the GIS broke all records in 2002, with extreme melting reaching up to a record 2000 meters in elevation."

- Other studies in the last 3 years show increasing discharges to the sea from Antarctic ice and signs of instability in the West Antarctic Ice Sheet (WAIS).

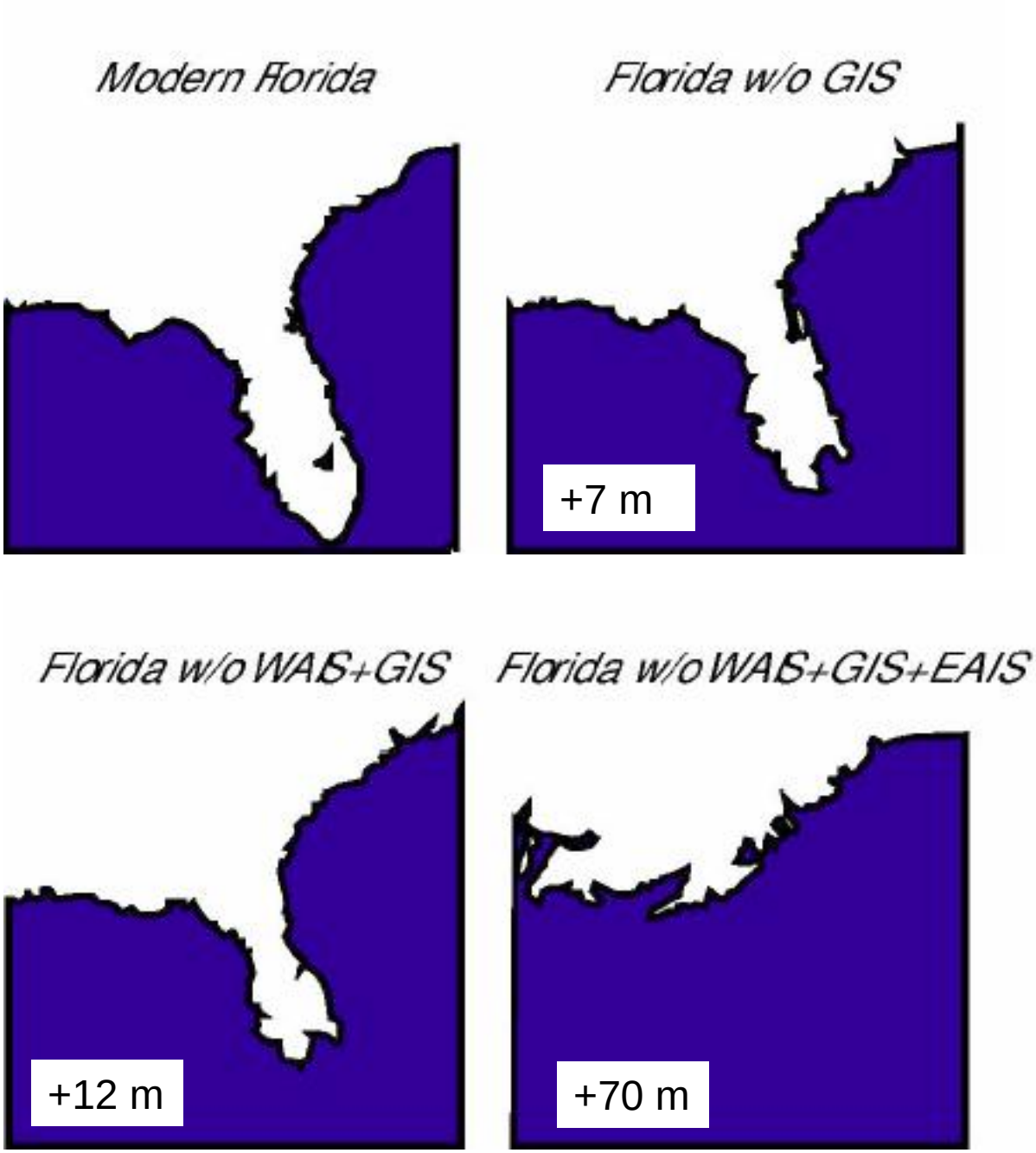
  At the time of the 2001 IPCC report, rapid melting in Greenland and accelerating ice loss from WAIS were thought to be improbable.

