Global Climate Change-the Sustainability Challenge

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A&WMA: Greenhouse Gas Strategies in a Changing Climate

November 17, 2011

The views expressed in this presentation are those of the author and do not necessarily reflect the views or policies of the U.S. Environmental Protection Agency.

Presentation Objectives

- Discuss the global climate/energy sustainability challenge
- Sustainability "levers" available: *new generation of production & end use technologies* & cultural changes
- Discuss driving forces for greenhouse gas emissions
- Quantify the mitigation challenge
- Explain the role that technology can/must play

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Advances in Global Change Research 38
Frank Princiotta
Editor
Global Climate Change - The Technology Challenge

In order to avoid the potentially catastrophic impacts of global warming, the current 3% CO_2 global emission growth rate must be transformed to a 1 to 3% declining rate, as soon as possible. This will require a rapid and radical transformation of the world's energy production and end use systems. The current generation of energy technologies are not capable of achieving the level of mitigation required. Next generations of renewable, low carbon generation and end use technologies will be needed.

This book quantifies the mitigation challenge. It then considers the status of key technologies needed to protect the planet from serious climate change impact. Current and emerging technologies are characterized for their mitigation potential, status of development and potential environmental impacts. Power generation, mobile sources, industrial and building sectors are evaluated in detail. The importance and unique challenges for rapidly developing countries, such as China and India are discussed. Current global research and development efforts for key technologies are discussed. It is concluded that it will be necessary to substantially upgrade and accelerate the current worldwide RDD&D effort on both emerging energy technologies and those enabling technologies needed to improve mitigation effectiveness and economics. It will also be necessary to carefully evaluate the potential environmental characteristics of next generation technologies to avoid unacceptable health and ecological impacts.

Finally, given the monumental technological challenge associated with transforming the world's energy system, an assessment of geoengineering options are evaluated, since if successfully deployed, they have the potential to allow more time for the necessary energy system transformation.

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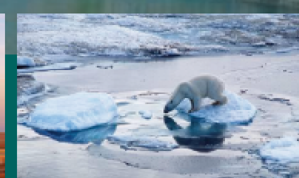
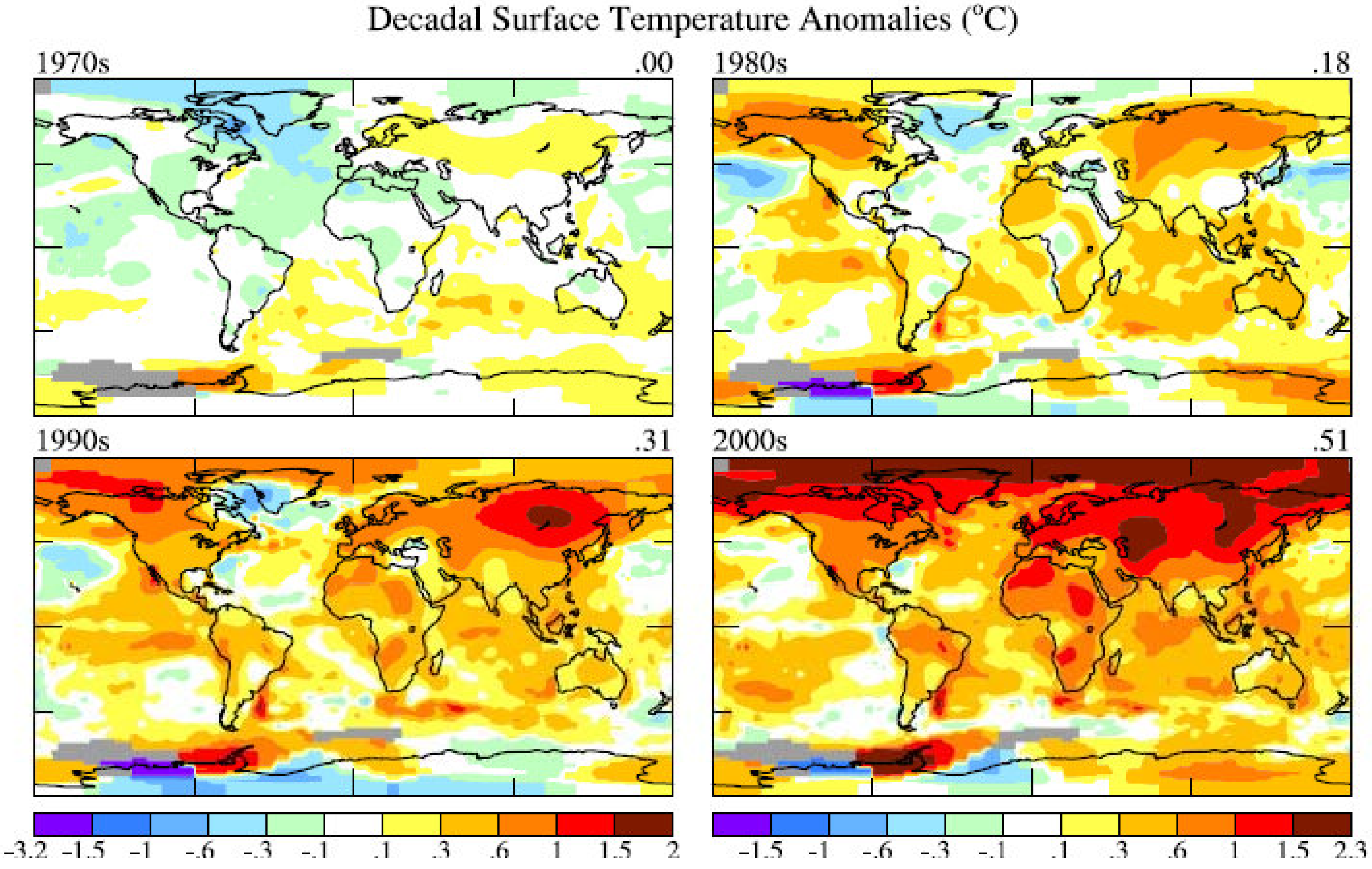
Global Climate Change - The Technology Challenge



Springer

Decadal Warming Trends from the 1970's to the 2000's (NASA, 2010)



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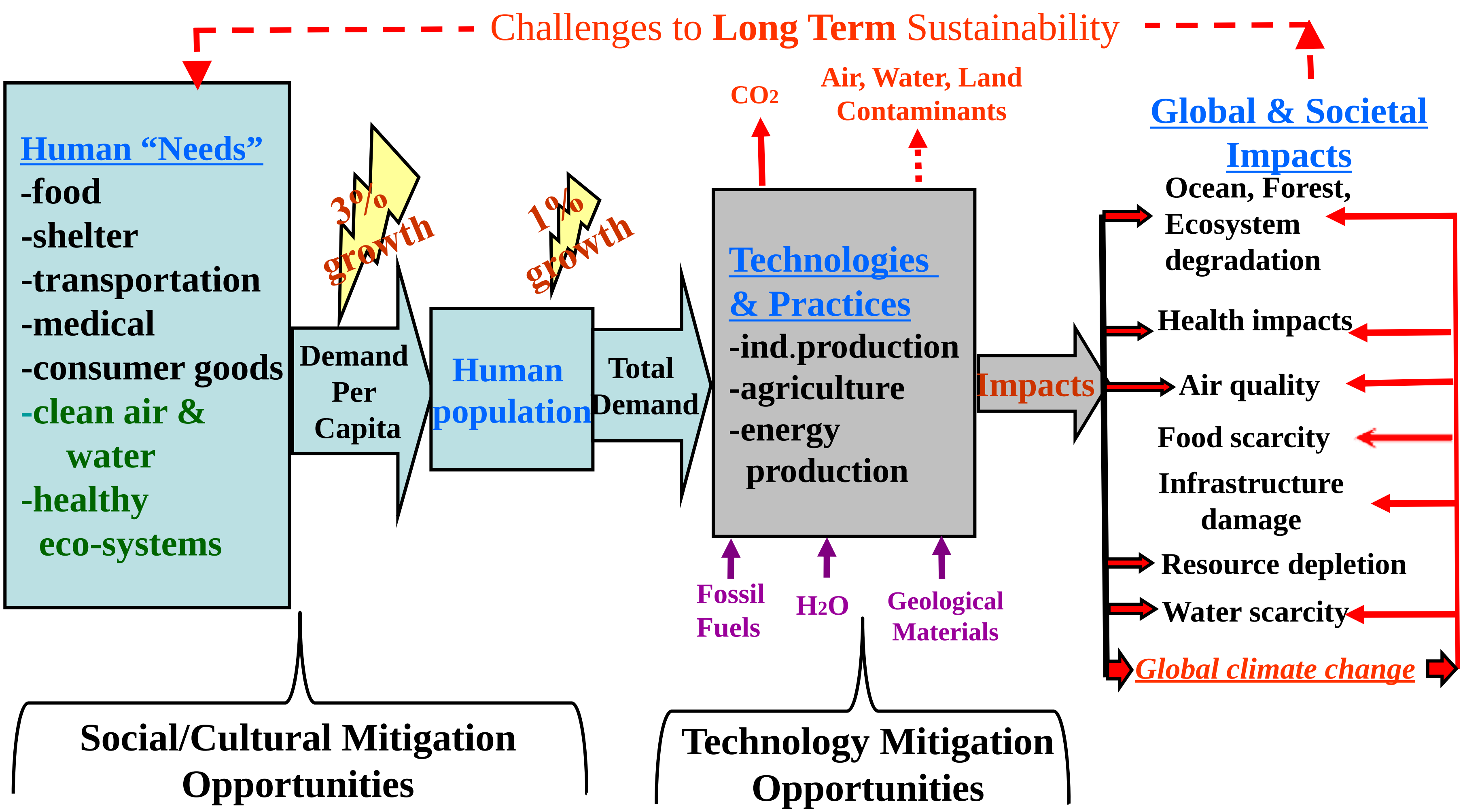
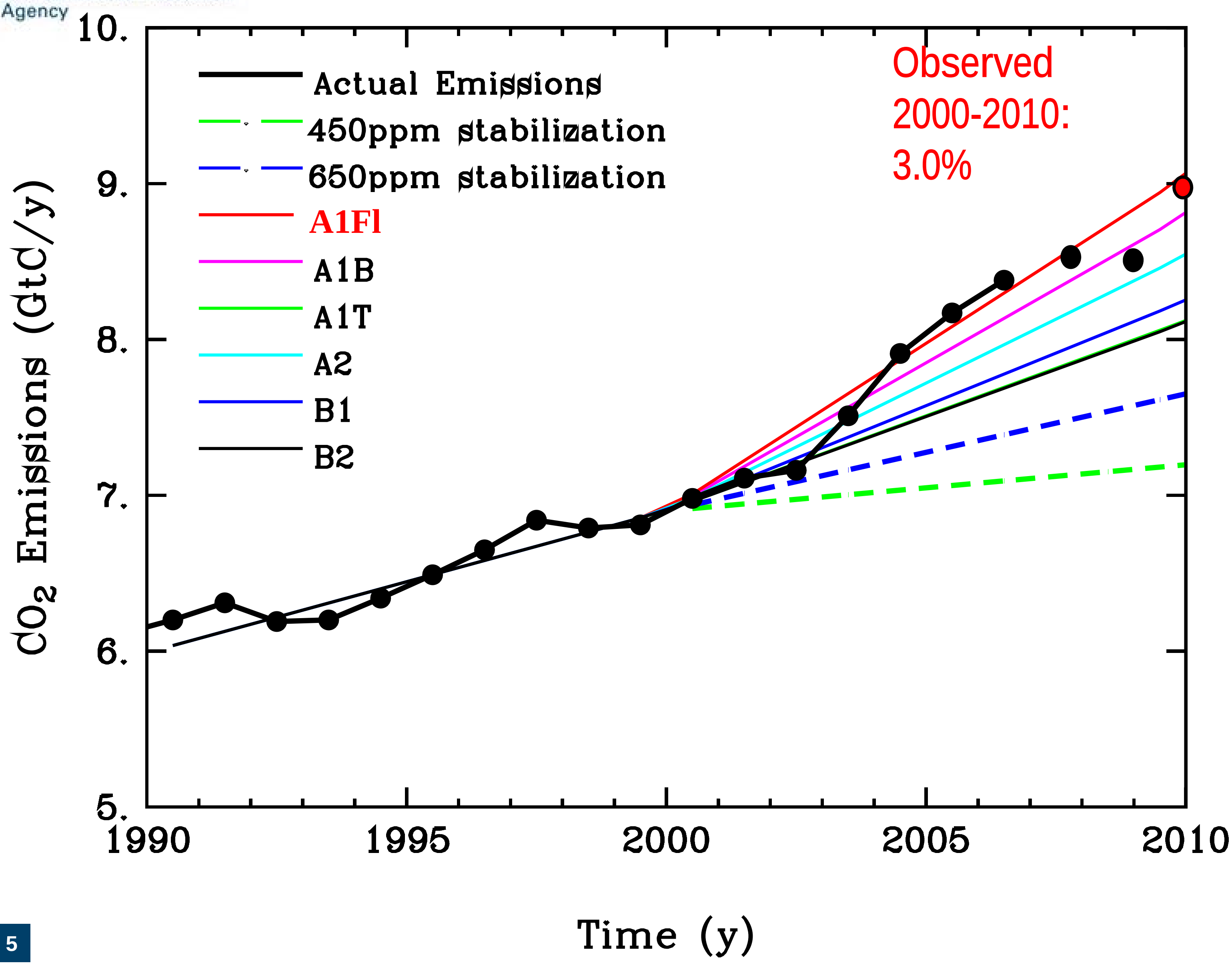
The Macro View of Humanity's Sustainability Challenge

