

Climate-Change Mitigation Through Renewables & Energy Efficiency: Necessity & Opportunity

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The nature of the necessity

- Global climate change is real, accelerating, and caused mainly by emissions from civilization's energy system.
- The changes are already causing significant harm:
 - increased frequency and intensity of floods, droughts, heat waves, wildfires
 - expanded ranges of temperature-dependent pests & pathogens
 - other unwelcome changes in species ranges and abundances

The necessity (continued)

- Much greater damage is ahead on the “business as usual” trajectory, including likelihood of:
 - loss of coral reefs, polar bears, and as much as 30% of global biodiversity in this century;
 - reduced agricultural productivity;
 - greater frequency of extreme tropical storms;and a real possibility of
 - rapidly accelerating sea-level rise (2-5 m/century??)
- Significantly improving our chances of escaping an unmanageable degree of climatic disruption requires that a major change of direction be underway, worldwide, by 2015.
- If the United States leads, others will follow.

To be clear...

The climate challenge gives us only three options:

- greatly increased efforts at mitigation;
- greatly increased efforts at adaptation;
- greatly increased suffering.

We are already doing some of each; what's up for grabs is the future mix.

- Mitigation alone won't work because climate change is already occurring & can't be stopped quickly.
- Adaptation alone won't work because adaptation gets costlier & less effective as climate change grows.
- The more mitigation we can manage, the more likely that adaptation can avoid the worst of the suffering.

Options for mitigation are suggested by past & projected climate “forcings” from human influences (watts/meter²)

<i>Influence</i>	<i>Forcing to 2000</i>	<i>Forcing to 2100</i>	<i>Mitigation opportunities</i>
carbon dioxide (CO ₂)	1.5	5.1	fossil fuels, forests, soils
CH ₄ , N ₂ O, halocarbons	1.0	1.6	fossil fuels, industry, agriculture, waste mngm't
net tropospheric ozone	0.3	0.9	fossil fuels
black soot	0.4	0.7	fossil fuels, fires
reflective particles	-0.8	-1.6	fossil fuels, fires
cloud-forming effects of particles	-0.7	-1.3	fossil fuels, fires
surface reflectivity	-0.2	-0.1?	land-cover change
TOTAL	1.5	5.4	

Values are central estimates with uncertainties ±10-50%.

Mitigation options

Definitely reduce

- CO₂ emissions from energy sector
- CO₂ emissions from deforestation & soil-carbon depletion (then reverse with reforestation, afforestation, improved soil management)
- CH₄ emissions from energy, waste, agriculture
- black soot from energy, agriculture
- N₂O from energy, agriculture
- CFCs from industry

Conceivably

- Remove CO₂ from atmosphere technologically
- Geo-engineer to create cooling to offset GHG

Energy-sector CO₂ is the biggest problem

- CO₂ contributed 47% of the cumulative positive anthropogenic forcing up to 2000.
- It's share is increasing: Under BAU, it will have contributed over 60% as of 2100.
- Currently 75-80% of the CO₂ emissions come from fossil-fuel burning, 20-25% from land-use change (mostly tropical deforestation), and 2-3% from cement production.
- The fossil-fuel contribution resists reduction because
 - fossil fuels are 80% of world energy supply;
 - volume of combustion-product CO₂ is huge;
 - part of atmospheric increase persists for centuries.

Options for reducing fossil CO₂ emissions

Reduce growth of energy use by...

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

Reduce CO₂/E ratio by...

- substituting natural gas for oil & coal
- replacing fossil fuels with renewables
- replacing fossil fuels with nuclear energy
- capturing & sequestering CO₂ from fossil-fuel use

There is no silver bullet

All of the options have limitations & liabilities (some of which translate into increased energy costs).

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

Big problem & lack of silver bullet mean...

- We'll need a portfolio of approaches
 - Not just one or two, but many;
 - although not necessarily everything on the menu, as developing the better options to their full potential may allow foregoing some that prove very costly or risky.
- We need increased research & development on all of the options to try to
 - raise their limits,
 - lower their liabilities, and
 - reduce the uncertainties,

