Meeting the Energy-Climate Challenge

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The nature of "the energy problem"

- Few people, other than energy specialists, are interested in gigajoules, kilowatt-hours, or quadrillions of Btus…
- They are interested in energy services
  - comfortable rooms, cold beer, cooked food, convenient transportation…
- And they are interested in
  - the state of the economy;
  - the state of the environment; and
  - their personal and national security;

thus interested in energy choices if those put any of these values at risk.

Economically…

- Affordable energy = crucial ingredient of prosperity, prerequisite for economic development.
- Energy costs typically ~7-10% of the cost of living; if they rise too much, we get inflation, recession, frustration of the economic aspirations of the poor.
- Investments in energy-supply systems ~$500 billion/yr worldwide; ~15% of gross domestic investment in developing countries.
- Energy accounts for ~7% of world trade and ~25% of the US trade deficit.

Environmentally…

- Energy supply = major contributor to many of most dangerous & difficult environmental problems – locally, regionally, globally.
- For example, energy supply is the source of
  - most indoor and outdoor air pollution
  - most radioactive waste
  - much of the hydrocarbon and trace-metal pollution of soil and ground water
  - essentially all of the oil added by humans to the seas
  - most of the anthropogenic emissions of greenhouse gases that are altering the global climate.

Security problems linked to energy…

- Energy systems as targets and weapons for terrorists: nuclear-energy facilities, hydro dams, oil refineries, natural gas storage…
- Potential for conflict over access to remaining supplies of inexpensive oil & gas
- Links between nuclear-energy technologies and nuclear-weapon capabilities
- Political tensions & upheavals resulting from energy-strategy inadequacies that create or perpetuate economic or environmental impoverishment.

Fashioning an energy policy is hard because there are so many things we need to get right simultaneously.

THE MULTIPLE AIMS OF ENERGY POLICY

ECONOMIC

- reliably meet fuel & electricity needs of a growing economy
- limit consumer costs of energy
- limit cost & vulnerability from imported oil
- help provide energy basis for economic growth elsewhere

ENVIRONMENTAL

- improve urban and regional air quality
- avoid nuclear-reactor accidents & waste-mgmt mishaps
- limit greenhouse-gas contribution to climate-change risks
- limit impacts of energy development on fragile ecosystems

NATIONAL SECURITY

- minimize dangers of conflict over oil & gas resources
- avoid spread of nuclear weapons from nuclear energy
- reduce vulnerability of energy systems to terrorist attack
- avoid energy blunders that perpetuate or create deprivation

…**and fashioning a coherent energy policy is harder still because these separate aims are often in tension with one another.**

There is no "silver bullet": No known energy option is free of significant liabilities

• oil and gas:	not enough resources
• coal:	not enough atmosphere
• biomass:	not enough land
• hydropower & wind:	not enough sites
• nuclear fission:	too unforgiving
• nuclear fusion:	too difficult
• photovoltaics:	too expensive
• hydrogen:	needs energy to produce it
• end-use efficiency:	needs end-users who are paying attention

That there's no silver bullet doesn't mean we should reject everything.

- To disparage all the options for their liabilities and reject everything is to have nothing. This would be the height of folly.
- We need instead to work on all of them, to try to reduce their liabilities & maximize their possibilities.
- Even with all plausible progress in that endeavor, there is no possibility that any one of these options can do the job alone; we will need a <u>portfolio</u>.

A portfolio doesn't mean we'll end up <u>keeping everything</u>.

- Some liabilities will prove harder to overcome or reduce than others.
- R&D entail relatively modest investments in finding out what can be done.
- Demonstrations entail somewhat larger investments in finding out how the most promising possibilities work out at near-commercial to commercial scale.
- Decisions on the huge investments for widespread deployment are best made in the marketplace, based on the information derived from RD&D and on cost & price signals tweaked to account for important externalities and public goods.
- Some options may be rejected in the market, even after every effort to improve them through RD&D, because other options prove more attractive in the same niche.

WHAT IMPROVED TECHNOLOGY CAN DO

ONLY WITH IMPROVED TECHNOLOGIES CAN WE

- limit oil imports without incurring excessive economic or environmental costs
- improve urban air quality while meeting growing demand for automobiles
- use abundant US and world coal resources without intolerable impacts on regional air quality, acid rain, and global climate
- expand the use of nuclear energy while reducing accident and proliferation risks

...AND WHY WE ALSO NEED BETTER POLICIES

ONLY WITH IMPROVED POLICIES CAN WE

- provide the scale, continuity, and coordination of effort in energy research & development needed to realize in a timely way the required technological innovations
- gain the benefits of market competition in the electricity sector while protecting public goods (provision of basic energy services to the poor, preservation of adequate system reliability, and protection of environment)
- ensure the rapid diffusion of cleaner and more efficient energy technologies across the least developed countries and sectors
- devise and implement an equitable, adequate, and achievable cooperative framework for limiting global emissions of greenhouse gases

As the foregoing lists of what we need from innovation in technology & policy begin to imply, the most demanding of the tensions afflicting energy policy are those between energy's economic benefits and its environmental liabilities.