Extent of ice melt in Greenland, 1992 and 2002

Arctic Climate Impact Assessment 2004

Greenland & Antarctic (continued)

- IPCC 2001 “central estimate” of ~0.5 meter further sea-level rise by 2100 now looks like an underestimate…maybe a big underestimate.
- All the ice on Greenland ≈ 7 m increase in sea level; ice in WAIS ≈ 5 m.
- Rates at which this ice could become sea water are still highly uncertain, but 12 m in 350-500 years is possible (~3 m per century); some think even faster is possible (Hansen 2005).
- East Antarctic Ice Sheet could add another 70 m, presumably only over many centuries…but recent surprises indicate science uncertain here.



GIS = Greenland Ice Sheet

WAIS = West Antarctic Ice Sheet

EAIS = East Antarctic Ice Sheet

From a presentation by Richard B. Alley, U of Pennsylvania

Locating the leverage for reducing climate-change risks

Role of CO_2 emissions from the energy sector

- The increasing concentrations of GHG and black soot in the atmosphere are the dominant drivers of current global climate change.
- Among these, CO_2 is already the most important, and its importance relative to the other GHG and soot is expected to grow significantly during the 21st century.

  CO_2 accounted for about half of the total positive anthropogenic forcing in 2000. Under the IS92a scenario of the IPCC, it would account for about 75% in 2100.

- Fossil-fuel combustion is the dominant source of anthropogenic CO_2 emissions.

  Central estimates of anthropogenic CO_2 emissions in 2000 are 6.4 GtC from fossil fuels, 1.6 GtC from deforestation, 0.2 GtC from cement production. Under IS92a, fossil & cement contributions increase ~3-fold by 2100, deforestation shrinks.

Role of CO2 emissions from energy (continued)

- Reducing soot & non-CO_2 GHG will be helpful, but CO_2 is the 800-pound gorilla in this issue.
- Reducing CO_2 emissions will be difficult because their principal source – fossil-fuel combustion – provides almost 80% of civilization's energy and the technologies used for this today do not lend themselves to capturing the CO_2.

Can other approaches avoid the need to reduce CO_2 emissions?

- Remove CO_2 from the atmosphere?
  - Growing more trees and plankton could, at most, remove 20% of the increment of atmospheric CO_2 to 2100 expected under BAU.
  - "Scrubbing" CO_2 out of the atmosphere technologically is much costlier than avoiding emissions.
- "Engineer" the climate to compensate for the extra CO_2?
  - For example, inject shiny particles into orbit to reflect sunlight, cooling the Earth in compensation for CO_2's warming.
  - Needs more study; re-engineering the climatic machinery with insufficient knowledge could make things worse.
- Adapt to whatever climate changes come?
  - E.g., build more dams & dikes, modify agricultural practices, air condition more of our habitat.
  - We're doing this already and must do <u>much</u> more of it. But adaptation gets costlier & less effective as climate changes get bigger.

What are the options for reducing CO_2 emissions?

The emissions arise from a 4-fold product…

$$C = P \times GDP / P \times E / GDP \times C / E$$

where C = carbon content of emitted CO_2 (kilograms), and the four contributing factors are

P = population, persons

GDP / P = economic activity per person, $/pers

E / GDP = energy intensity of economic activity, GJ/$

C / E = carbon intensity of energy supply, kg/GJ

For example, in the year 2000, the world figures were…

6.1×10^9 pers x $7400/pers x 0.01 GJ/$ x 14 kgC/GJ

$= 6.4 \times 10^{12}$ kgC = 6.4 billion tonnes C

Where's the leverage for reductions in these?

POPULATION

Lower is better for lots of reasons: 8 billion people in 2100 is preferable by far to 12 billion. Reduced growth can be achieved by measures that are attractive in their own right (e.g., education, opportunity, health care, reproductive rights for women).

GDP PER PERSON

This is not a lever that anybody wants to pull on purpose, because higher is generally accepted to be better. But we are not getting rich as fast as we think if GDP growth comes at the expense of the environmental underpinnings of well-being. Internalizing environmental costs (including those of climate change) may slow GDP growth a bit.

Leverage against emissions (continued)

ENERGY INTENSITY OF GDP

Getting more GDP out of less energy – i.e. increasing energy efficiency – is a trend that has been underway for a long time. It could be accelerated. This opportunity offers the largest, cheapest, fastest leverage on carbon emissions.

CARBON INTENSITY OF ENERGY SUPPY

This has been falling, but more slowly than energy intensity of GDP. Reducing it entails changing the mix of fossil & non-fossil energy sources (most importantly more renewables and/or nuclear) and the characteristics of fossil-fuel technologies (most importantly with carbon capture & sequestration).

