The Role of Technology in Mitigating Global Climate Change

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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.

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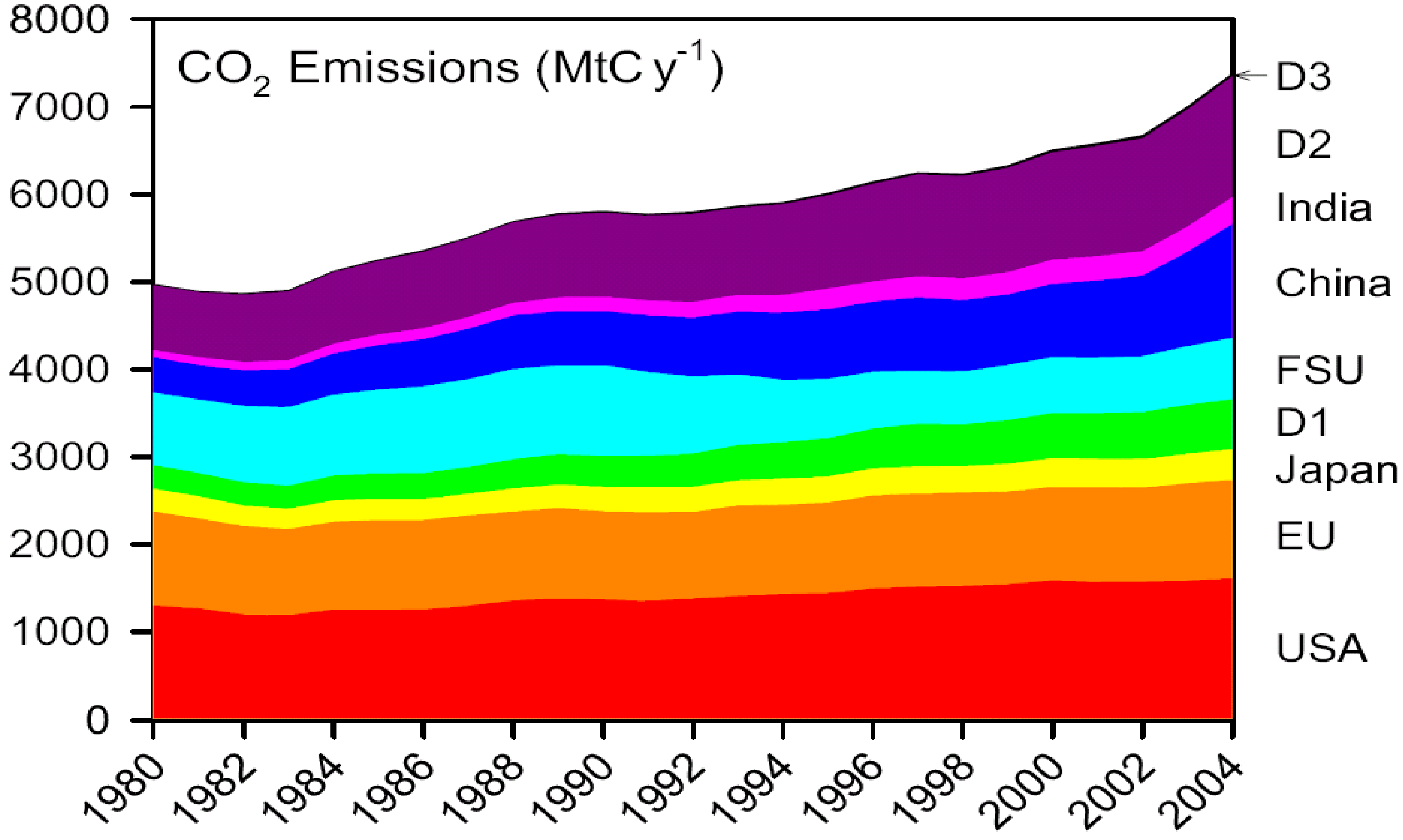
Presentation Objectives

- What are credible warming scenarios given current and projected emission trends? What factors and sectors drive emissions? Which countries are the major emitters?
- What level of emission reductions will constrain warming to acceptable levels?
- What technologies will be needed to constrain emissions to acceptable levels?
- What role can coal, nuclear, renewables play? How important is end use efficiency?
- Are such technologies available and if not is R,D,D&D adequate?