Indeed, my 35 years working on these issues have convinced me that…

- Environment is the hardest part of the energy problem;
- energy is the hardest part of the environment problem; and
- the energy / environment / economy nexus is the hardest part of the sustainable prosperity problem.

Climate change is the most dangerous & difficult of all of energy's environmental impacts

- It's the most dangerous because climate is the "envelope" within which all other environmental conditions and processes operate. That envelope is not just a matter of average temperature but of averages and extremes of
  - hot & cold
  - wet & dry
  - snowpack & snowmelt
  - winds & storm tracks
  - ocean currents & upwellings

and not just how much & where, but also when.

Why climate change is so dangerous (continued)

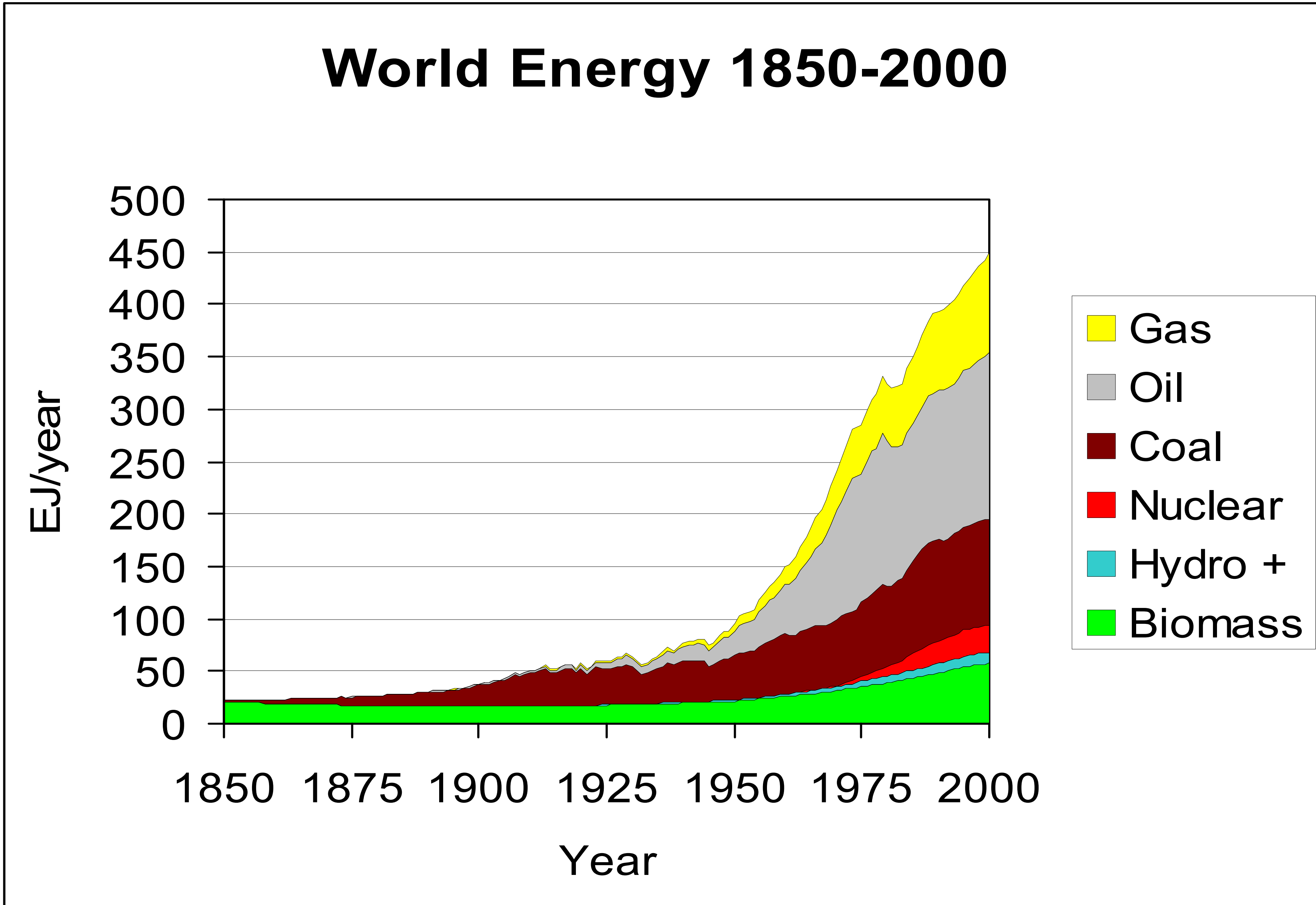
- Distortions of this envelope of the magnitude that are in prospect are likely to so badly disrupt these conditions and processes as to impact adversely every dimension of human well-being that is tied to environment:
  - Productivity of farms, forests, & fisheries
  - Geography of disease
  - Livability of cities in summer
  - Damages from storms, floods, wildfires
  - Property losses from sea-level rise
  - Expenditures on engineered environments
  - Distribution & abundance of species