F. Princiotta 2010

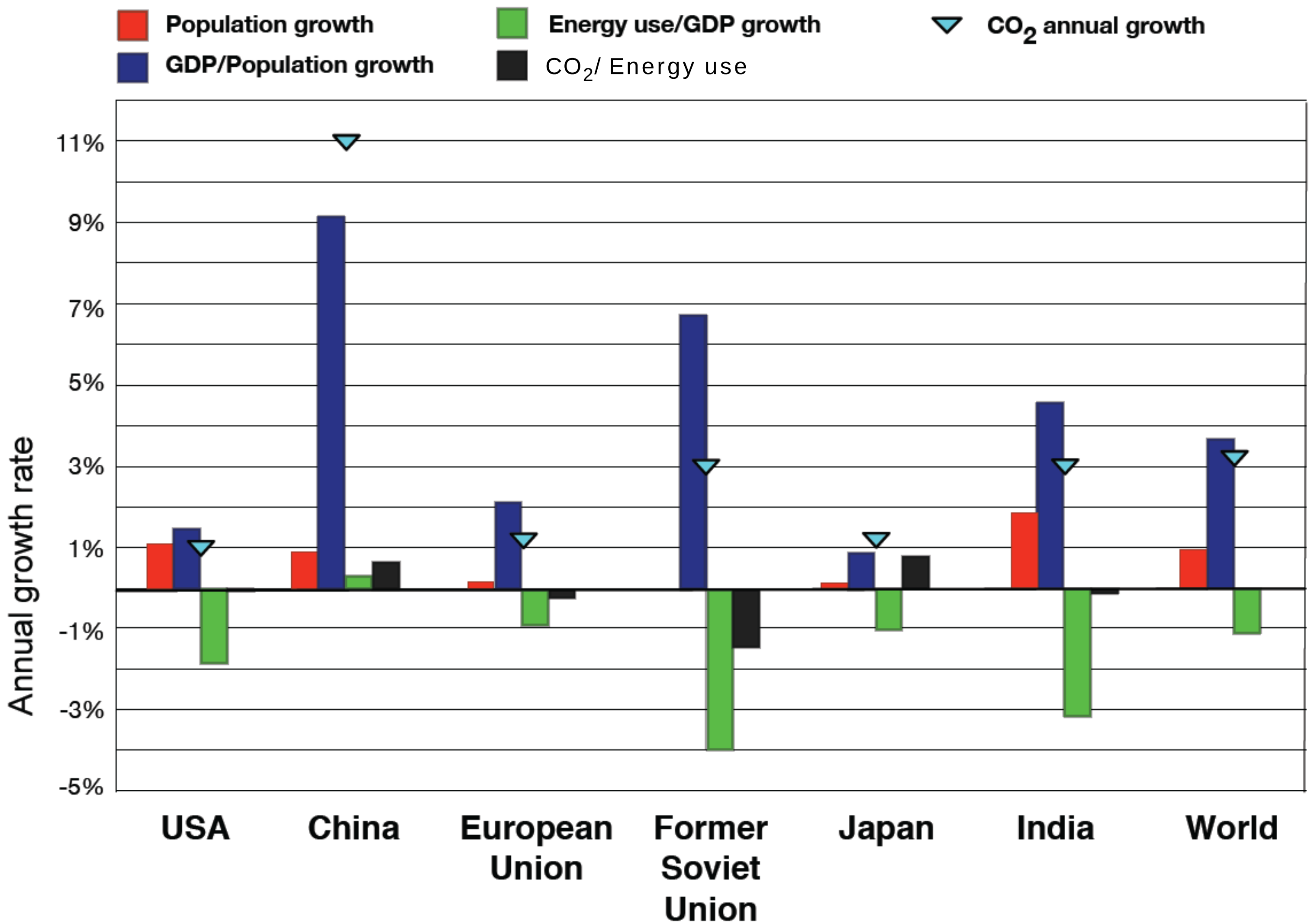


Trajectory of Global Fossil Fuel Emissions



Raupach et al. 2007, PNAS

Factors Influencing CO_2 Growth Rate; 2000 to 2004



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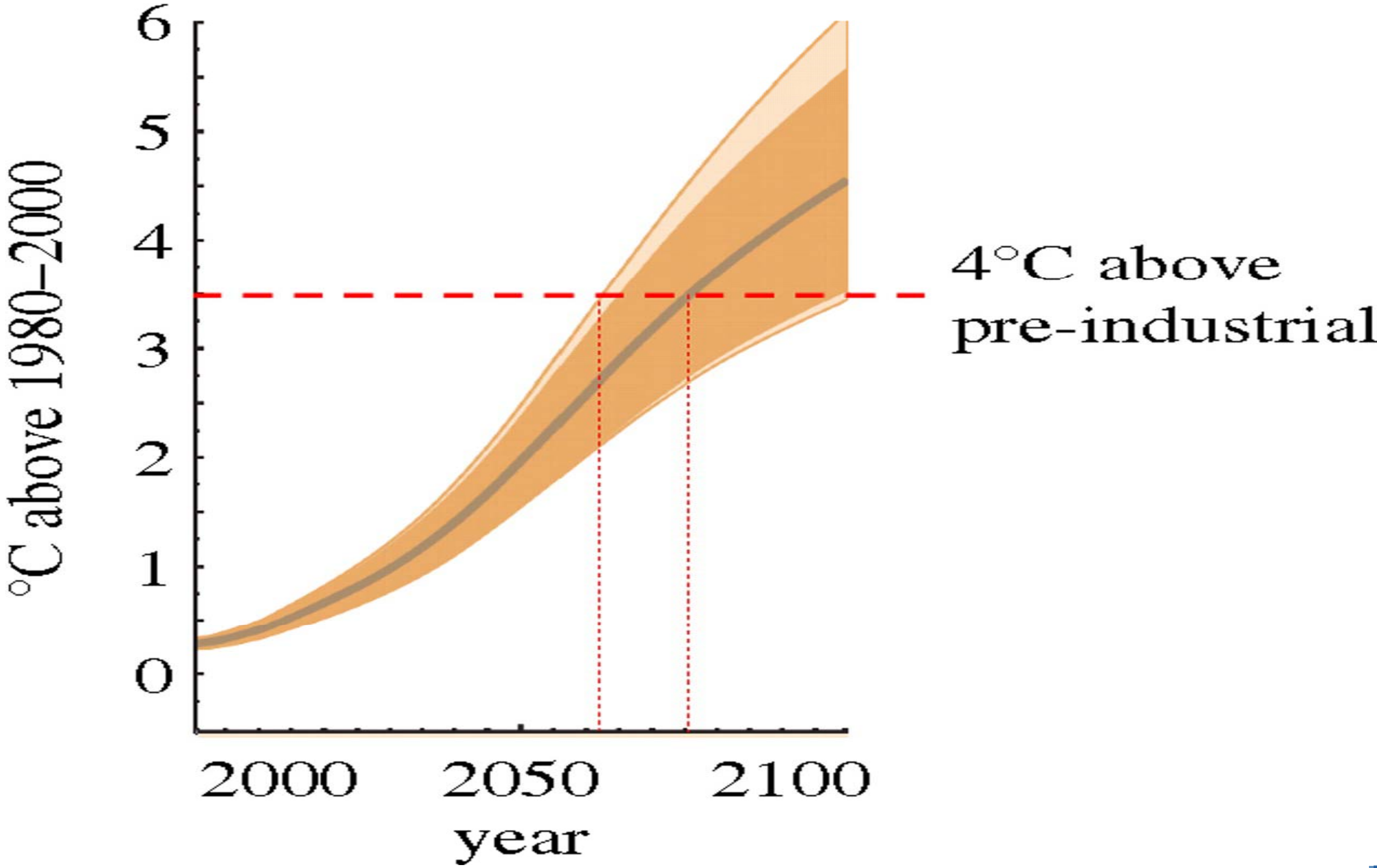
Jan 2011 Warming Projections by The Royal Society (UK): Global Warming Relative to Pre-Industrial for the IPCC A1FI Emissions Scenario, Using an Ensemble of Model Simulations



©2011 by The Royal Society

Betts R A et al. Phil. Trans. R. Soc. A 2011;369:67-84

Royal Society (Jan/2011): Implications of 4 deg. Warming

- ***"Enormous adaptation challenges in the agricultural sector, with large areas of cropland becoming unsuitable for cultivation, and declining agricultural yields. "***
- ***"…this world would … rapidly be losing its ecosystem services, owing to large losses in biodiversity, forests, coastal wetlands, mangroves and saltmarshes, and terrestrial carbon stores, supported by an acidified and potentially dysfunctional marine ecosystem."***
- ***"…drought and desertification would be widespread, with large numbers of people experiencing increased water stress, and others experiencing changes in seasonality of water supply."***
- ***"Human and natural systems would be subject to increasing levels of agricultural pests and diseases, and increases in the frequency and intensity of extreme weather events. …"***