Approaches for reducing energy intensity and carbon intensity

TECHNICAL POSSIBILITIES

- switching from coal & oil to natural gas
- capturing & sequestering carbon when fossil fuels are transformed or used
- increased deployment of renewable & nuclear energy options
- increased efficiency of conversion of fossil fuels to end-use energy forms
- increased efficiency of energy end-use in buildings, transportation, & industry
- transition to a lower-energy-intensity mix of economic activities

Policy options for reducing E- & C-intensity

Measures to affect choices among available technologies

- analysis of and education about the options
- correction of perverse incentives
- lowering bureaucratic barriers
- financing for targeted options
- performance & portfolio standards
- subsidies for targeted options
- emission cap & trade programs
- taxes on carbon or energy

Measures to improve mix of available technologies

- improving capabilities for RD&D
- encouraging RD&D with tax policy & other policies
- funding the conduct of RD&D
- promoting niche & pre-commercial deployment
- international transfer of resulting technologies

What's a suitable target for CO_2 reductions?

- The climate-policy aim negotiated in the process of formulating the UN Framework Convention on Climate Change (signed by President George H. W. Bush in 1992 and ratified by consent of the U.S. Senate in the same year) was…

  …stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner.

- There was no formal consensus at that time about what level is "dangerous" in this sense.

Suitable CO_2 target? (continued)

- While there's still no formal consensus, it's increasingly clear that the current level of anthropogenic interference is dangerous.

  Significant impacts in terms of floods, droughts, wildfires, species, and melting ice are already evident at ~0.8°C above pre-industrial T_{avg}, and current GHG concentrations commit us to 0.5-0.6°C more.

- It is now all too plausible that…
  - ΔT_{avg} ~ 1.5°C will mean the end of coral reefs & polar bears
  - ΔT_{avg} ~ 2°C will mean catastrophic melting of Greenland & Antarctic ice, with commitment to multi-meter rises in sea level
  - ΔT_{avg} ~ 2.5°C will reduce agricultural productivity worldwide
- This means stopping at a doubling of pre-industrial CO_2 (550 ppmv, corresponding to ~3°C and once thought a reasonable target by many) is not good enough.

Even a 550 ppmv CO_2 target is not easy to attain

- In 2000, world energy supply was 350 exajoules/yr from fossil fuels and 100 exajoules of energy per year from carbon-free sources (biomass, nuclear, hydro, wind, solar).
- To stay below 550 ppmv CO_2 with "business as usual" growth of population and prosperity…
  - We'd need 600 EJ/yr of C-free energy by 2050 and 1500 EJ/yr by 2100, if energy efficiency continued to improve at the long-term historical rate of 1%/yr.
  - In addition to nuclear & renewables, fossil-fuel technologies that capture & sequester the CO_2 could contribute to the C-free energy.
  - Even if energy efficiency improved 1.5%/yr, over the whole world and the whole century, we'd need 350 EJ/yr of C-free energy in 2050 and 800 EJ/yr in 2100.
  - Only by doubling efficiency improvement rate to 2%/yr can we reduce C-free energy requirement in 2100 to ~ fossil-fuel use in 2000.

What should be done?

- In the USA, impose a carbon emissions cap, implemented through tradable permits & declining over time, to promote
  - low- and no-carbon choices from the current energy-technology menu; and
  - increased private-sector innovation to improve the menu over time.
- Increase US-government investments in energy-technology innovation: R&D, demonstration, & early deployment:
  - low- and no-carbon energy-supply technologies (a doubling or more)
  - advances that increase energy-end-use efficiency (a doubling or more)
  - international cooperation on E-technology innovation (tripling or more)
- Sharply increase US efforts (and US support for international efforts) on adaptation to climate-change.
- Return to the UNFCC process and help devise an adequate, affordable, and equitable global framework for reducing climate-change risks (because we are all in this together).

Recommendations of the National Commission on Energy Policy (NCEP, 2004)

- Initiate in 2010 a mandatory, economy-wide, tradable-permits system to limit greenhouse gas emissions.
  - Number of permits based on reducing GHG intensity of the economy (tons of carbon-equivalent emissions per million dollars of real GDP) at 2.4% per year.
  - Cap initial costs to the U.S. economy at $7 per metric ton of CO_2-equivalent ($26/tC) via a “safety valve” mechanism; safety valve to increase at 5%/yr in nominal terms.
- Link subsequent U.S. action with comparable efforts by other developed and developing nations via a program review in 2015 and every five years thereafter.

NCEP recommendations: dampening growth of demand for liquid fuels

- Significantly strengthen federal fuel economy standards for cars and light trucks while also reforming CAFE program.

  Range explored was 10-20 mpg increase by 2015; proposed Congress ask NHTSA to recommend figure.

- Provide manufacturer & consumer incentives to promote domestic production and increased use of highly efficient advanced diesel & hybrid-electric vehicles.