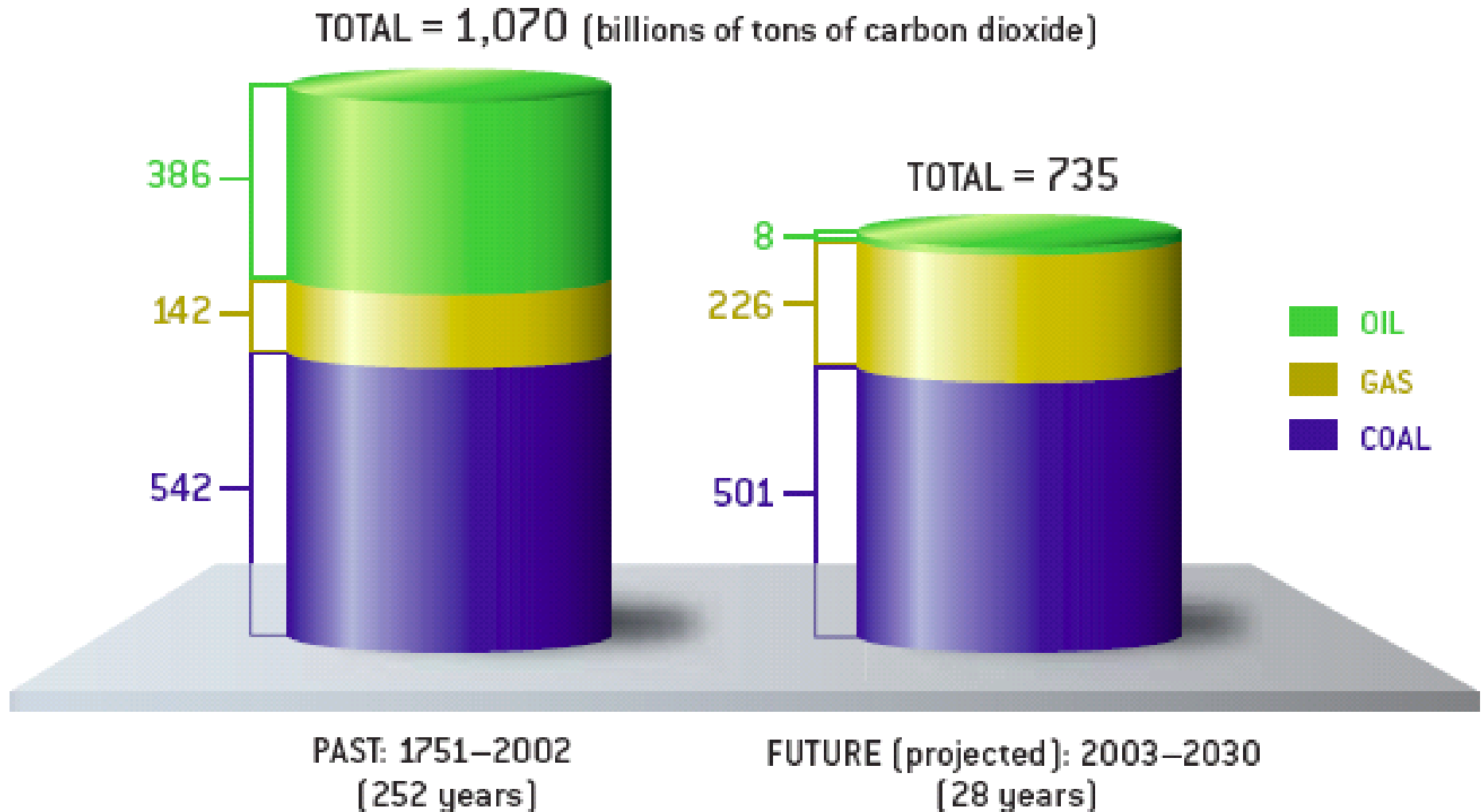
so that the future menu can be both better than today's and more transparent about what one is buying.

One key conclusion is already clear

- Increasing the efficiency of energy end-use has the largest near-term and mid-term potential, the lowest costs, and the smallest nonmonetary liabilities of any of the available approaches.
- Currently economic efficiency options offer the fastest, largest, cheapest, surest, cleanest, safest leverage against the climate-change challenge – an immense orchard of low-hanging fruit.
- Alas, the challenge is so large that the low-hanging fruit alone will not suffice. Thus...
 - we need increased investment in R&D to lower some of the fruit that hangs out of reach today;
 - we must expect to reach higher & pay more before the job is done.

Some observations on leverage and magnitudes

The CCS challenge under BAU



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

Courtesy David Hawkins, Rob Socolow, & Scientific American

How much could renewables do?

SUNLIGHT: 100,000 TW reaches Earth's surface (100,000 TWy/year = 3.15 million EJ/yr), 30% on land.

Thus 1% of the land area receives 300 TWy/yr, so converting this to usable forms at 10% efficiency would yield 30 TWy/yr, about twice civilization's rate of energy use in 2004.

WIND: Solar energy flowing into the wind is ~2,000 TW.

Wind power estimated to be harvestable from windy sites covering 2% of Earth's land surface is about twice world electricity generation in 2004.

BIOMASS: Solar energy is stored by photosynthesis on land at a rate of about 60 TW.

Energy crops at twice the average terrestrial photosynthetic yield would give 12 TW from 10% of land area (equal to what's now used for agriculture). Converted to liquid biofuels at 50% efficiency, this would be 6 TWy/yr, more than world oil use in 2004.

Renewable energy potential is immense. Questions are what it will cost & how much society wants to pay for environmental & security advantages.

Would the nuclear option be easier?

- If world electricity demand grows 2%/year until 2050 and nuclear share of electricity supply is to rise from 1/6 to 1/3...
 - nuclear capacity would have to grow from 350 GWe in 2000 to 1700 GWe in 2050;
 - this means 1,700 reactors of 1,000 MWe each).
- If these were light-water reactors on the once-through fuel cycle...
 - enrichment of their fuel will require ~250 million Separative Work Units (SWU);
 - diversion of 0.1% of this enrichment to production of HEU from natural uranium would make ~20 gun-type or ~80 implosion-type bombs.

The nuclear option (continued)

- If half the reactors were recycling their plutonium...
 - the associated flow of separated, directly weapon-usable plutonium would be 170,000 kg per year;
 - diversion of 0.1% of this quantity would make ~30 implosion-type bombs.
- Spent-fuel production in the once-through case would be...
 - 34,000 tonnes/yr, a (nominal) Yucca Mountain every two years.

The efficiency opportunity: Transportation

- Oil used as transport fuel \approx 25% of global CO₂ from fossil-fuel combustion
- Growth in these uses can be reduced by...
 - increasing the efficiency of cars, trucks, buses, trains, aircraft
 - Increasing the load factors of these (e.g., passengers per vehicle per trip)
 - mode switching (e.g., cars \rightarrow buses, trucks \rightarrow trains)
 - urban & economic planning that affects living & production patterns so as to reduce commuting and freight transport

The efficiency opportunity: Buildings

- Heating, cooling, refrigeration, lighting, office equipment \approx 33% of global CO₂ from fossil-fuel combustion.
- Energy used for these purposes can be reduced by...
 - improvements in building envelopes (wall & roof insulation, high-performance windows)
 - improved building orientation, shading, passive energy storage;
 - increased efficiency of heating & cooling (improved furnaces, air conditioners, ground-water heat pumps)
 - increased efficiency of lighting, refrigerators, computers, other appliances

The efficiency opportunity: Industry

- Industrial energy use \approx 40% of global CO₂ from fossil-fuel combustion.
- Biggest users include oil refining, plastics, fertilizers, iron & steel, aluminum, cement, pulp & paper.
- Energy used for these purposes can be reduced by...
 - improved efficiency of electric motors & individual industrial processes
 - increased use of on-site combined heat & power (CHP)
 - increased recycling of energy-intensive materials
 - shift in composition of industrial activity from materials-intensive to knowledge- and information-intensive goods & services

Efficiency's leverage: a thought experiment

How does rate of efficiency improvement affect the need for C-free energy to stabilize at 550 ppmv?