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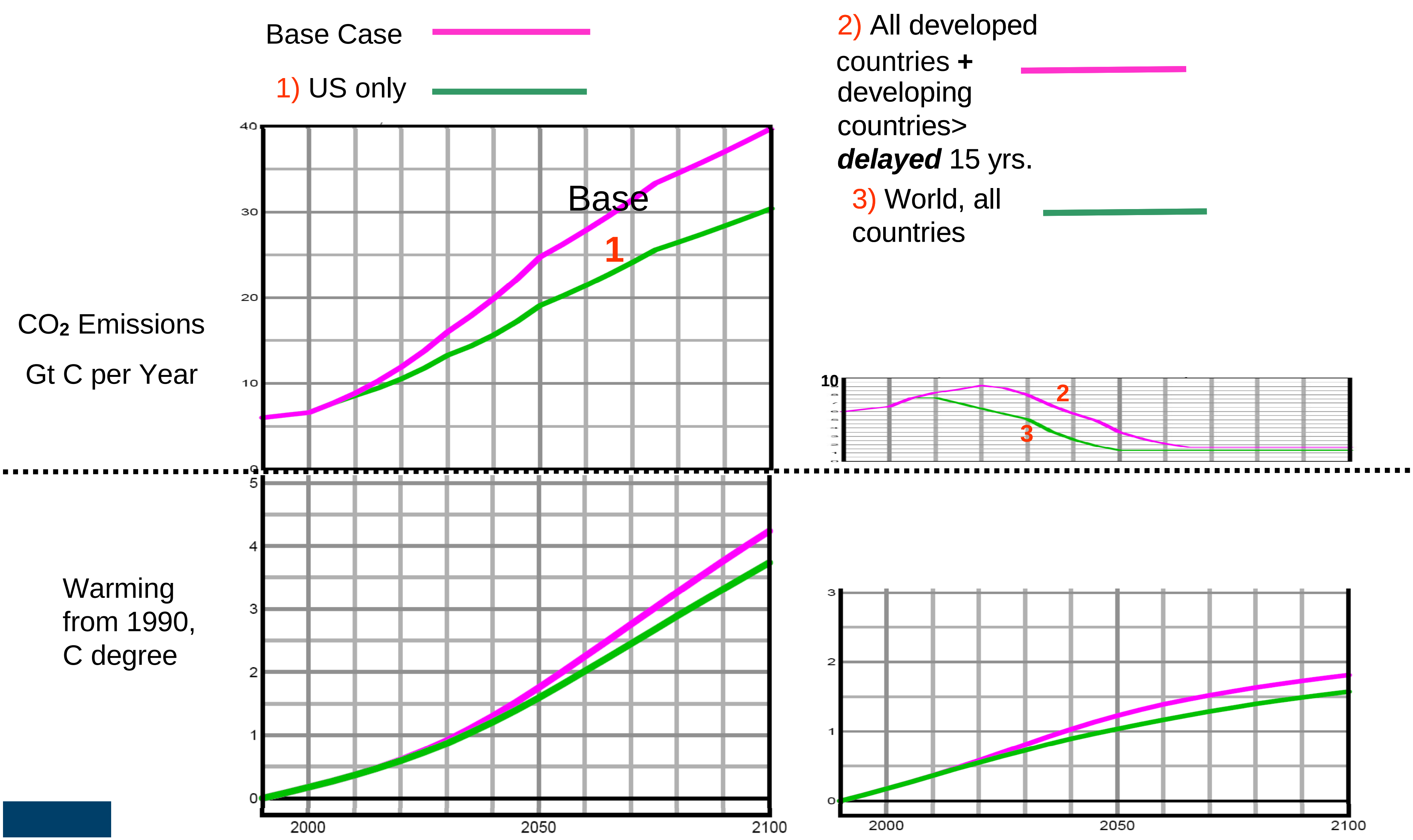
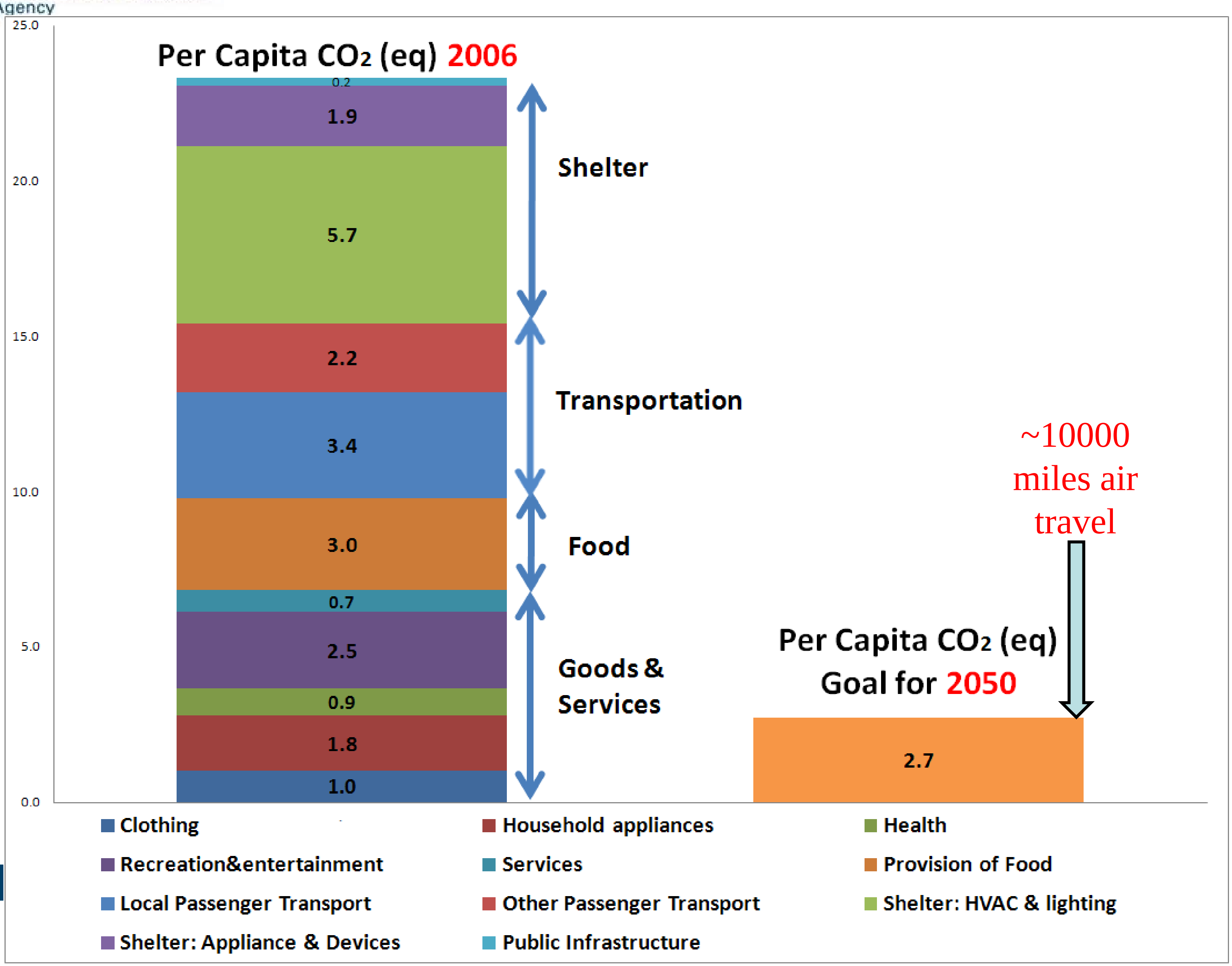
US vs. World CO_2 Emission Reductions: Base Case & 3 Aggressive Mitigation (CO_2 only) Cases:



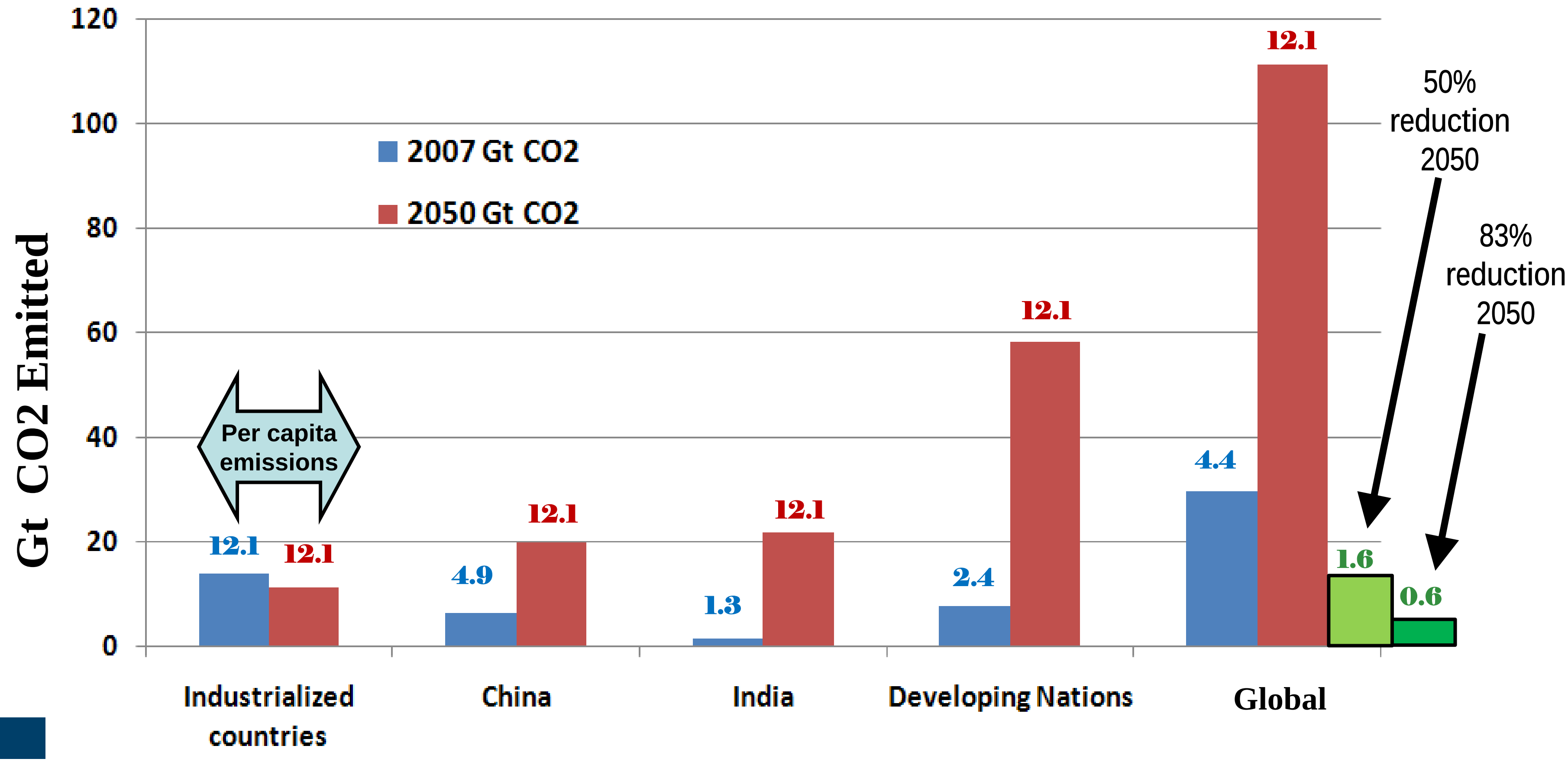
Assumed aggressive mitigation: 2005 to 2012:capped; 2005 to 2020:-17%,2005to2030:-34%;2005 to 2050:-83%

US Per Capita CO_2 (eq) Emissions in 2006 Versus President Obama's 83% Reduction Goal for 2050



Industrialized Countries' Per Capita Emission Rate Not Sustainable Globally

Assumptions: By 2050 all countries achieve current industralized per capita rate of 12.1 ton/yr & population growth slows; 9.2 billion in 2050 (Note: US per capita rate =19.5)



What Can Be Done to Move Humanity To a Sustainable Path?

- **Develop/utilize low carbon/low resource intensive technologies; *focus of this presentation***
- Humanity Makes Fundamental Lifestyle Changes
- For climate change, change Earth's heat transfer characterisitics to compensate for GHG emissions, i.e., geoengineering

Social Responses to Climate Change

Easier

- Individual decisions to minimize environmental footprint
  - Use more efficient light bulbs
  - Conscientious recycling
  - Purchase fuel efficient car; minimize driving
  - Purchase/maintain energy efficient heating/cooling
- Societies make fundamental lifestyle changes
  - Materials mgt; focus on recycling & minimum use of new materials
  - Limitations on embodied & energy use for new buildings
  - Limits on per capita transportation emissions; focus on mass transit, minimize air travel
  - Restrictive use of land; focus on forest expansion
  - Move toward a vegetarian diet
  - Population stabilization

Harder

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In July 2010 IEA Updated the 2008 version of Energy Technology Perspectives

- Mandate by G-8 Leaders and Energy Ministers
- In light of IPCC (2007), they analyzed *Blue* scenario to limit warming to ~ 2.3 C; this requires 2050 emissions to be 1/2 of 2005 values (1.5% annual reduction for 45+ years)
- They concluded:

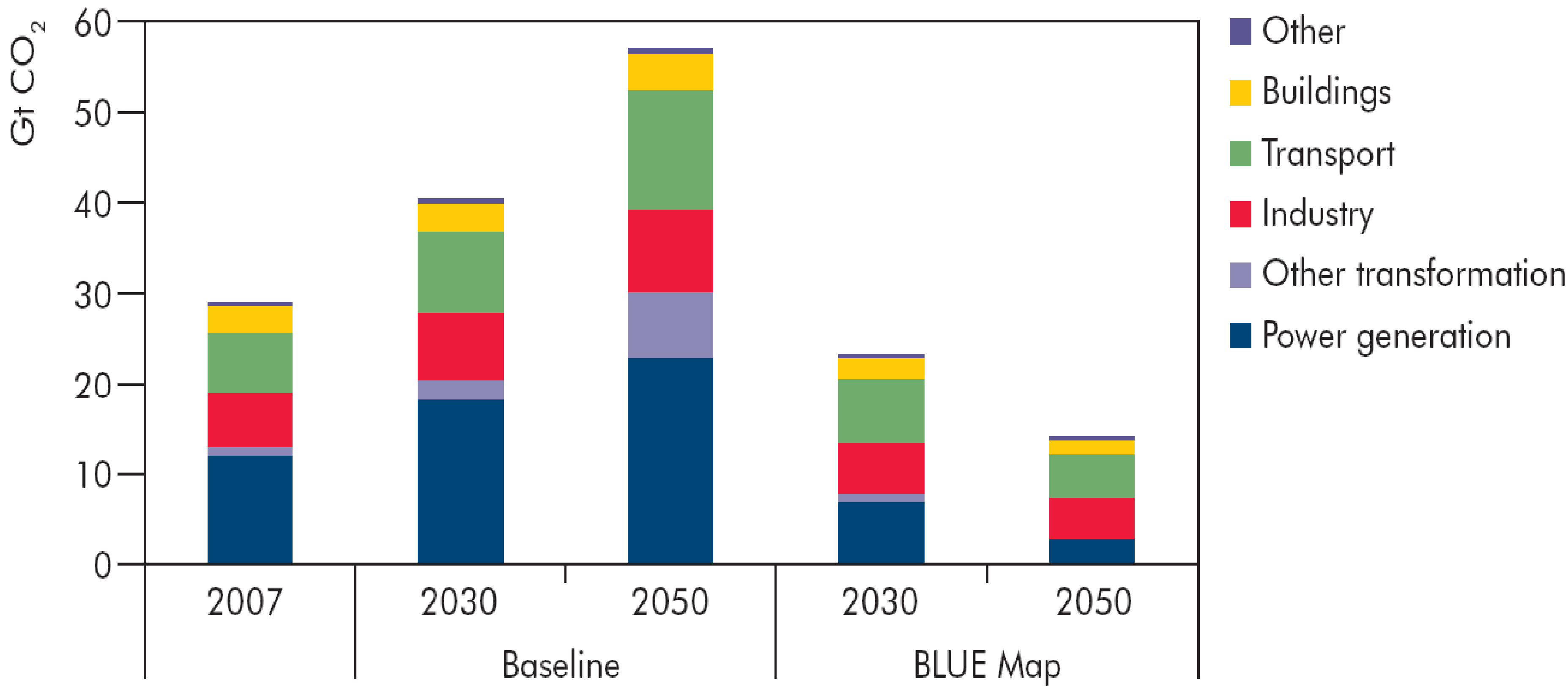
"We are facing serious challenges in energy sector"