Why the problem is so difficult

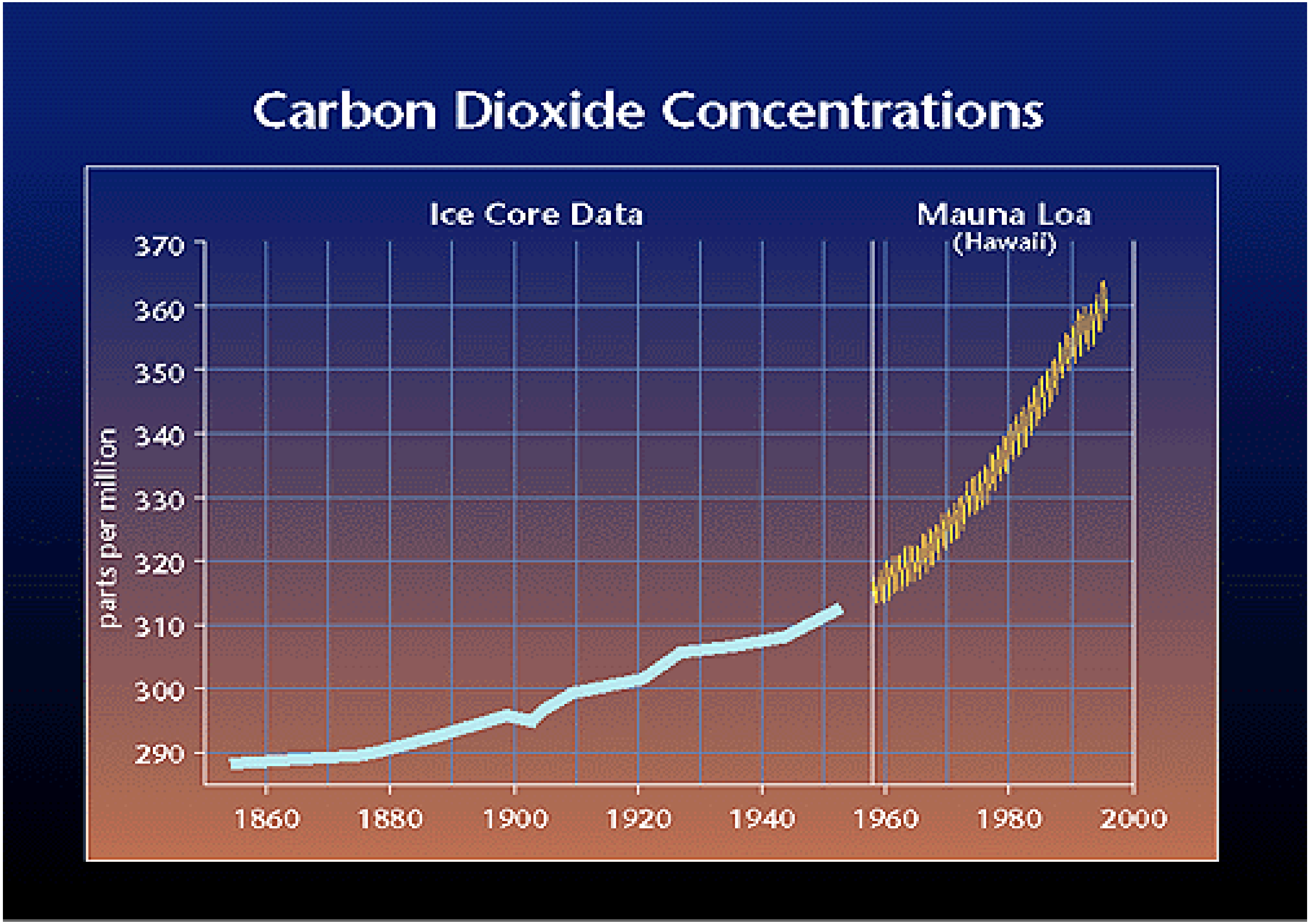
- The climate problem is so difficult because
  - the dominant cause of the disruption – emission of CO_2 from fossil-fuel combustion – arises from the process that currently supplies nearly 80 percent of civilization's energy
  - the technologies involved cannot be quickly or inexpensively changed or replaced in ways that would eliminate the problem.

  This is not CFCs all over again: an issue where a few kinds of chemicals used in a relatively limited set of applications were found to have ready substitutes at low cost.

Energy & climate:
Where we’ve been & where we’re going



Fossil fuels drove most of the growth & were almost 80% of supply in 2000.



Atmospheric CO2 grew from 290 to 370 ppmv over the same period.

Evidence for recent unusual climate change

The average temperature of the earth is rising:

- up 0.7±0.2°C in last 140 years (instrumental records);
- 19 of the 20 warmest years since 1860 have all occurred since 1980, the 12 warmest all since 1990;
- 1998 was the warmest year in the instrumental record and probably the warmest in 1,000 years (tree rings, ice cores); 2002 was 2nd warmest; 2003 3rd warmest;
- the last 50 years appear to have been the warmest half century in 6,000 years (ice cores);
- compilation of worldwide ocean-temperature measurements shows significant ocean warming between the mid-1950s and the mid-1990s.