Carbon-free energy in 2000 (from renewables and nuclear energy) \approx 100 exajoules/year. (Fossil fuels \approx 350 EJ/yr)

With BAU economic growth, the future need for C-free energy (renewables, nuclear, & advanced fossil with CO₂ sequestration) depends on rate of improvement of energy efficiency as follows:

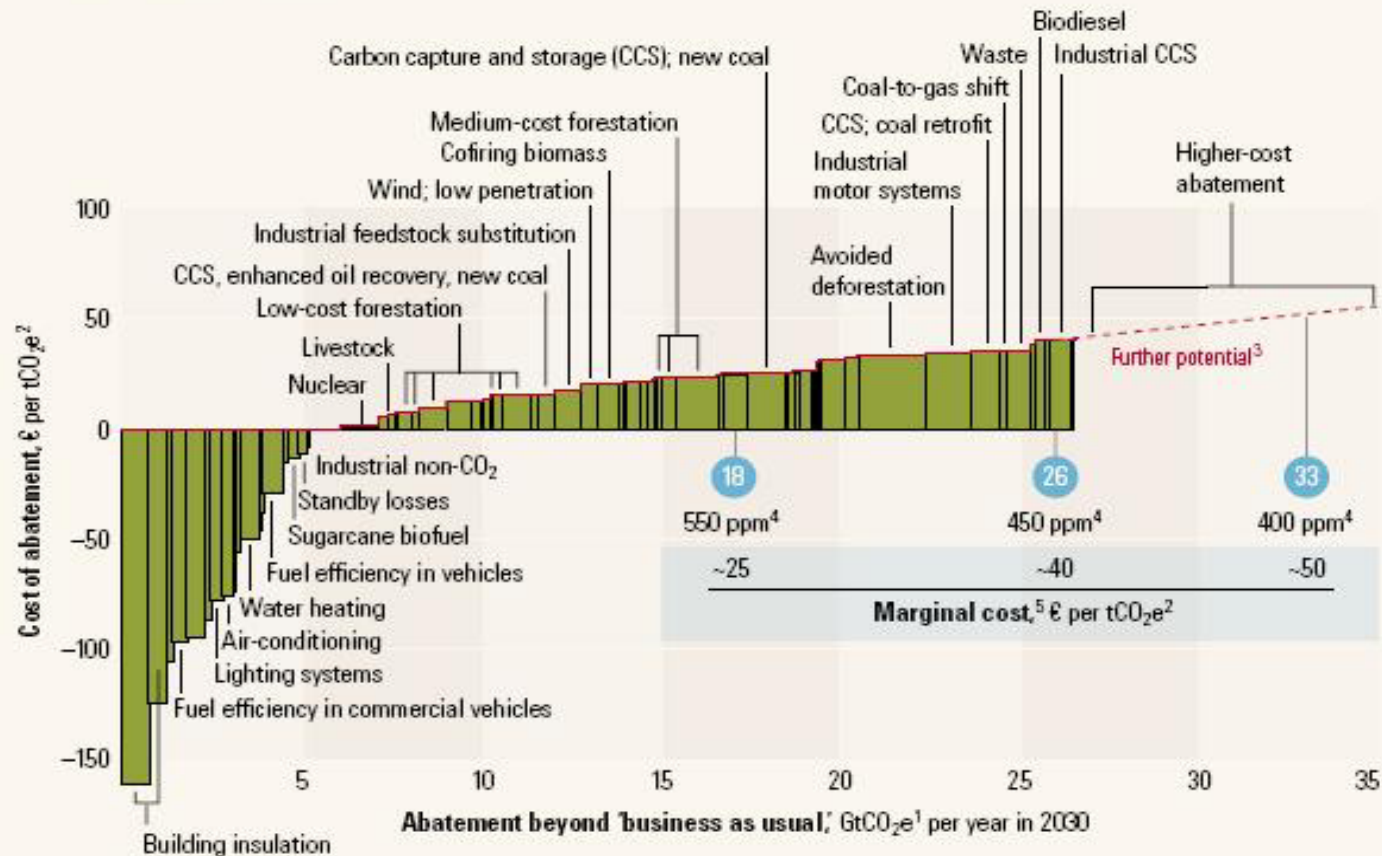
C-free energy (exajoules) in	2050	2100
	-----	-----
E/GDP falls 1%/yr (BAU)	600	1500
E/GDP falls 1.5%/yr	350	800
E/GCP falls 2.0%/yr	180	350

A supply curve for GHG reductions

What might it cost?

Global cost curve for greenhouse gas abatement measures beyond 'business as usual'; greenhouse gases measured in GtCO₂e¹

- Approximate abatement required beyond 'business as usual,' 2030



¹ GtCO₂e = gigaton of carbon dioxide equivalent; "business as usual" based on emissions growth driven mainly by increasing demand for energy and transport around the world and by tropical deforestation.

² tCO₂e = ton of carbon dioxide equivalent.

³ Measures costing more than €40 a ton were not the focus of this study.

⁴ Atmospheric concentration of all greenhouse gases recalculated into CO₂ equivalents; ppm = parts per million.