"A global revolution is needed in ways that energy is supplied and used"

"The Blue scenarios require urgent implementation of unprecedented and far reaching new policies in the energy sector"

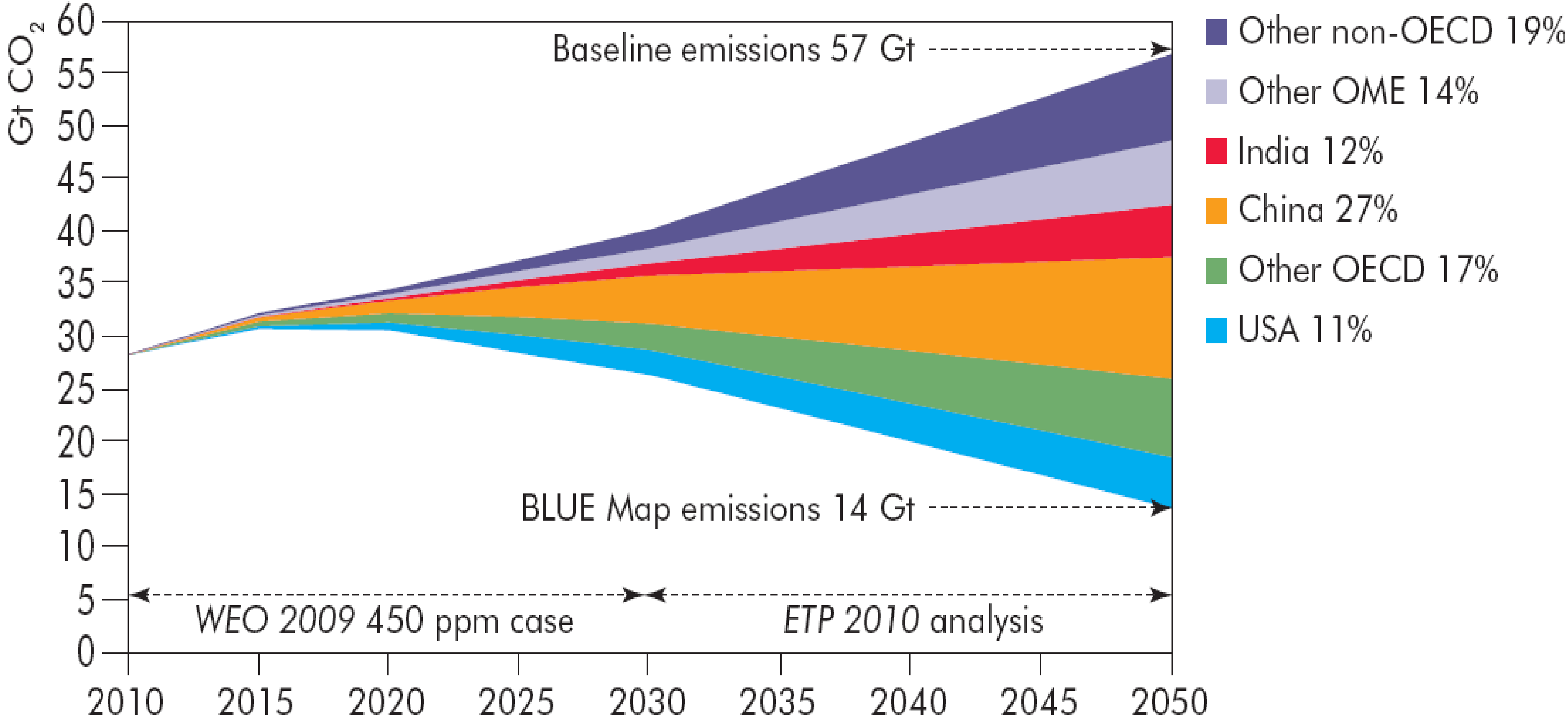
IEA CO2 Projections: Baseline and Blue Scenarios

Gt CO2



Source: IEA Energy Technology Perspectives 2010

World Energy Related CO2 Emissions by Region; Baseline and Blue Scenarios

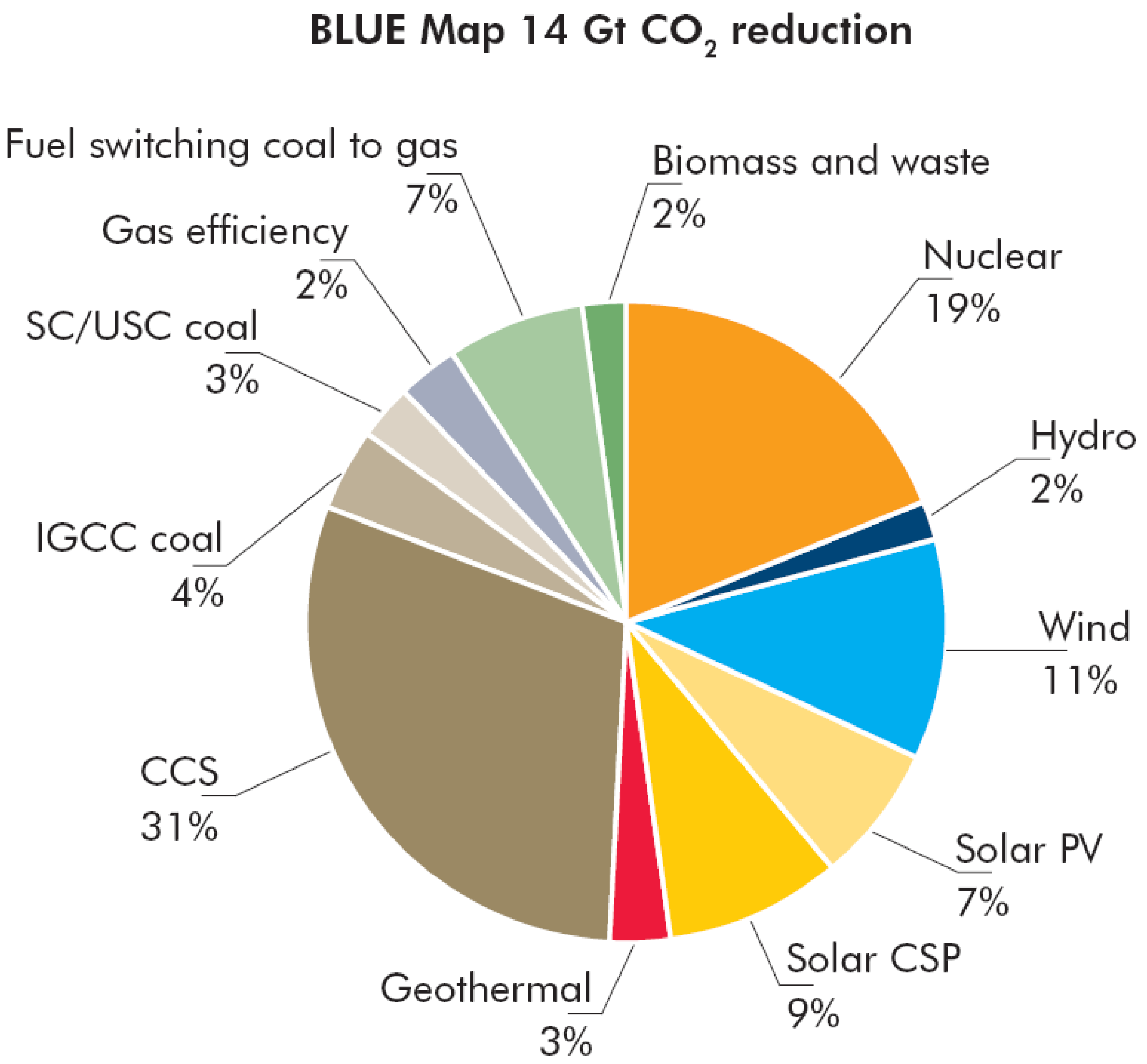


Source: IEA Energy Technology Perspectives 2010

Power Generation Mitigation; a Critical Sector

- **Worldwide energy-related CO_2 emissions from coal use are expected to grow substantially through 2030**
- **Since coal-fired power plants are large sources, they potentially offer attractive opportunities for cost-effective reductions in CO_2**
- **Upgrading existing boilers to enhance efficiency will only yield modest CO2 reductions**
- **Considering the climate change challenge, rapid development & utilization of CCS technologies for coal-fired power plants is needed; special focus should be on China & India since they have expanding & continue to expand coal capacity so aggressively**
- **Time is not on our side, mitigative action needed in the near term**

Contributions of Key Power Sector Technologies to Achieve Blue Scenario Emission Reductions



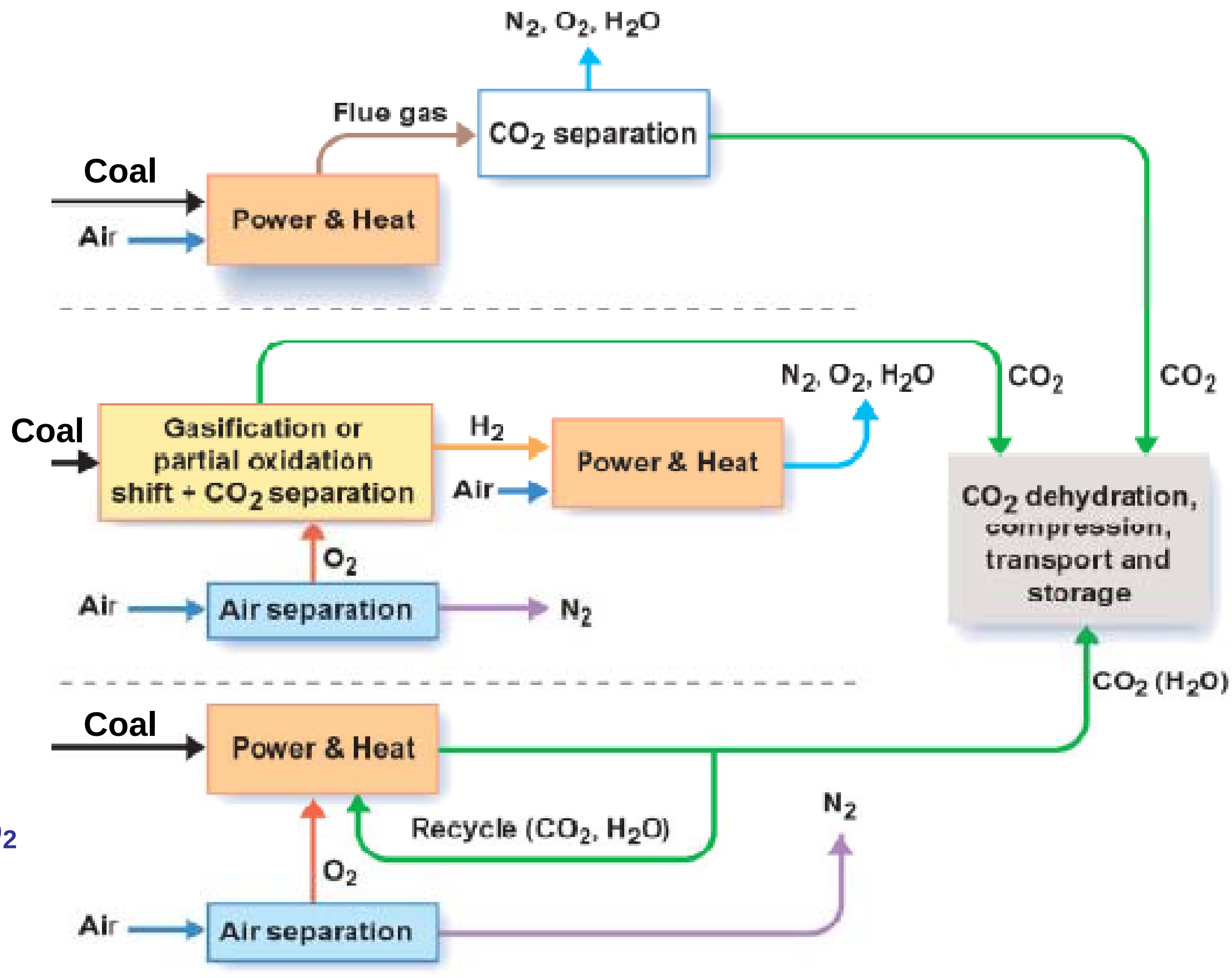
Source: IEA Energy Technology Perspectives 2010

Carbon Capture Technologies (the CC part of CCS)