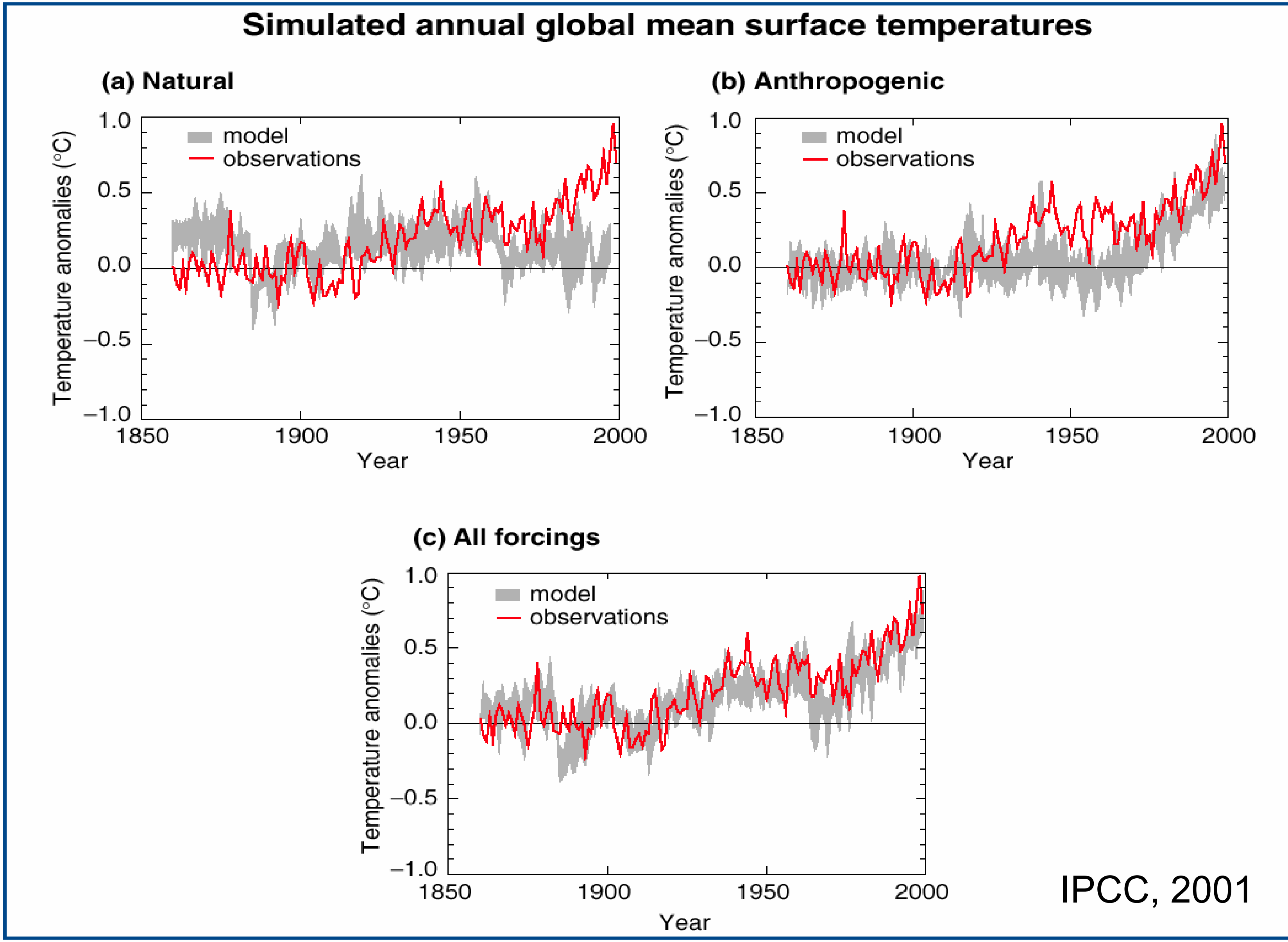
Evidence that climate is changing (cont)

Observations over recent decades also show…

- Evaporation & rainfall are increasing;
- More of the rainfall is occurring in downpours;
- Permafrost is melting;
- Corals are bleaching;
- Glaciers are retreating;
- Sea ice is shrinking;
- Sea level is rising;
- Wildfires are increasing;
- Storm & flood damages are soaring.

The smoking gun

- Essentially all of the observed climate-change phenomena are consistent with the predictions of climate science for GHG-induced warming.
- No alternative "culprit" identified so far – no potential cause of climate change other than greenhouse gases – yields this "fingerprint" match.
- A credible skeptic would need to explain both what the alternative cause of the observed changes is and how it could be that GHGs are NOT having the effects that all current scientific understanding says they should have. (No skeptic has done either thing.)



Computer models of climate match observations only if natural forcings (sun, volcanoes) and human ones (GHG, particulates) are included. The human forcings are responsible for most of the rapid warming 1970-2000.