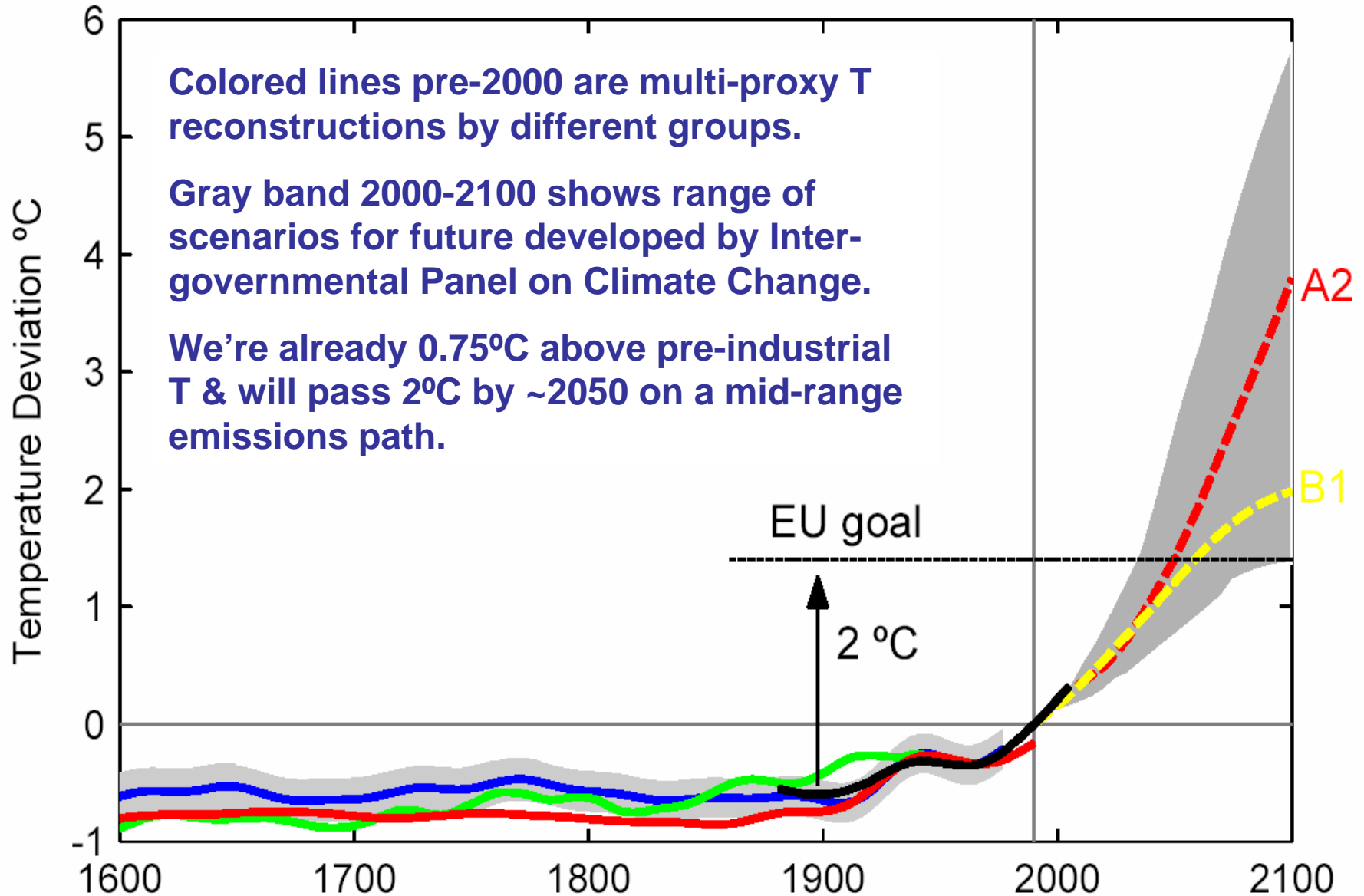
⁵ Marginal cost of avoiding emissions of 1 ton of CO₂ equivalents in each abatement demand scenario.

How much mitigation do we need?