Post - combustion CO_2 Capture

IGCC: Pre-combustion CO_2 Capture

Oxy-fuel Combustion CO_2 Removal

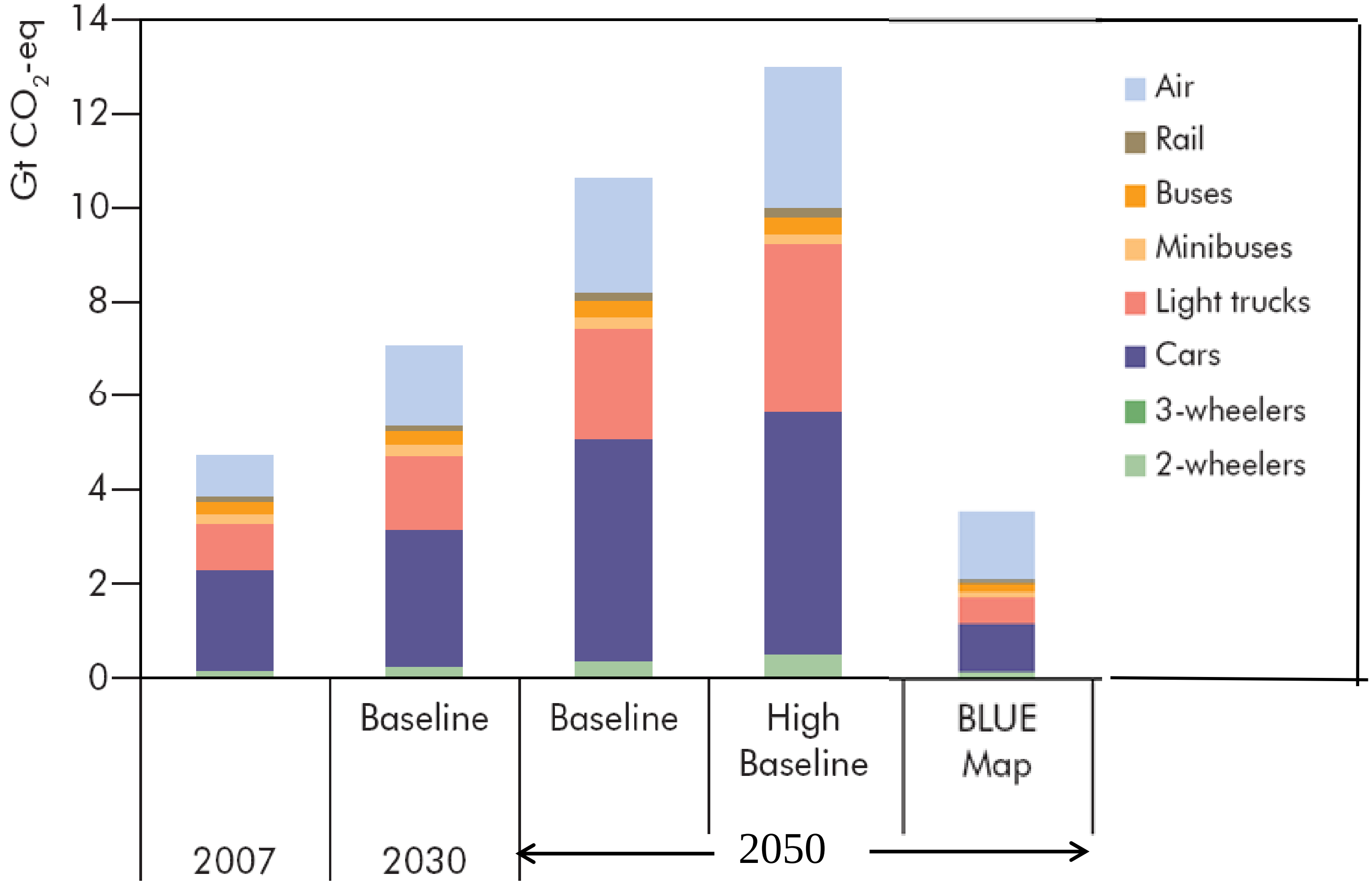


CCS Projected to Play Key Role; However Formidable Challenges

- Capture technologies in various stages of development; energy penalty 20 to 30%
- Retrofit with CCS difficult; challenging requirements include: space, water & proximity to sequestration sites
- Pre-combustion/gasification technology, closest to commercial, can not be readily retrofitted
- The most productive role for CCS in the US may be for *new* coal & gas-fired units; retrofits may be needed in China and India
- Underground sequestration unproven at required scale; long term stability, safety, environmental and legal issues unresolved
- In order to fulfill the requirements of the Blue Scenario 900,000 Mw(e) of CCS needed by 2050

Projected Global Greenhouse Gas Emissions for Transportation

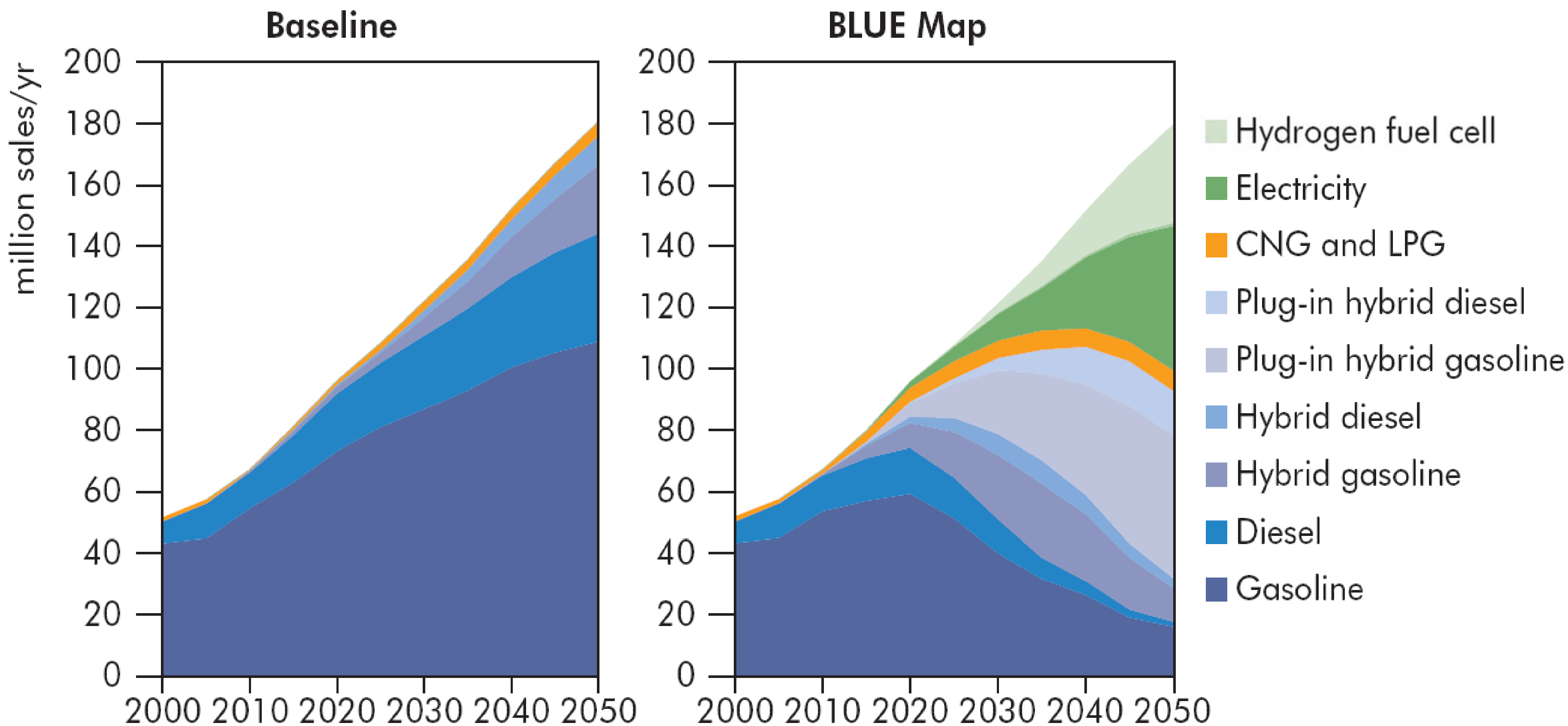
Baseline Versus Blue Scenarios



Source: IEA Energy Technology Perspectives 2010

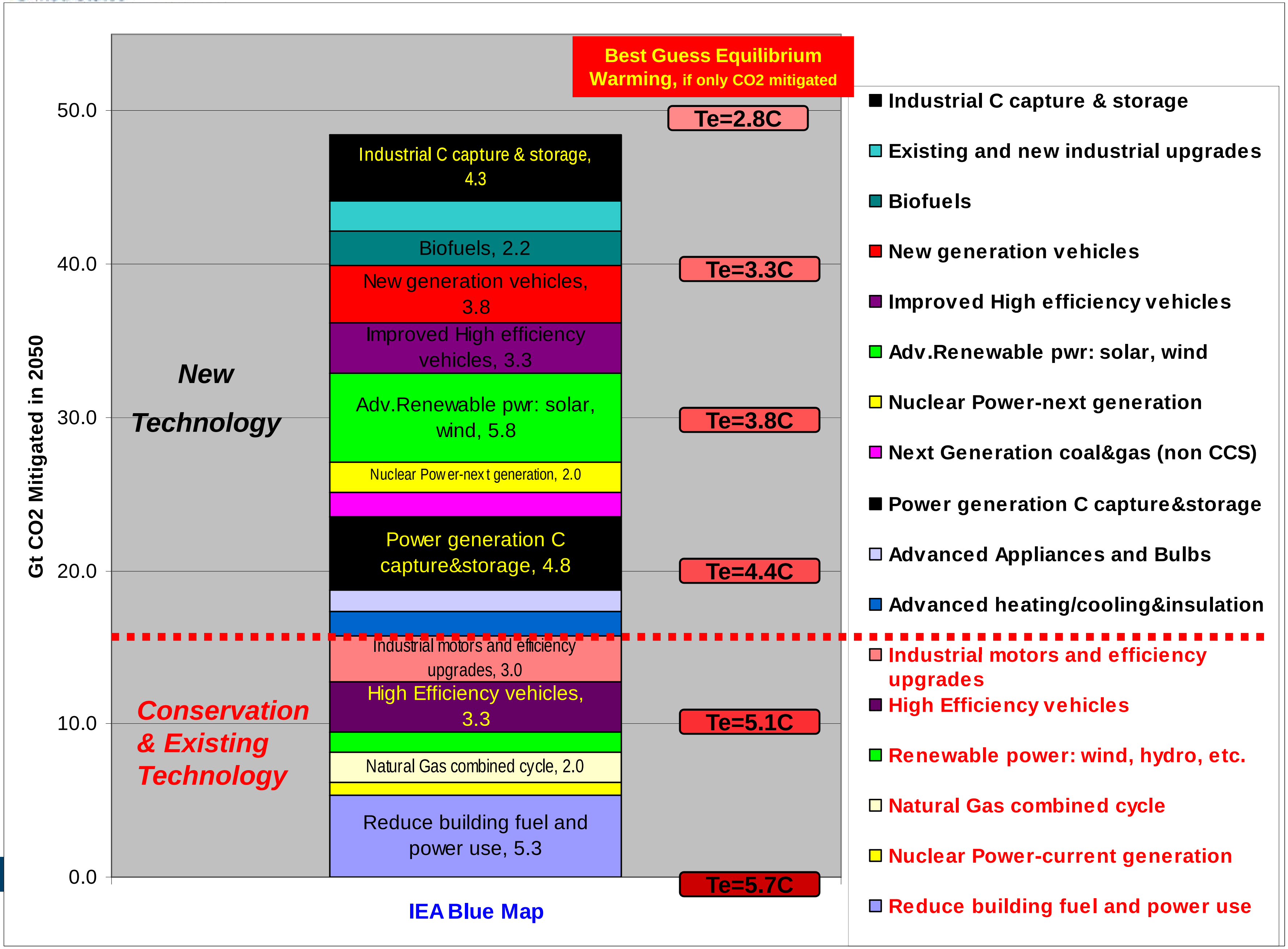
Projected Auto Sales by Technology

Baseline Versus Blue Scenarios



Source: IEA Energy Technology Perspectives 2010

Energy Technology Categories-existing & new: their potential to mitigate global Gt CO_2 in 2050 and impact on equil. warming, T_{eq}



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IEA Estimate of RD&D Funding Gap to Meet Blue Scenario; by Technology

	Annual investment in RD&D needed to achieve the BLUE Map scenario outcomes in 2050 (USD million)[1]	Current annual public RD&D spending (USD million)[2]	Estimated annual RD&D spending gap (USD million)
Advanced vehicles (includes EVs, PHEVs + FCVs; energy efficiency in transport)	22 500 – 45 000	1860	20 640 – 43 140
Bioenergy (biomass combustion and biofuels)	1 500 – 3 000	740	760 – 2 260
CCS (power generation, industry, fuel transformation)	9 000 – 18 000	540	8 460 – 17 460
Energy efficiency (industry)[3]	5 000 – 10 000	530	4 470 – 9 470
Higher-efficiency coal (IGCC + USCSC)[4]	1 300 – 2 600	850	450 – 1 750
Nuclear fission	1 500 – 3 000	4 030	0[5]
Smart grids	5 600 – 11 200	530	5 070 – 10 670
Solar energy (PV + CSP + solar heating)	1 800 – 3 600	680	1 120 – 2 920
Wind energy	1 800 – 3 600	240	1 560 – 3 360
Total across technologies	50 000 – 100 000	10 000	40 000 – 90 000