THE "BUSINESS AS USUAL" SCENARIO TO 2100

- World population increases from 6.1 billion in 2000 to 9.8 billion in 2050, stabilizing by 2100 at about 11 billion.
- Aggregate real economic growth averages 2.8%/year 2000-2020, 2.5%/year 2000-2100; ppp-corrected world economic product grows from ~$45 trillion in 2000 to $180 trillion in 2050, $500 trillion in 2100 (2000 US$). Industrial-developing country "gap" in ppp-GDP/person falls from 7x in 2000 to 3.5x in 2050, 2x in 2100.
- Energy intensity of economic activity falls at the long-term historical rate of 1%/yr. Energy use increases about 2.5 fold by 2050 and quadruples by 2100 (giving 1850 EJ/yr in 2100 compared to 450 EJ/yr in 2000).
- Carbon intensity of energy supply falls at 0.2%/yr. Carbon emissions from fossil-fuel burning go from a bit over 6 billion tonnes/yr in 2000 to some 20 billion tonnes/yr in 2100. LDCs = industrial countries by ~2035.

Is there enough fossil fuel for BAU? YES.

REMAINING ULTIMATELY RECOVERABLE NONRENEWABLE RESOURCES (in terawatt-years, rounded & highly approximate)

	TWy
OIL & GAS, CONVENTIONAL	1,000
UNCONVENTIONAL OIL & GAS (excluding clathrates)	2,000
COAL	5,000
METHANE CLATHRATES	20,000
OIL SHALE	30,000
URANIUM IN CONVENTIONAL REACTORS	2,000
...IN BREEDER REACTORS	2,000,000
FUSION, D-T FUEL (limited by lithium availability)	100,000,000
...D-D FUEL	200,000,000,000
GEOTHERMAL STEAM	4,000
...HOT DRY ROCK	1,000,000

1 TWy ≈ 30 EJ; today the world uses only ~15 TWy per year in total.

Consequences of continued “business as usual”

The scientific-consensus **“best estimates”** are that:

- Continuing "business as usual" GHG emissions will lead to increases of 0.2-0.4°C per decade in global-average surface temperature, or 2-4°C warmer than now by 2100.* Mid-continent warming will be 2-3x greater.
  - The earth will then be warmer than at any time in the last 160,000 years. Sea level will be 20-100 cm higher than today (best estimate 50 cm).
  - This global-average warming will entail major changes in climatic patterns: storm tracks, distribution of precipitation & soil moisture, extremes of hot & cold.
- Because of the pace and magnitude of the changes in climatic patterns and because society’s interactions with the environment are attuned to the current climate, impacts on human well-being will be far more negative than positive.

* The full range of IPCC scenarios (from lower emissions than my BAU to higher) gives 1.4-5.8°C increase by 2100.

IPCC 2001 WG II report on impacts..

"Projected adverse impacts based on models and other studies include

- A general reduction in potential crop yields in most tropical and sub-tropical regions for most projected increases in temperature;
- A general reduction, with some variation, in potential crop yields in most regions in mid-latitudes for increases in average-annual temperature of more than a few degrees C;
- Decreased water availability for populations in many water-scarce regions, particularly in the sub-tropics;
- An increase in the number of people exposed to vector-borne diseases (e.g. malaria) and water-borne diseases (e.g. cholera) and an increase in heat-stress mortality;
- A widespread increase in the risk of flooding for many human settlements (tens of millions of inhabitants in settlements studied) from both increased heavy precipitation events and sea-level rise;
- Increased energy demand for space cooling due to higher summer temperatures."

IPCC WG2: The benefit side of impacts

"Projected beneficial impacts based on models and other studies include:

- Increased potential crop yields in some regions at mid-latitudes for increases in temperature of less than a few degrees C;
- A potential increase in global timber supply from appropriately managed forests;
- Increased water availability for populations in some water-scarce regions, e.g., in parts of South East Asia;
- Reduced winter mortality in mid- and high-latitudes;
- Reduced energy demand for space heating due to higher winter temperatures."