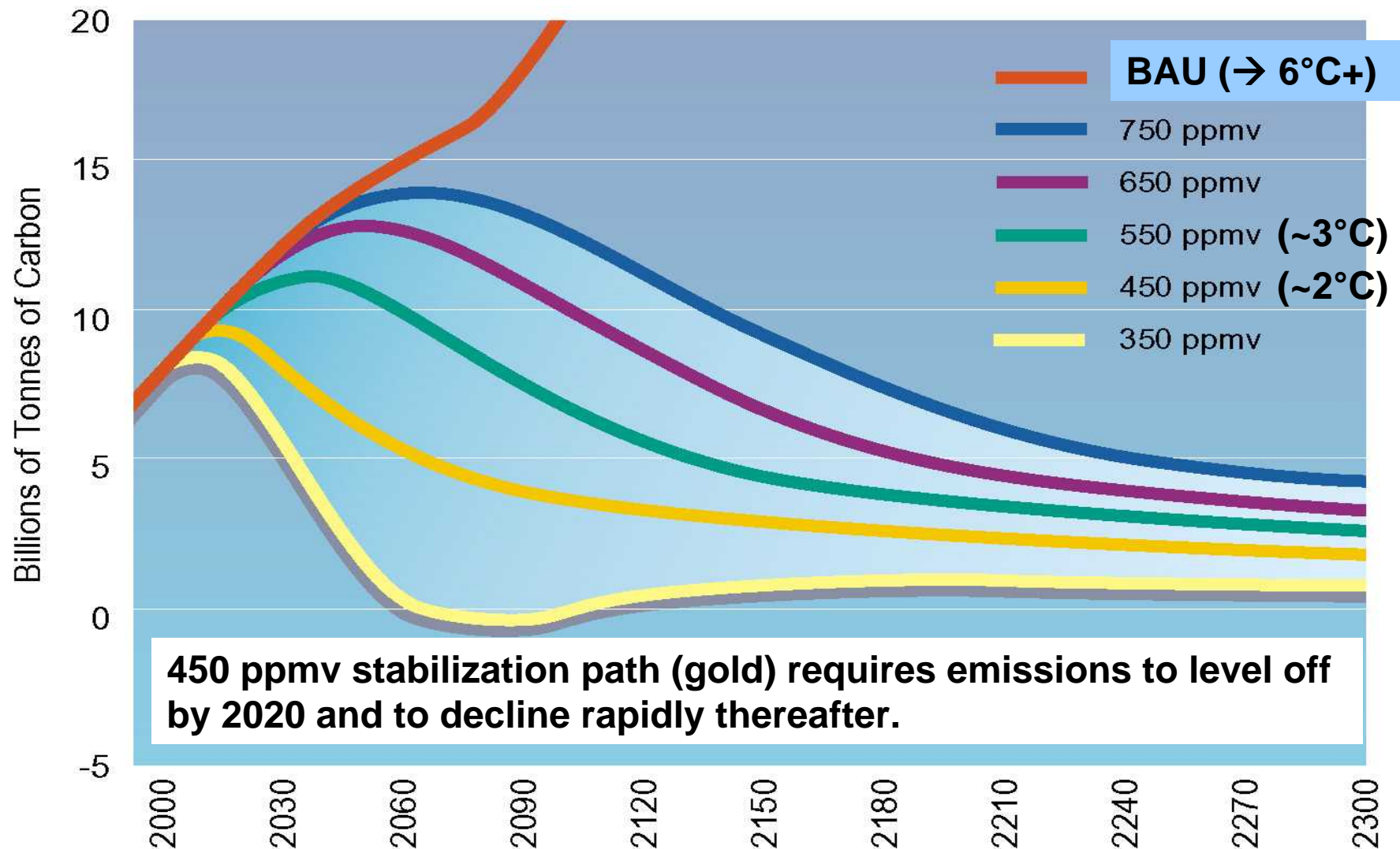
- UNFCCC goal of “avoiding dangerous anthropogenic interference in the climate system” is already out of reach:
 - Current level of interference is dangerous.
 - Issue is whether catastrophic interference is avoidable.
- Best chance to avoid catastrophe is by limiting increase in global-average surface temperature (ΔT_{avg}) to 2-2.5°C above 1880-1900 level.
 - Achieving a 50% chance of not exceeding 2°C requires stabilizing atmosphere at 450 ppmv CO₂-equivalent.
 - 50% chance of not exceeding 2.5°C requires stabilizing at 500 ppmv CO₂-equivalent.

Where we're headed under BAU:

The next 100 years compared to the last 400

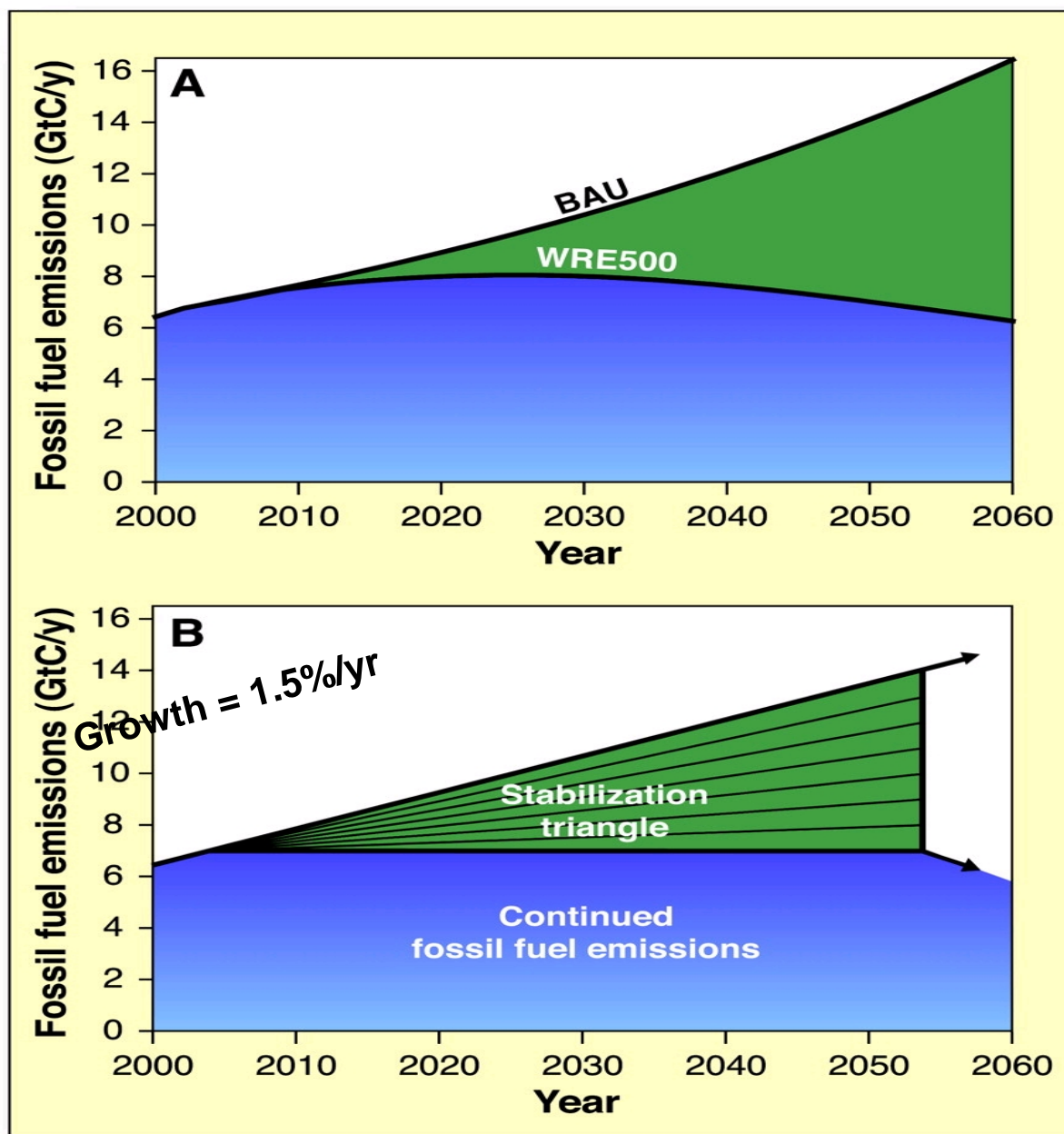


If biosphere is CO₂-neutral and if non-CO₂ influences cancel, fossil CO₂ emission trajectories relate to different stabilization levels as follows:



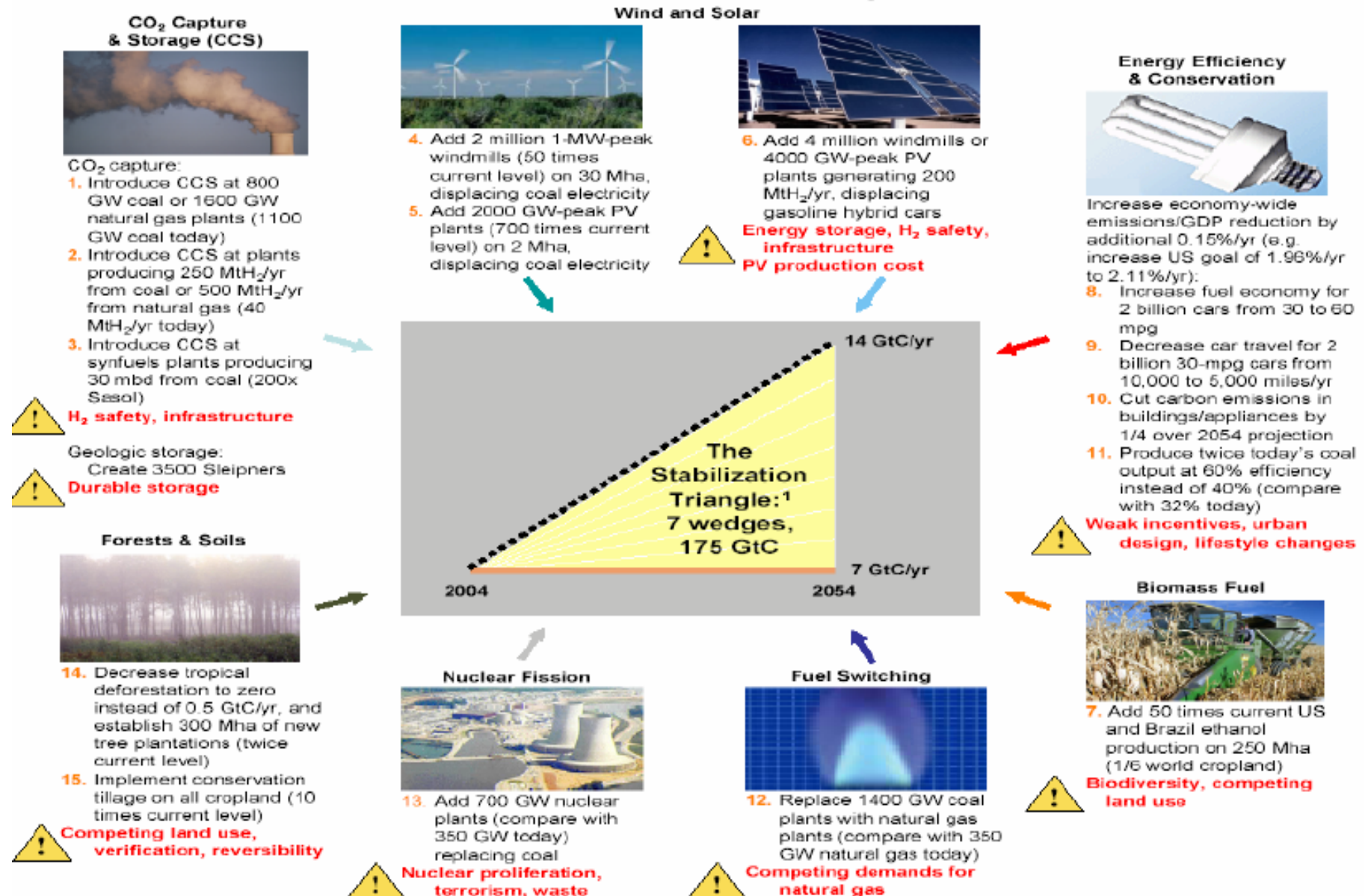
**Socolow-Pacala
“wedge” model
approximates
the trajectory for
500 ppmv CO₂-
equivalent as
level 2005-55,
then declining**

Difference between
BAU and the 500
ppmv stabilization
trajectory is seven
“wedges”, each of
which avoids 1 GtC
per year in 2055.