Source: IEA Energy Technology Perspectives 2010

Recent Trends are Deepening the Challenge

- Emissions are growing at >3% annual rate again (5.9% in 2010)*
- Emerging economies are growing fast with high dependence on fossil fuels; 80% of power stations in use in 2020 are either built or under construction *
- Following the tsunami damage at Fukushima, Japan and Germany have called a halt to their nuclear programs
- U.S. budget battles don't bode well for an expanded energy technology program
- United Nations-led negotiations on a new global treaty on climate change have stalled

* *IEA, 2011*

The Climate Change Technology Challenge

- **Man is pumping CO_2 in the atmosphere at unprecedented rates; 32 billion tons last year, and growing at 3% annually from 2000 to 2010. Although US is large emitter, much of recent growth is due to China; key drivers: economic and population growth**
- **It is too late to avoid substantial warming and significant impacts; at least 2 C inevitable, the challenge remaining: avoid catastrophic warming. Limiting warming to below 2.5 C will be a monumental challenge; growth rate of 3% must change to >-2%; sooner control starts, the better**
- **Available technology if aggressively utilized, will only avoid about 40% of required CO_2 by 2050; *next generation low emission/high efficiency technologies need to be developed and utilized ASAP***

The Climate Change Technology Challenge-continued

- **Major technology advances necessary, especially in critical power generation and mobile source sectors; *carbon capture and storage, renewables, nuclear reactors, and low emission vehicles are critical technologies***
- **In a carbon constrained world coal is projected to continue to play an important role, but only if CCS is extensively utilized**
- **Research funding is grossly inadequate; "too few eggs in too few baskets". *FY 2009 Stimulus funding & ARPA-E funding - steps in the right direction***
- ***IEA, 2008: "A global revolution is needed in ways that energy is supplied and used*"**
- **Technology is necessary but not sufficient, aggressive global mitigation commitments needed**
- ***Given the monumental nature of the mitigation challenge, it appears prudent assess what cultural changes can be considered to move humanity toward a more sustainable culture and to analyze the feasibility of geoengineering options***

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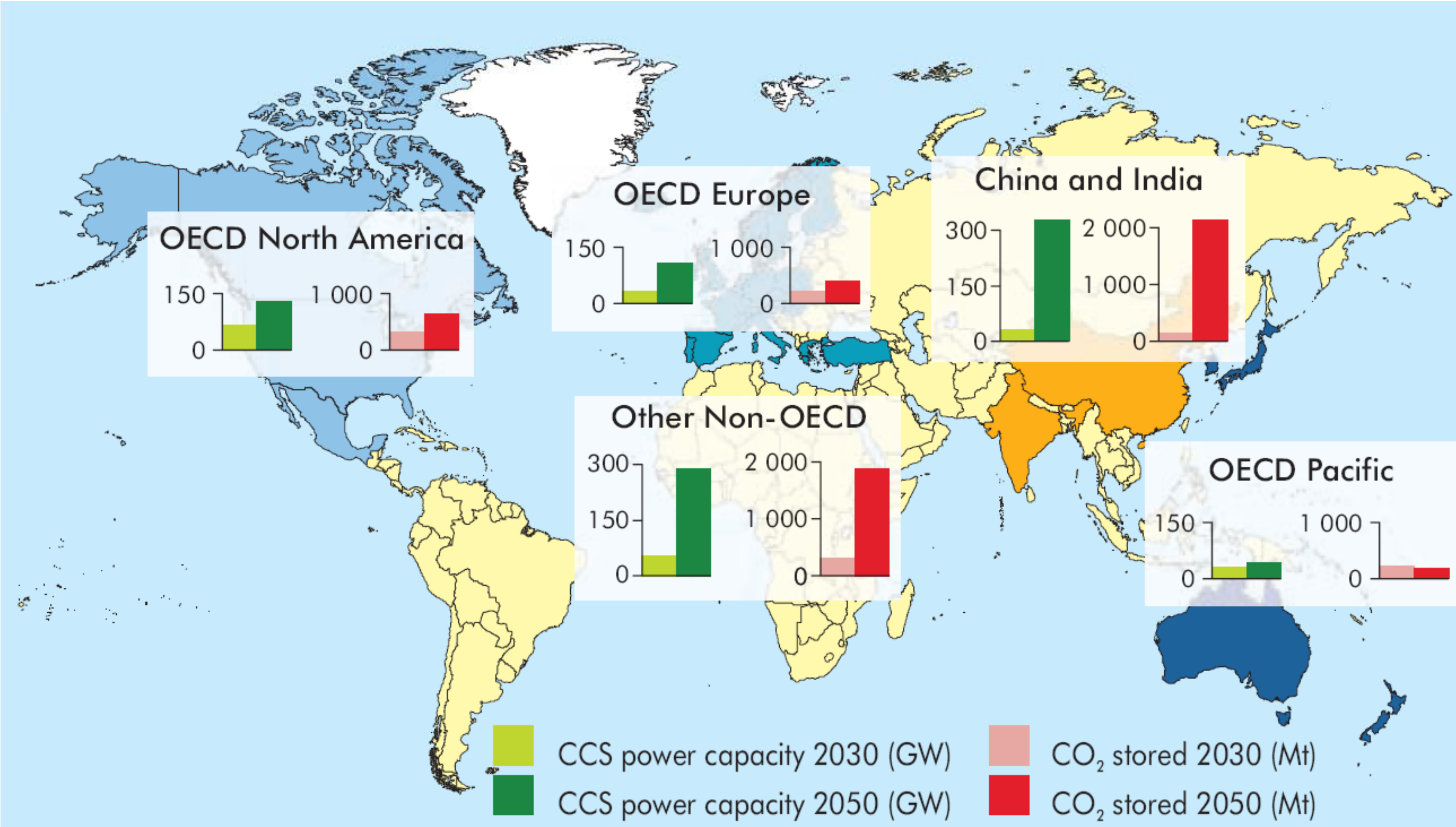
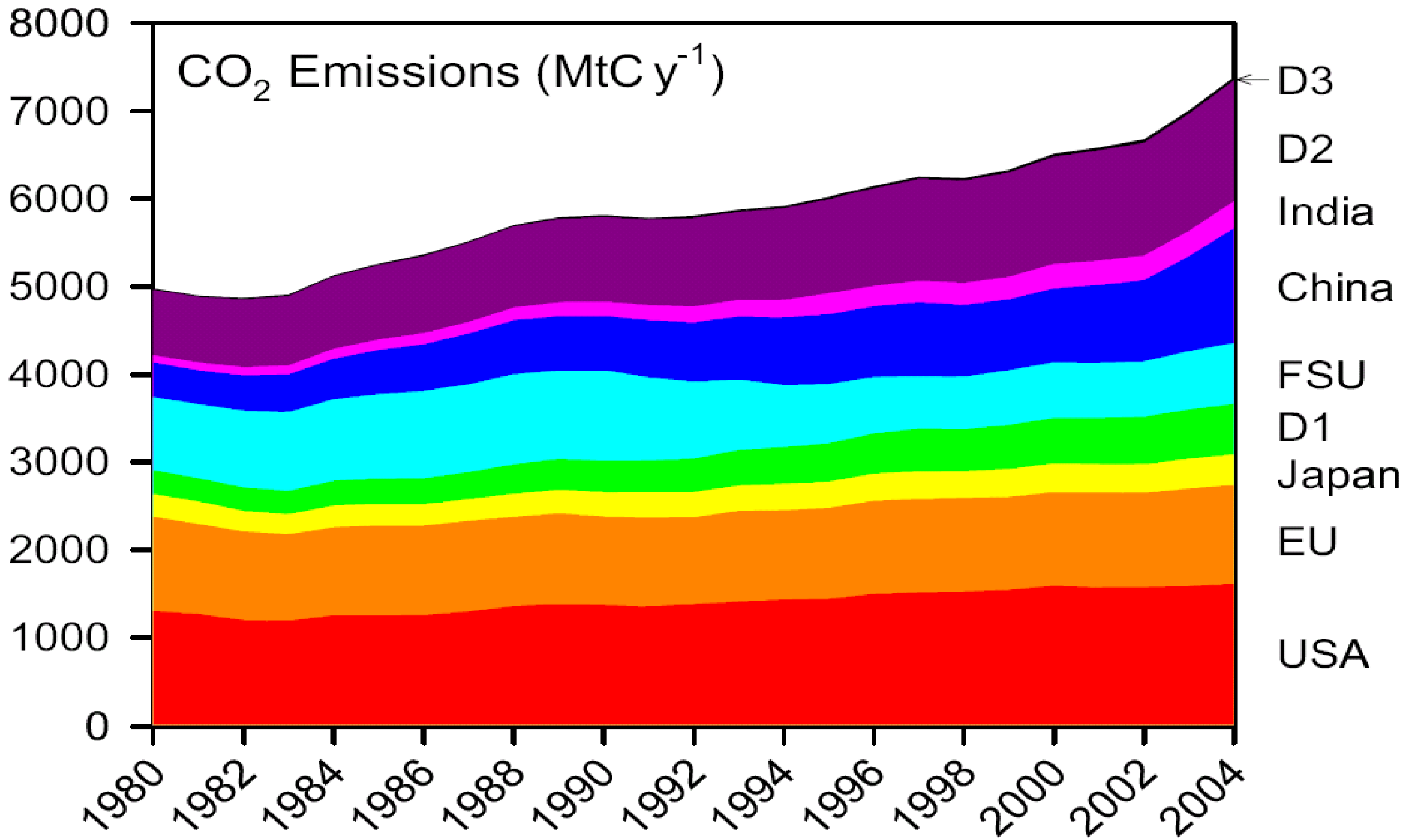
Our Stakeholders Count on Us;
They will reap from seeds we sow

Regional Deployment of CCS for Power Generation: Blue Scenario



Source: IEA Energy Technology Perspectives 2010

Most Recent CO_2 Emission Data by Countries and Sectors



FSU=republics of the former Soviet Union,
D1=15 other developed nations, including Australia, Canada, S. Korea and Taiwan,
D2=102 actively developing countries, from Albania to Zimbabwe and
D3= 52 least developed countries, from Afghanistan to Zambia.

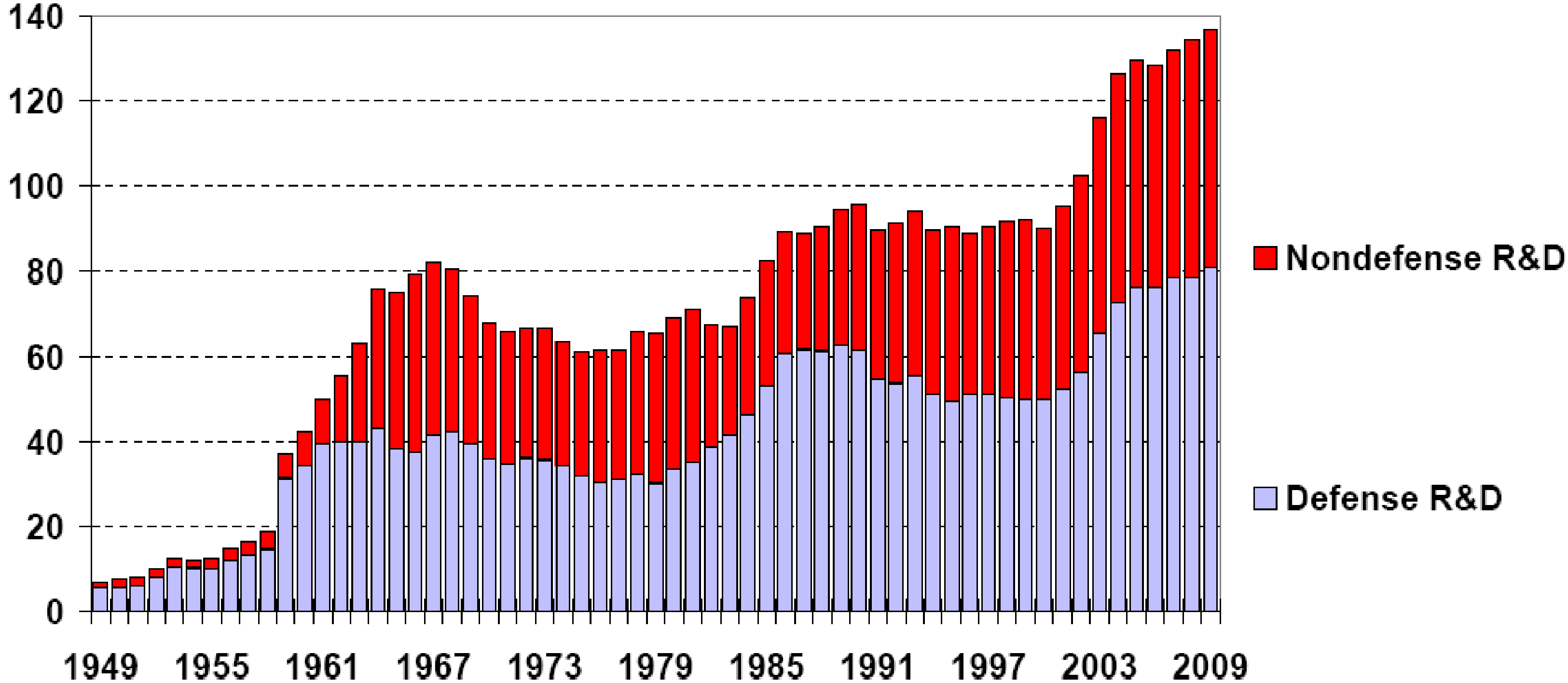
United States Environmental Protection Agency