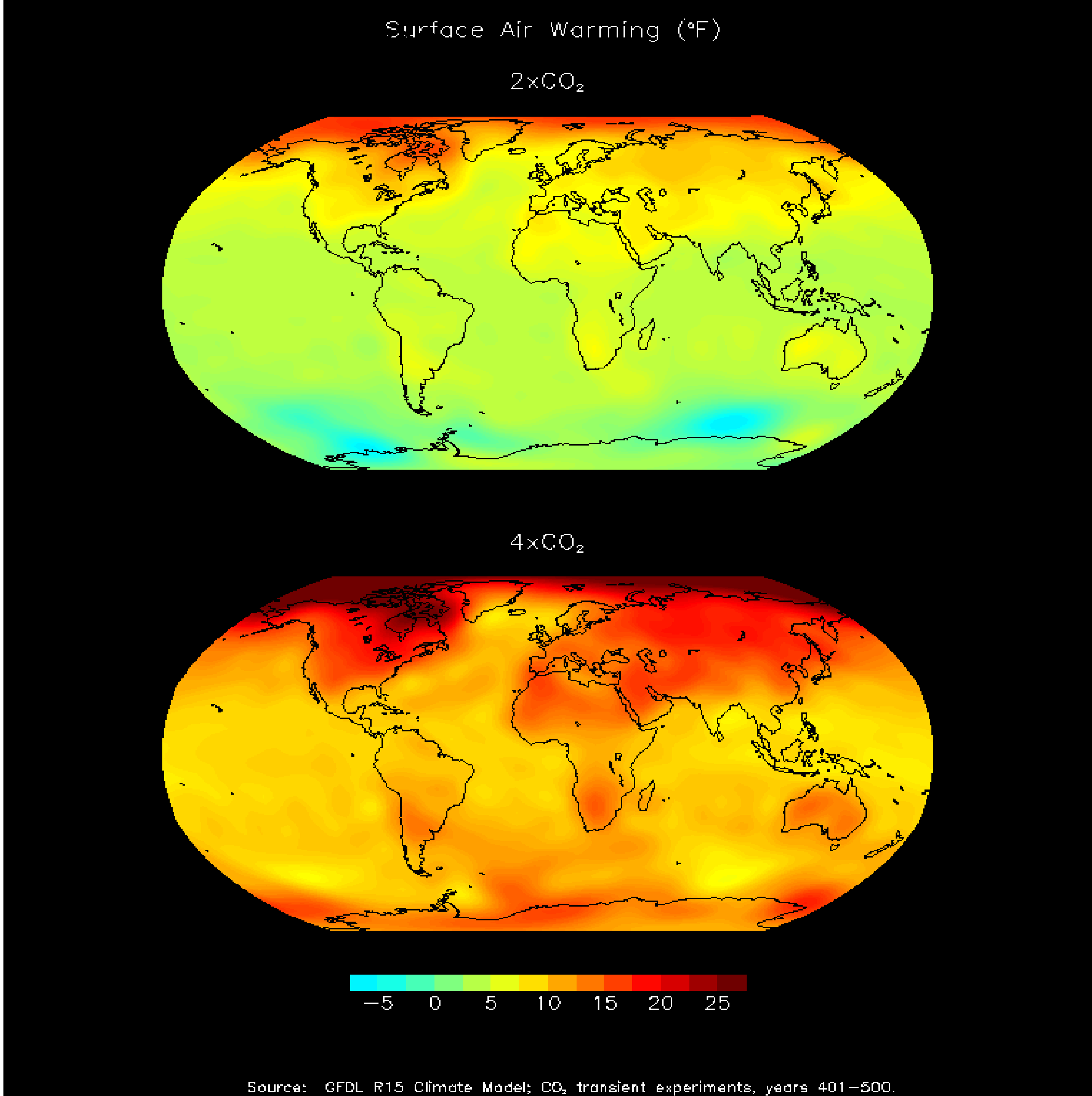
But…

- Most studies to date of adverse & beneficial impacts of climate change have focused on just a doubling of pre-industrial CO2 (for comparability among models).
- Alas, under BAU, we'll careen past a doubling around mid-century, heading for a tripling by 2100 and a quadrupling soon after.
- At these higher levels of forcing and resulting climate disruption, early positive impacts are reversed, negative ones grow beyond manageability, and unpleasant surprises must be expected.

The two globes summarize computer simulations performed by the Princeton Geophysical Fluid Dynamics Lab to compare the warming expected under a doubling of CO_2 from the pre-industrial level with the warming expected from a quadrupling.

Note that N hemisphere mid-continent average warming in the $4xCO_2$ world is 15-25°F!

This is a roasted world.



Possibilities for unpleasant "surprises"

- Large increases in the frequency of highly destructive storms
- Drastic shifts in ocean current systems that control regional climates (e.g., Gulf stream / Western Europe)
- Multi-meter sea-level rise, over a period of centuries, from disintegration of West-Antarctic ice sheet
- Runaway greenhouse effect from decomposition of methane clathrates, drastically increasing the severity of all expected impacts as well as the probability of big surprises.

These outcomes are all possible but none can be assigned a probability with confidence at the current state of knowledge. Our ignorance is <u>not</u> a reason for complacency!

What could be done?

WHAT ARE THE OPTIONS FOR CORRECTIVE ACTION?

POSSIBLE APPROACHES

1. **REDUCE** EMISSIONS OF GREENHOUSE GASES
2. **REMOVE** GHGs FROM THE ATMOSPHERE (by growing more trees, or phytoplankton, or by technological means)
3. **COUNTERACT** THEIR CLIMATIC EFFECTS (by "geotechnical engineering")
4. **ADAPT** TO GHG-INDUCED CLIMATE CHANGE (dams, dikes, changed patterns of agriculture…)
5. **COMPENSATE** THE VICTIMS

Nos. 2-5 cannot avoid the need for No.1. Adaptation becomes costlier & less effective as degree of climate disruption grows. <u>Emissions reductions are essential.</u>

Determinants of CO_2 emissions

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

where

C = carbon content of emitted CO_2, kilograms

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, we had

6.1×10^{9} pers x \$7400/pers x 0.061 GJ/\$ x 14 kgC/GJ

= 6.4×10^{12} kgC = 6.4 billion tonnes C

What is the leverage in the different determinants of emissions?

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., increased education, opportunity, health care 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 somewhat.

Leverage (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 and/or the characteristics of fossil-fuel technologies. This will need to be done, because the combined leverage in the other factors will not do all that is required.