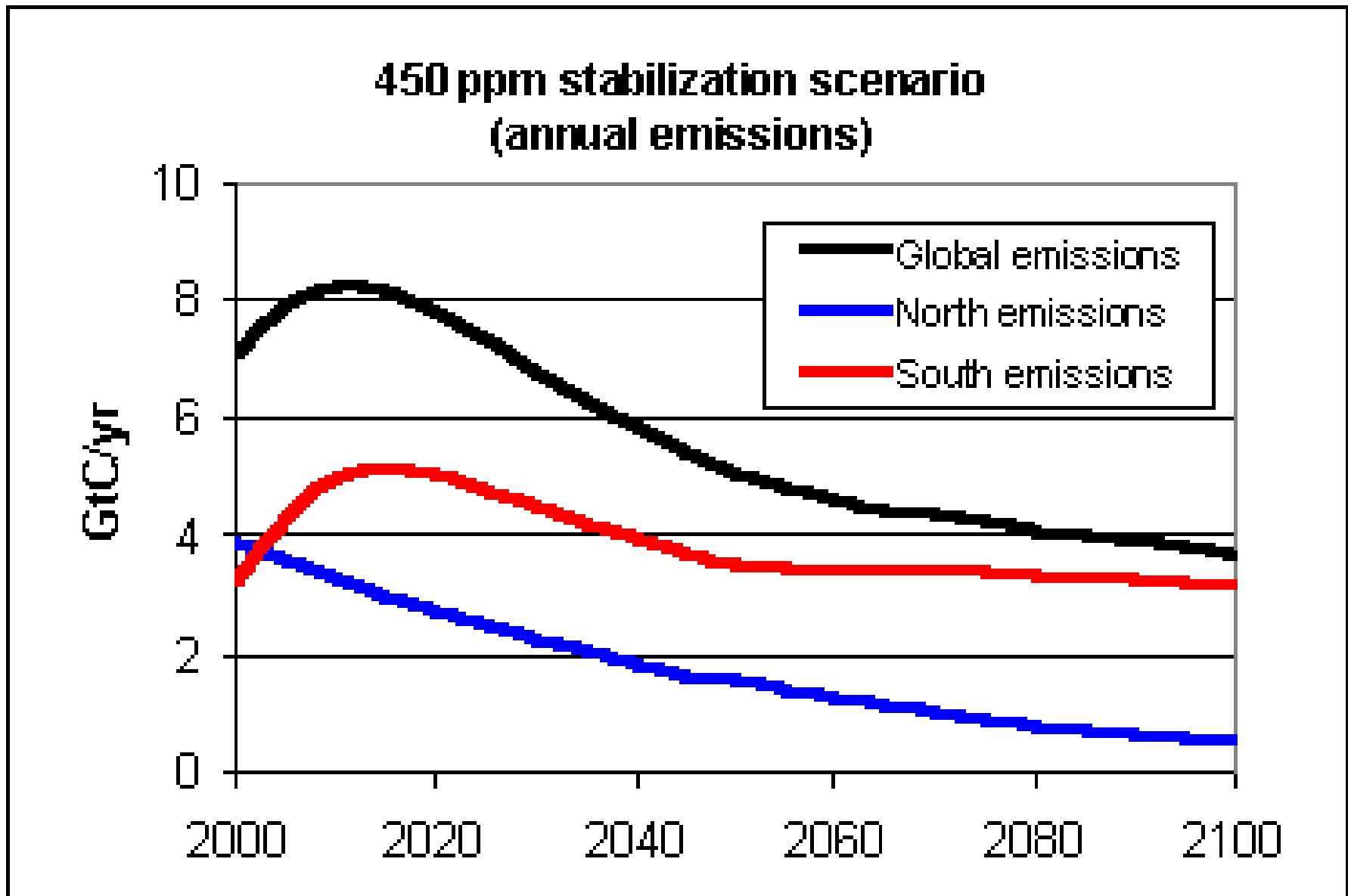


Source: Stabilization Wedges: Pacala and Socolow, Science Vol 305, page 968

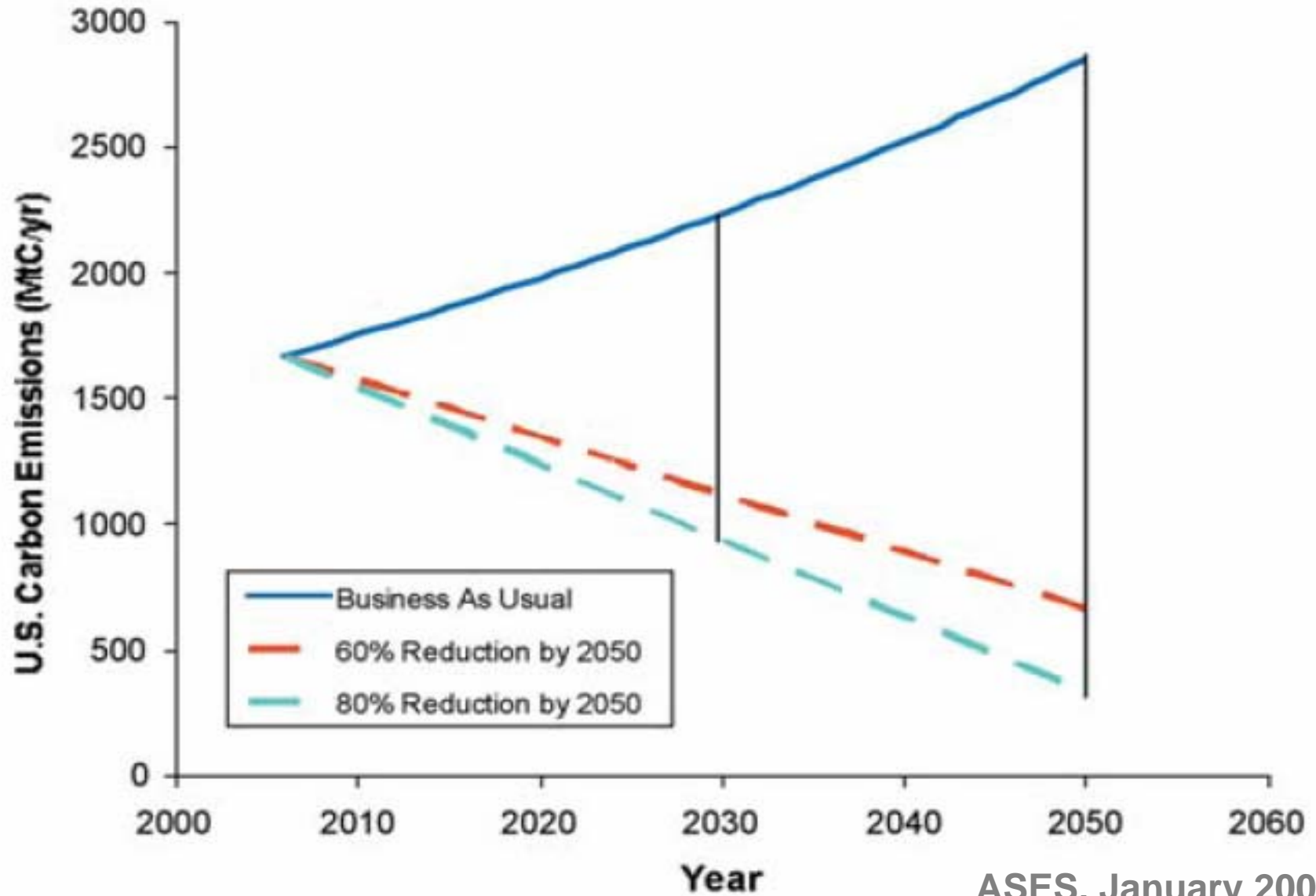
One wedge is a lot: Some examples...