The Book: Global Climate Change-the Technology Challenge; Chapters & Authors

Number	Chapter Title	Author(s)
1	The Global Climate Mitigation Challenge, Overview	Frank. Princiotta, EPA/ORD
2	Power Generation-Coal and Biomass	Jim Katzer- Exxon Mobil, retired; MIT,retired
3	Coal and Biomass to Liquid Fuels	Jim Katzer- Exxon Mobil, retired; MIT, retired
4	Power generation-nuclear	Anthony Baratta, Nuclear Regulatory Commission
5	Power Generation-Renewables	International Energy Agency, From Energy Technology Perpectives
6	Mobile Sources	Michael Walsh, consultant, prevously served as Director of EPA's motor vehicle pollution control efforts.
7	Buildings (with consideration of health impacts)	Bob Thompson, Jim Jetter, David Marr, Clyde Owens, EPA/ORD
8	Industrial Sources	Ravi Srivastava and Samudra Vijay, EPA ORD
9	Geoengineering: Direct Mitigation of Climate Change	Brooke Hemming, Gayle Hagler EPA/ORD
10	Research, Development, Demonstration and Deployment Challenges	Bruce Rising, Siemens Corp.
11	Role of Technologies in Developing Economies	Sumudra Vijay, ORISE, EPA, Ananth Chikkatur, JFK School of Government
12	Environmental consequences of next generation energy technologies	Andy Miller, Cynthia Gage, EPA/ORD

Federal Spending on Defense and Nondefense R&D

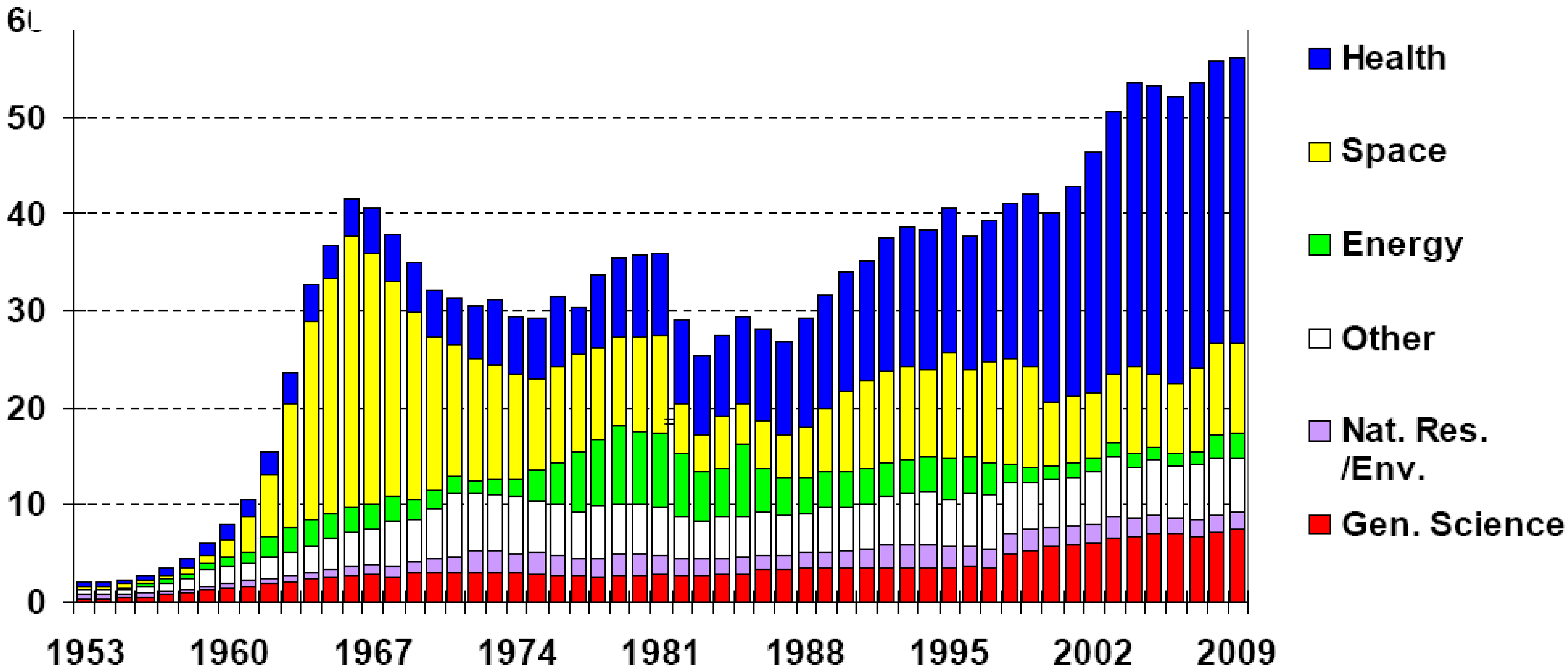
Outlays for the conduct of R&D, FY 1949-2009, billions of constant FY 2008 dollars



Source: AAAS, based on OMB Historical Tables in *Budget of the United States Government FY 2009*. Constant dollar conversions based on GDP deflators.
FY 2009 is the President's request.
Note: Some Energy programs shifted to General Science beginning in FY 1998.
FEB. '08 © 2008 AAAS

Trends in Nondefense R&D by Function, FY 1953-2009

outlays for the conduct of R&D, billions of constant FY 2008 dollars



Source: AAAS, based on OMB Historical Tables in *Budget of the United States Government FY 2009.* Constant dollar conversions based on GDP deflators. FY 2009 is the President's request.

Note: Some Energy programs shifted to General Science beginning in FY 1998.

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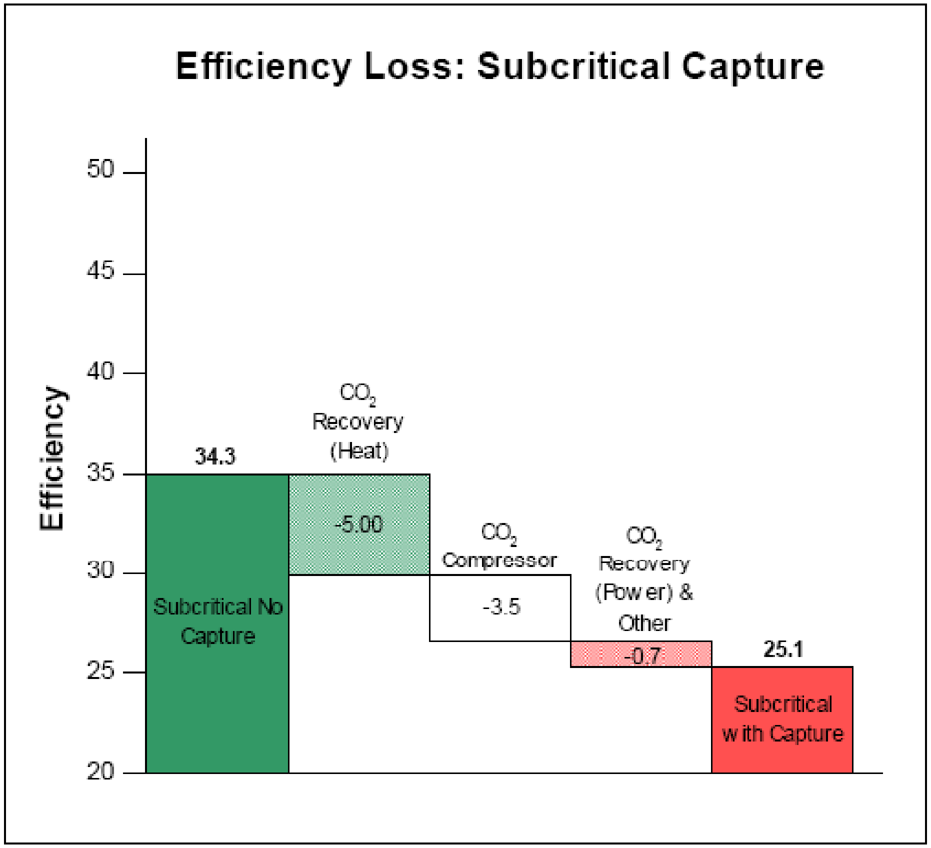
Amine-based Post-combustion Capture: Example Efficiency Loss



Losses cause the efficiency to drop by 9.2 points from 34.3% to 25.1%. For supercritical and USC plants, the same losses would be experienced in terms of category and quantity, and the losses are simply subtracted from a higher original efficiency. For example, an USC plant with an efficiency of 43.3% would lose 9.2 efficiency points to have an efficiency of 34.1% with capture.