Options for reducing E-intensity, C-intensity

TECHNICAL POSSIBILITIES

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

POLICY MEASURES

- increased incentives & diminished barriers for low-carbon choices from existing energy-technology mix
- research, development, & demonstration to improve characteristics of low-carbon options

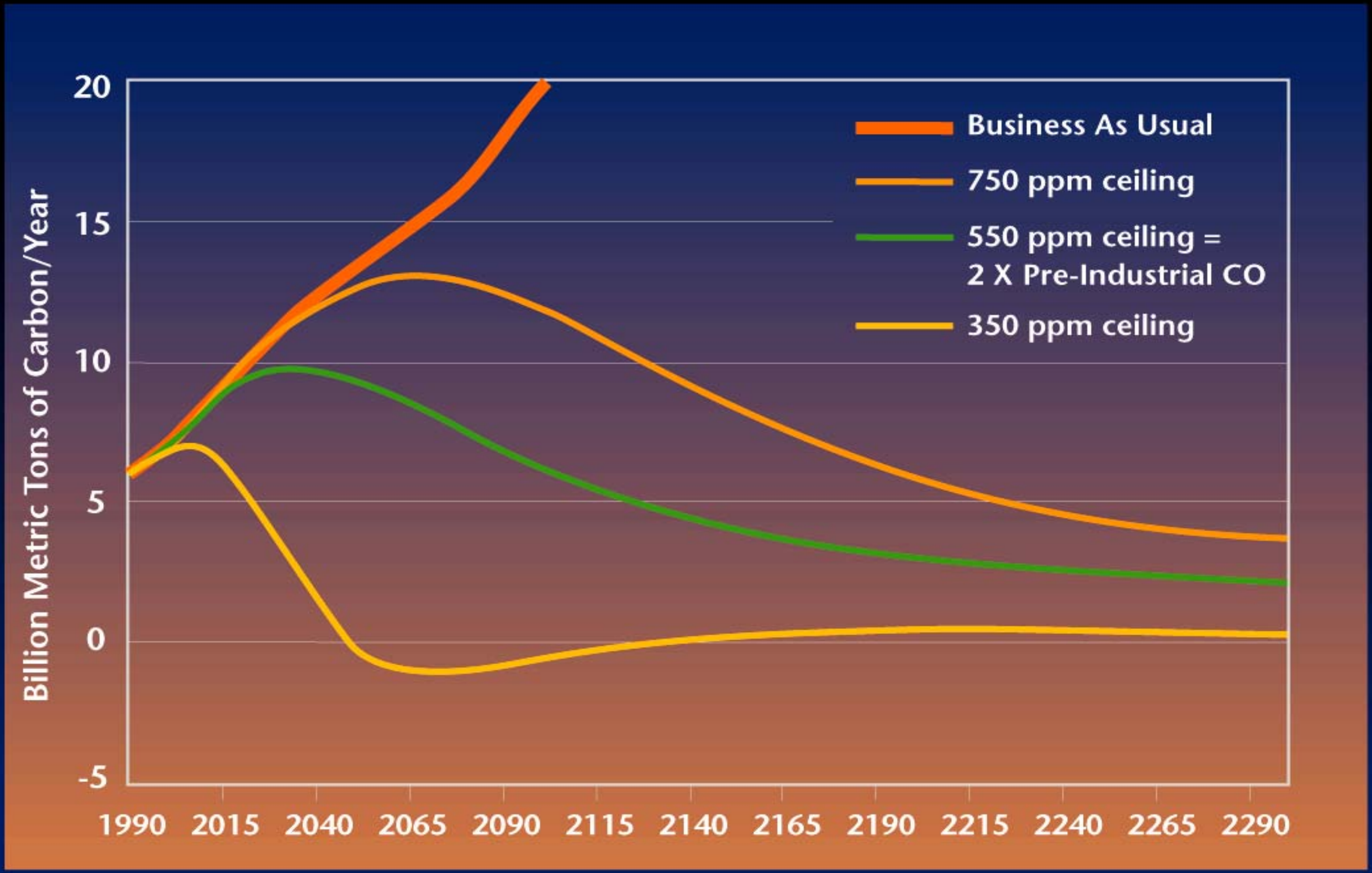
By how much must emissions be reduced?

What would such reductions entail in the way of

– improvements in energy efficiency?

– expansion of carbon-free energy supply?

Atmospheric Stabilization Emissions Paths



Stabilizing at $2xCO_2$ (green curve) is by no means “safe”, but achieving this much will be very difficult and more might not be possible.

Increase in C-free energy needed to stabilize atmospheric CO_2 below 550 ppm_v

To avoid a doubling of preindustrial CO_2, conventional fossil primary energy must not exceed 500 EJ in 2050 and 350 EJ in 2100. Starting from 350 EJ of conventional fossil fuel in 2000 and BAU rates of change in world GDP and energy intensity, it follows that EJ/yr of C-free energy needed in 2050 and 2100, compared to 100 EJ/yr actual in 2000, are…

	2000	2050	2100
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C-free energy under BAU	100	600	1500
...if E/GDP falls 1.5%/yr	100	350	800
...if E/GCP falls 2.0%/yr	100	180	350

What do I think should be done?