Industrialized nations must start sooner

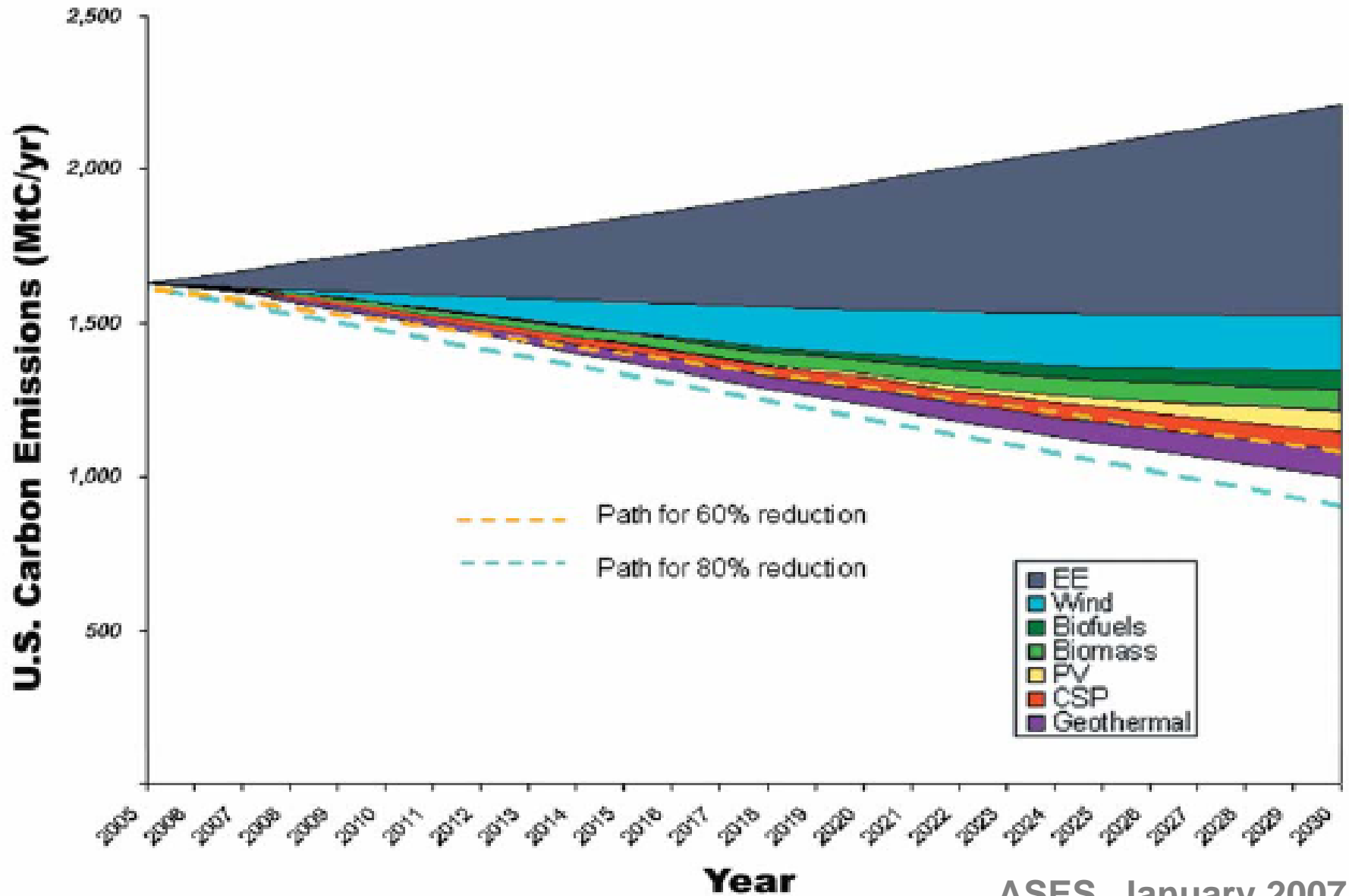


U.S. emissions trajectories to 2050



ASES, January 2007

Ingredients of potential U.S. reductions



Some key references

National Commission on Energy Policy, *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges*, December 2004, and *Energy Policy Recommendations for the President and the 110th Congress*, April 2007 <http://www.energycommission.org>

American Solar Energy Society, *Tackling Climate Change in the United States: Potential Carbon Emissions Reductions from Energy Efficiency and Renewable Energy by 2030*, January 2007 <http://www.ases.org/climatechange/>

UN Scientific Expert Group on Climate Change & Sustainable Development, *Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable*, United Nations Foundation, February 2007 <http://www.unfoundation.org/SEG/>

Intergovernmental Panel on Climate Change, *Climate Change 2007: Mitigation. Summary for Policy Makers*. May 2007 <http://www.ipcc.ch/>