- Pursue efficiency opportunities in heavy-duty truck fleet and existing passenger vehicle fleet.

NCEP recommendations: accelerating energy-technology innovation

- Revise the tax code to increase private-sector incentives to invest in energy research, development, demonstration, & early deployment.
- Roughly double annual real federal expenditures for energy research, development, & demonstration (ERD&D) in next 5 years (reaching ~3.3 billion 2004$ per yr in 2010).
  - Within this effort, triple the funding for international cooperation on ERD&D, to $750 million per year.
- Complement the increased RD&D activity with a tripling of federal expenditures supporting accelerated deployment of the most promising technologies that successfully pass the demonstration phase (reaching ~$2 billion/year in 2010).

Key focuses of the technology-innovation effort

CLEANER COAL TECHNOLOGY

- Speed up the commercialization of integrated gasification-combined-cycle (IGCC) multipurpose coal plants with $400 million per year in federal early-deployment incentives over the next decade.
- These plants can…
  - sharply reduce emissions of criteria air pollutants,
  - produce liquid and gaseous fuels as well as electricity,
  - be more easily retrofitted than conventional coal-burning plants to capture carbon dioxide.
- Accelerate the development and commercial-scale demonstration of CO_2 capture and sequestration technologies with $300 million per year in federal support over the next decade.

Key focuses of the technology-innovation effort

RENEWABLE ENERGY TECHNOLOGIES

- Accelerate development & deployment of non-petroleum transportation fuel alternatives, especially cellulosic ethanol and diesel from biomass and wastes.
  - Increase RD&D from $25M to $150M per year over next 5 yr; provide $0.75 billion in early-deployment incentives 2008-2017.
- Increase RD&D on solar photovoltaic and solar thermal energy systems from $83M to $300M per year.
- Extend the renewable production tax credit through 2009 and expand eligibility to all non-carbon energy sources, including not only wind, solar, and hydropower but also next-generation nuclear power plants and fossil-fuel power plants with carbon capture & sequestration.

Key focuses of the technology-innovation effort

NUCLEAR ENERGY TECHNOLOGIES

- Provide $2 billion over ten years from federal RDD&D budgets for 1-2 “first mover” advanced nuclear power plants to demonstrate improved safety & economics.
- Move expeditiously to establish a project for centralized, interim, engineered storage of spent fuel at no fewer than two U.S. locations.
- In parallel, work to reduce links of nuclear energy to weapon proliferation by…
  - reiterating commitment to continue indefinitely the long-standing US moratoria on commercial reprocessing of spent nuclear fuel and construction of commercial breeder reactors;
  - pursuing more actively than before the long-standing US policy of discouraging the accumulation of separated plutonium in civil fuel cycles elsewhere;
  - actively working to prevent the deployment of uranium-enrichment and spent-fuel-reprocessing capacity in additional countries.

Key focuses of the technology-innovation effort

ENERGY END-USE EFFICIENCY TECHNOLOGIES

- Increase manufacturer & consumer incentives for more efficient vehicles from $80M/yr in 2004 (consumers only) to $300M/yr.
- Increase federal RD&D on efficiency improvements in buildings and appliances from $60M/yr in 2004 to $300 M/yr.
- Increase federal RD&D on improved efficiency in industrial processes from $93M/yr in 2004 to $200M/yr.

Why should money managers care?

As I said here at the predecessor of this meeting in November 2003

Embedded in the challenge of climate change are both…

- immense dangers for firms and investors who make bad choices (or no choices) about how to respond to the risks posed by climate change and are then held accountable in the marketplace, the boardroom, or the courts; and
- immense possibilities for firms and investors to turn challenge into opportunity, acting prudently and creatively to help society reduce the risks it faces from climate change…and making money doing so.

Pursuit of these possibilities will be our main focus for the rest of the day.

A few references…

Intergovernmental Panel on Climate Change, *Climate Change 2001: Synthesis Report – Summary for Policymakers*, IPCC, 2001 http://www.ipcc.ch/pub/un/syreng/spm.pdf

National Academy of Sciences, *Climate Change Science: An Analysis of Some Key Questions*, National Academy Press, 2001 http://books.nap.edu/html/climatechange/climatechange.pdf

U.S. Global Change Research Program, *Climate Change Impacts on the United States*, USGCRP, 2001 http://www.usgcrp.gov/usgcrp/Library/nationalassessment/

National Commission on Energy Policy, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges,* December 2004) http://www.energycommission.org

The Arctic Council, *Arctic Climate Impact Assessment*, Arctic Council, 2005. http://www.acia.uaf.edu