- In the USA, impose an escalating carbon tax, starting at a low level, or, alternatively, a declining emissions cap implemented through tradable permits, to promote (i) low- and no-carbon choices from the current energy-technology menu and (ii) increased private-sector innovation to improve the menu over time.
- Increase US government investments in low- and no-carbon energy-technology innovation (supply-side & demand side) and in international cooperation on energy-technology innovation by 5-10x.
- Sharply increase US efforts (and US support for international efforts) on adaptation to climate-change.
- In the United Nations, devise an adequate, affordable, and equitable global framework for reducing climate-change risks (because we are all in this together).

Evaluating energy-climate policy in the current Administration: a mixed bag

- The Cheney Commission's national energy policy document, for all the uproar that has blown up around the process of producing it, has many good points:
  - quite balanced and comprehensive coverage of energy end-use efficiency, renewables, and advanced fossil-fuel technologies;
  - generally sensible recommendations about nuclear energy;
  - appropriate attention to needs in energy infrastructure.
- Its weaker points are
  - It contains a huge number of recommendations with too little indication about priorities and leverage (Where are the biggest gains to be had?)
  - It gives too little attention to the climate dimension (only a few lines) with little sense of the problem's likely magnitude and implications.

In climate policy beyond that report…

- The Administration is right to say there are important uncertainties & we need more good science, but wrong in my view to imply we know too little to justify action beyond voluntarism, and wrong to fail to provide the increases in climate-change research budgets the NAS says are needed to reduce the uncertainties in a timely way.
- The Administration is right to say that improved technology will be key to reducing climate-change risks in a cost-effective way, but wrong in my view to be spending so little R&D money to make this innovation happen.
- The Administration is right to say the Kyoto Protocol is flawed, but wrong in my view to scrap it rather than working to fix it on the fly.

Administration climate policy evaluated (cont)

- The Administration was right to say the metric of GHG emissions performance should be the ratio of emissions to GDP (rather than absolute emissions), but wrong to set a target for improvement in this ratio that is no more demanding in the next decade than what "business as usual" delivered in the 1990s.
- The Administration is right to say that markets are the best tool we have for making society's choices about its mix of energy sources, but wrong if it imagines that markets will deliver societally optimal outcomes when important environmental externalities and public goods are left out of the prices.

Afterword on controversy, uncertainty, & prudence

UNCERTAINTIES REMAIN

Significant uncertainties remain about the climate-change issue, and debates about them persist. But the argument is no longer about whether climate is changing or whether human GHG emissions are responsible, but about…

- the precise magnitude of the climatic changes to be expected by 2030, 2050, or 2100 if civilization does not change course;
- the details of the character, geographic distribution, and timing of the damages to human well-being to be expected, and the probability that much bigger than “expected” damages will result from pushing the climate over a threshold or “tipping point”;
- the feasibility, costs, and leverage of various potential remedies; and
- the appropriate character and timing of national and international policies to reduce the risks from anthropogenic disruption of global climate.

Afterword on controversy… (continued)

UNCERTAINTIES ARE TWO-SIDED

- Yes, it could be that the climate changes occurring under a continuation of business as usual would be less disruptive, and the adverse impacts on human well-being less severe, than the "best estimate" portrayals presented here (which are based on the work of the Intergovernmental Panel on Climate Change [IPCC] & other mainstream scientific groups).
- But it could equally well turn out that the climate changes under business as usual are <u>more</u> disruptive, and the impacts on human well-being <u>more</u> severe, than the current "best estimates" suggest.
- The assertion of the "skeptics" that the IPCC consensus scientific view has been biased by political pressures toward overstating the problem is nonsense. The principal political pressures on the IPCC have been in the other direction.

Afterword on controversy… (continued)

BURDEN OF PROOF

- The “skeptics” routinely brandish some single contrary piece of evidence or analysis, often a newly reported one that has not yet been subjected to the scrutiny of the scientific community, and declare that this new result invalidates the mainstream view.
- That’s not how science works. Contrary results appear regularly in all scientific fields. When a strong preponderance of evidence points the other way (as in the case of climate-change science), isolated apparent contradictions are given due scrutiny but not, initially, very much weight, because it’s <u>far more likely</u> that the “contradiction” will turn out to be explainable as a mistake, or otherwise consistent with the preponderance of evidence, than that the preponderance of evidence will turn out to have been wrong.

Afterword on controversy… (concluded)

PRUDENCE

- All science is contingent. It is always possible that persuasive new evidence and analysis will come to light that will change the mainstream view.
- But the greater the consistency and coherence of the existing body of evidence and analysis, the lower the likelihood that the principal conclusions derived from it will be overturned. The consistency and coherence of the evidence and analysis supporting the mainstream view of climate-change risks presented here are substantial.
- Supposedly prudent decision-makers, on whose decisions the preservation and expansion of their own and the public's well-being depends, are gambling against large odds if they bet that the mainstream position is wrong.
- Even a 50% chance that the mainstream is right would justify far more risk-reduction effort than is underway today.