Source: The Future of Coal, MIT, 2007

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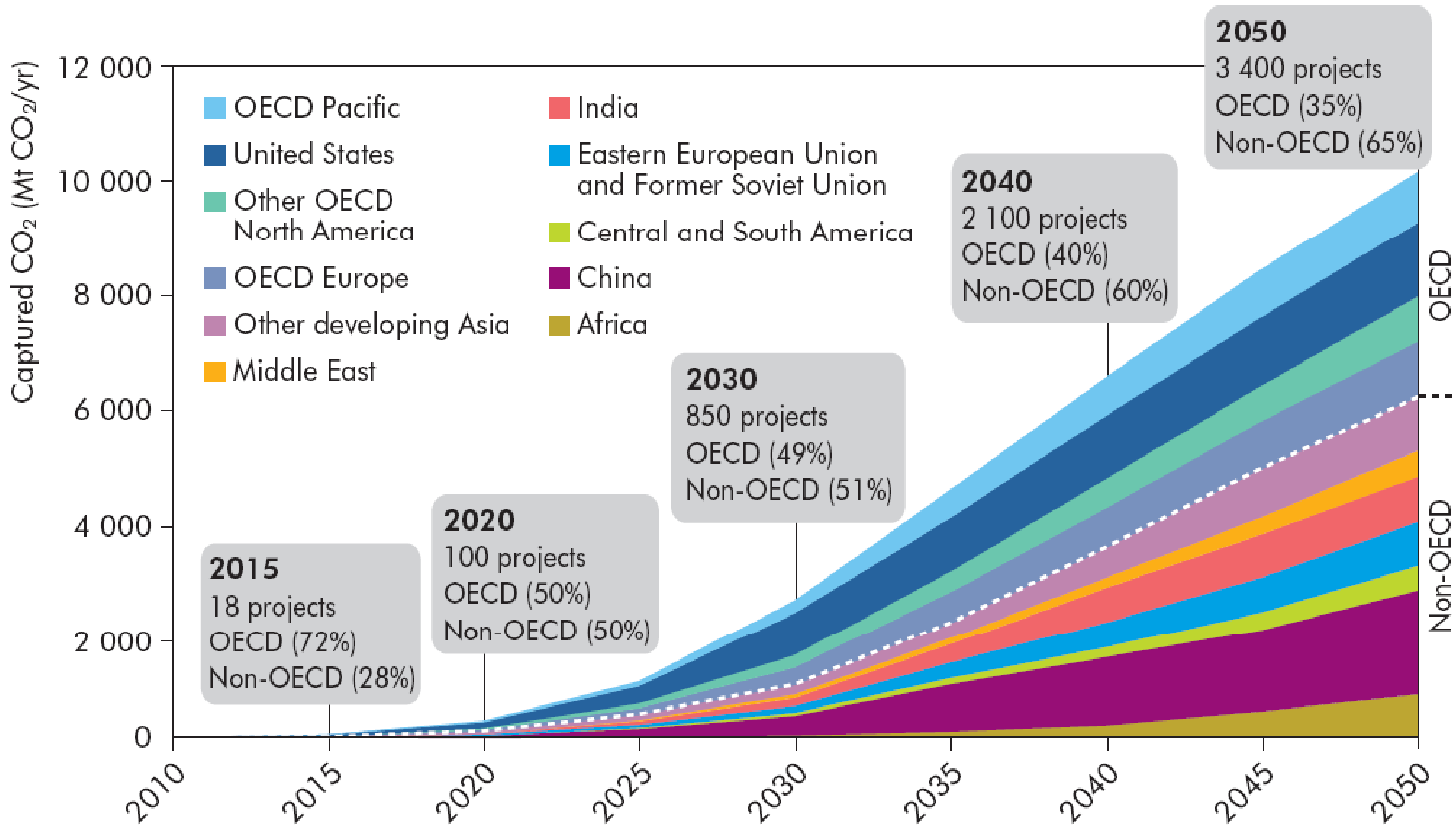
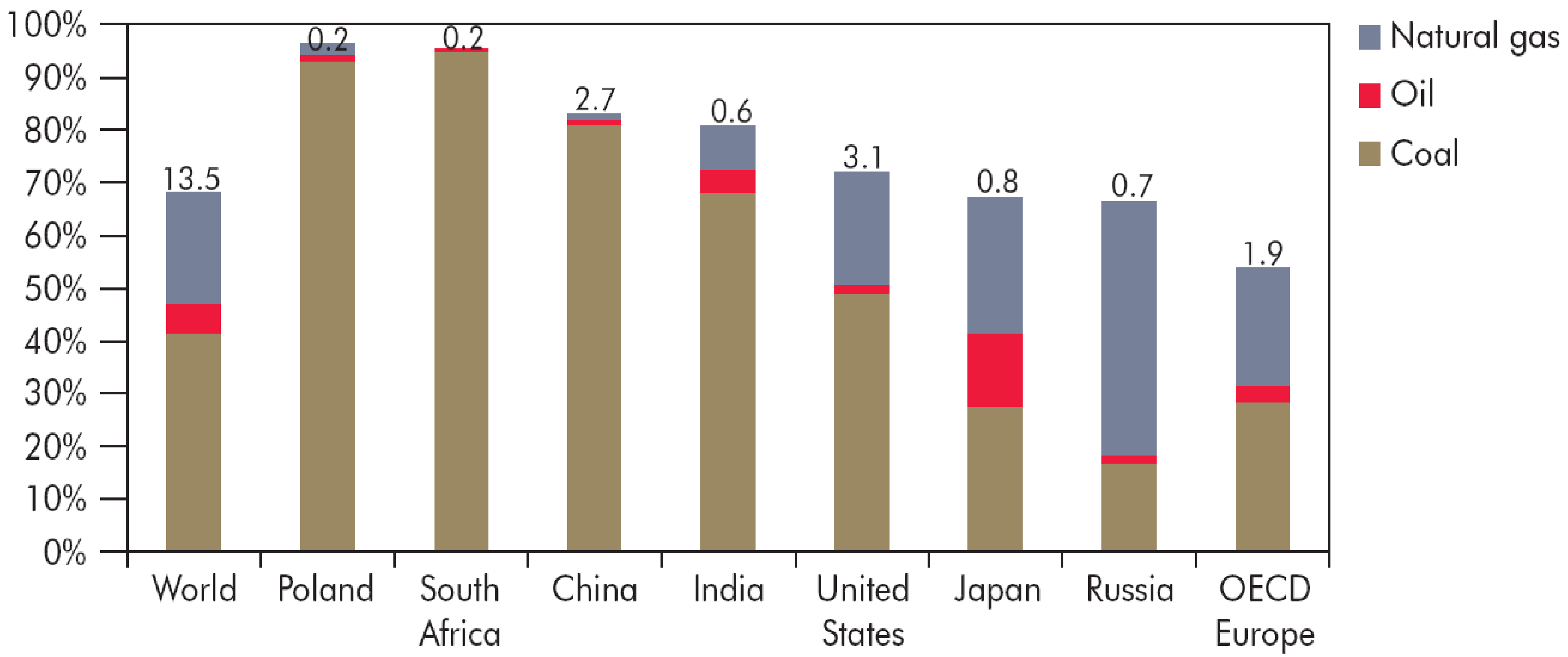
Aggressive Use of CCS needed to Meet Blue Scenario



Source: IEA Energy Technology Perspectives 2010

Coal is a critical component of electricity generation for many Countries



Source: IEA Energy Technology Perspectives 2010

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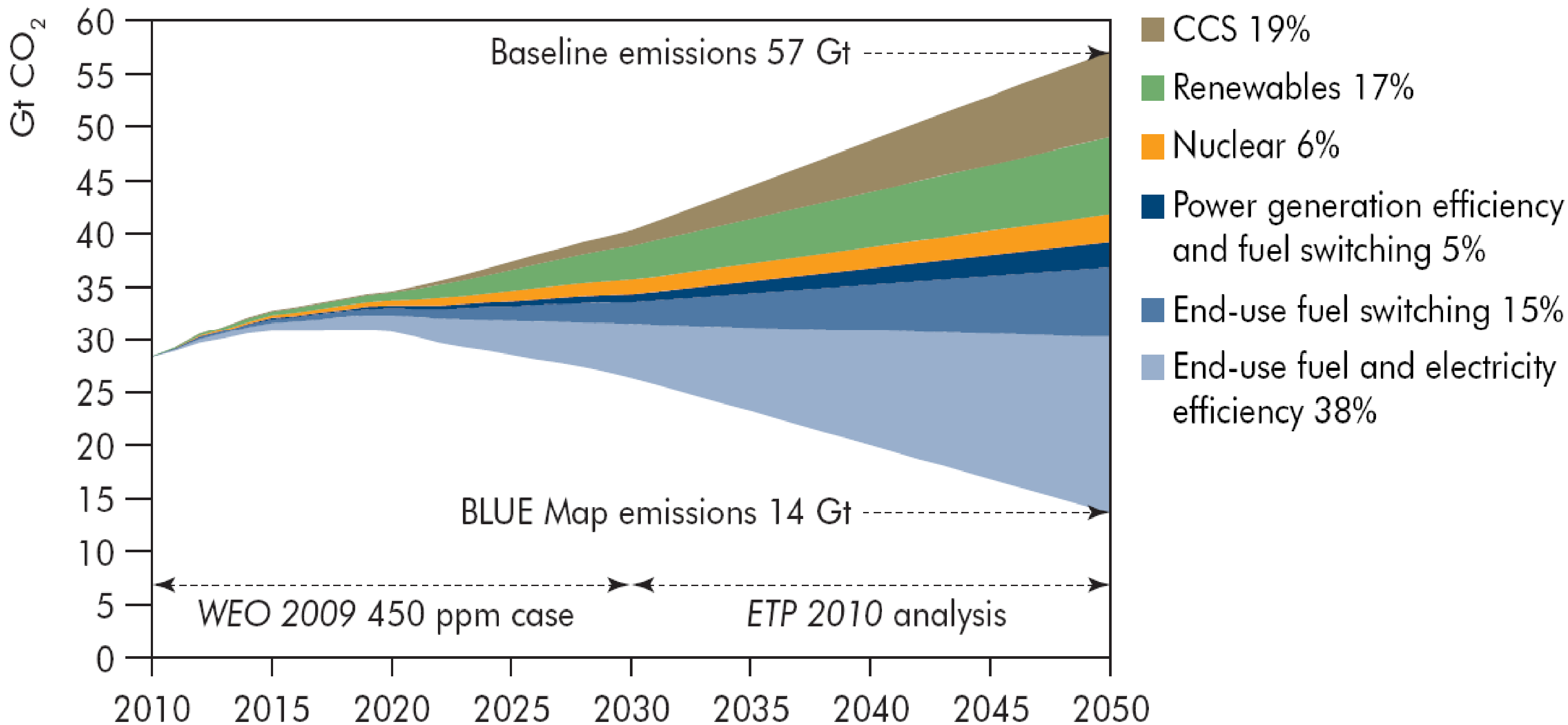
Comparison of Energy R&D Scenarios Versus Historical Government R&D Initiatives

Program	**Sector**	**Years**	**Additional spending over program duration (2002$ Billions)**
Manhattan Project	Defense	1942-45	$25.0
Apollo Program	Space	1963-72	$127.4
Project Independence	Energy	1975-82	$25.6
Reagan defense	Defense	1981-89	$100.3
Doubling NIH	Health	1999-04	$32.6
War on Terror	Defense	2002-04	$29.6
5x energy scenario	***Energy***	***2005-15***	***$47.9***
10x energy scenario	***Energy***	***2005-15***	***$105.4***

Source: Kammen and Nemet (2005) "Reversing the Incredible Shrinking US Energy R&D Budget" Issues on Science and Technology

Key Technologies to Achieve Blue Scenario Emissions; all sectors



Source: IEA Energy Technology Perspectives 2010

Power Generation Sector-Key Technologies Impact in 2050, *Gt CO2 per IEA, Cont'd*

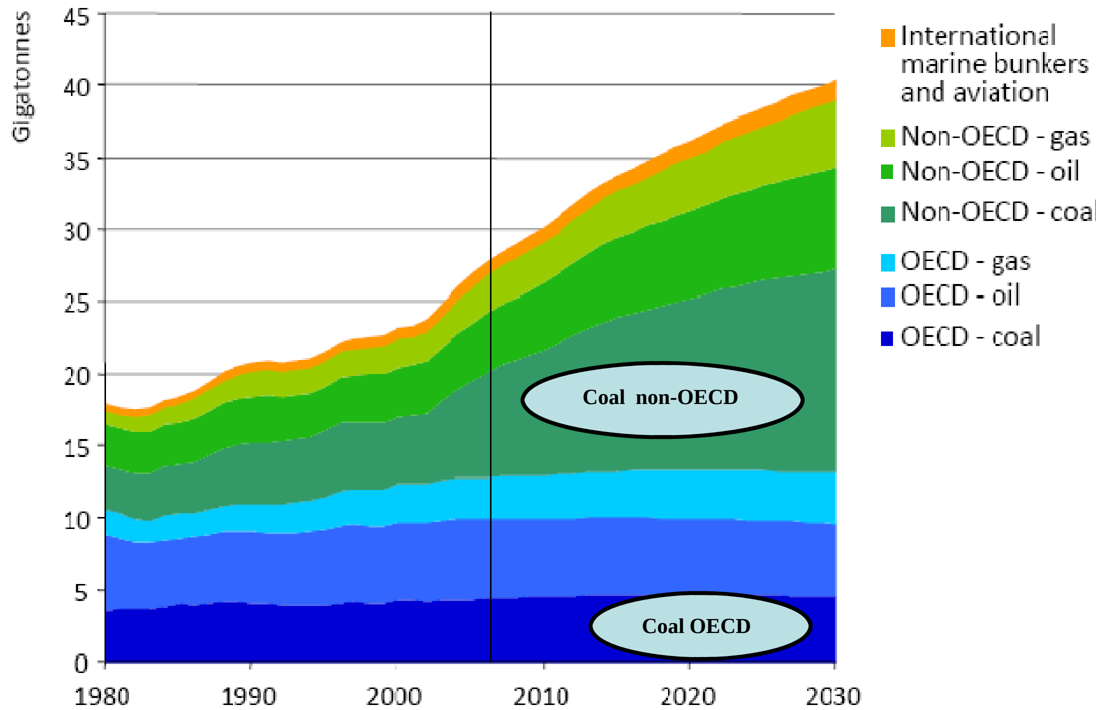
Candidate Technologies for CO2 Mitigation From Power Generation (projected impact in Gt/year of CO_2)

Technology	Blue 2050 Impact	Current State of the Art	Issues	Technology R,D&D Needs
Pre-combustion **Coal IGCC with CO_2 Capture and Storage**	**1.6**	*IGCC*: early commercialization, *Underground storage (US)*: early development.	*IGCC*:High capital costs, complexity and potential reliability concerns, not retrofittable; *US*: Cost, safety, efficacy and permanency	**High**, *IGCC*: Demos on a variety of coals, hot gas cleanup research; *US*: major program with long term demos evaluating large number of geological formations to evaluate environmental impact, efficacy, cost and safety
Combustion **Pulverized Coal/O_2 with CO_2 Capture and Storage**	**1.6**	Developmental, Underground storage (US): early development.	Although O_2 combustion facilitates CO2 rich stream; O2 production yields major plant derating; *US*: Cost, safety and permanency	**High**, large pilot followed by full scale demos needed, lower cost O_2 production needed, *US* requires major program
Post-Combustion **Pulverized Coal with CO_2 Capture and Storage**	**1.6**	CO2 scrubbing with MEA near commercial for refinery applications, Underground storage (US): early development.	CO_2 scrubbing energy intensive: yielding power output derating & high costs, US: Cost, safety and permanency	**High,** affordable less energy intensive technologies need to be developed and demonstrated, US requires major program

Coal-fired Power Generation: A Key Area of Focus

- Emissions from a total of about 1,000 coal-fired power plants globally were about 8 Gt CO_2 in 2007. This contributed to about 27% of total global CO_2 emissions. (IEA, 2008)
- Worldwide energy-related CO_2 emissions from coal use are expected to grow significantly through 2030.
- Since coal plants are large point sources, they potentially offer attractive opportunities for cost-effective reductions in CO_2.

Energy-related CO_2 Emissions



World Energy Outlook 2008, IEA