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.

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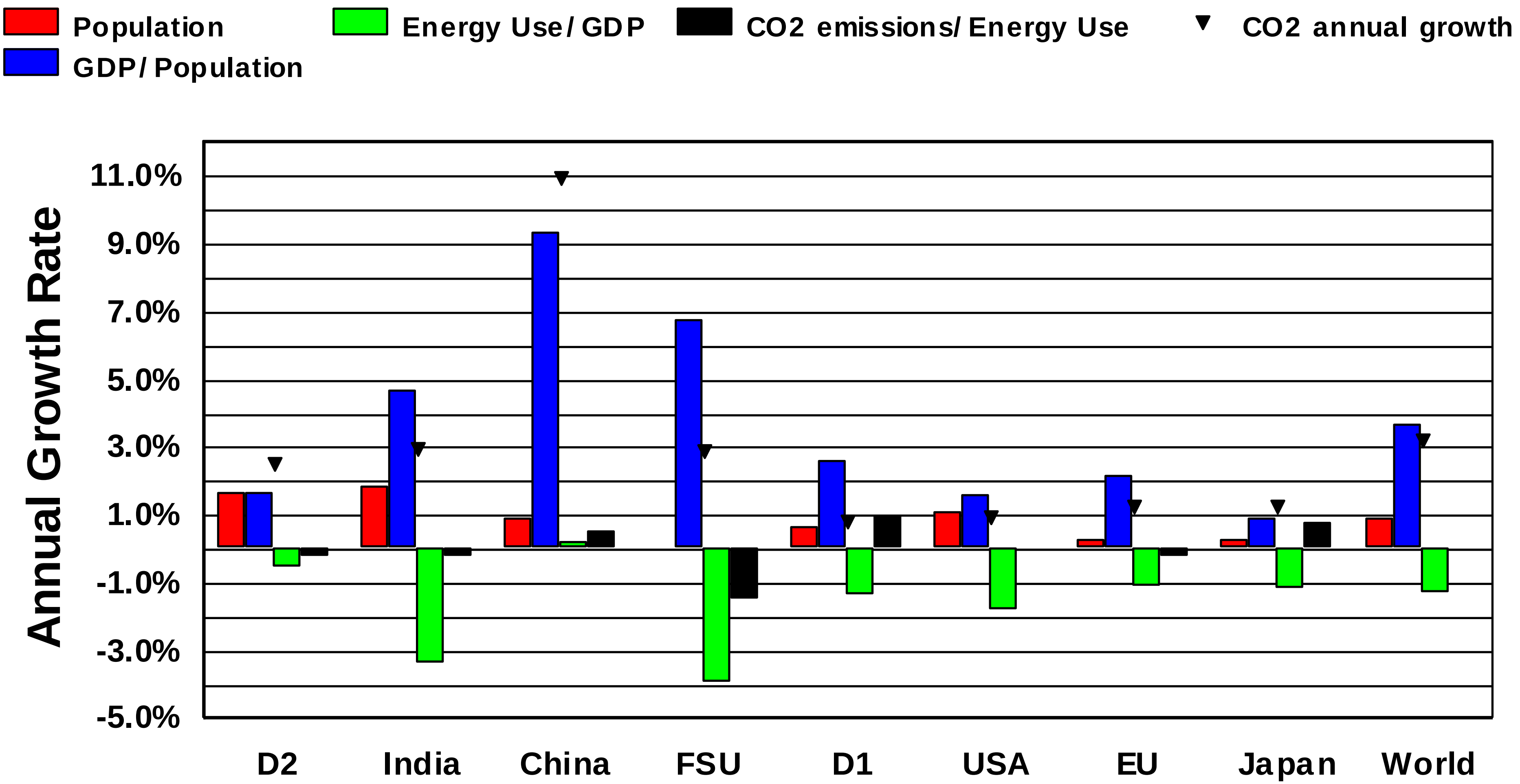
Factors Influencing CO2 Growth Rate; 2000 to 2004



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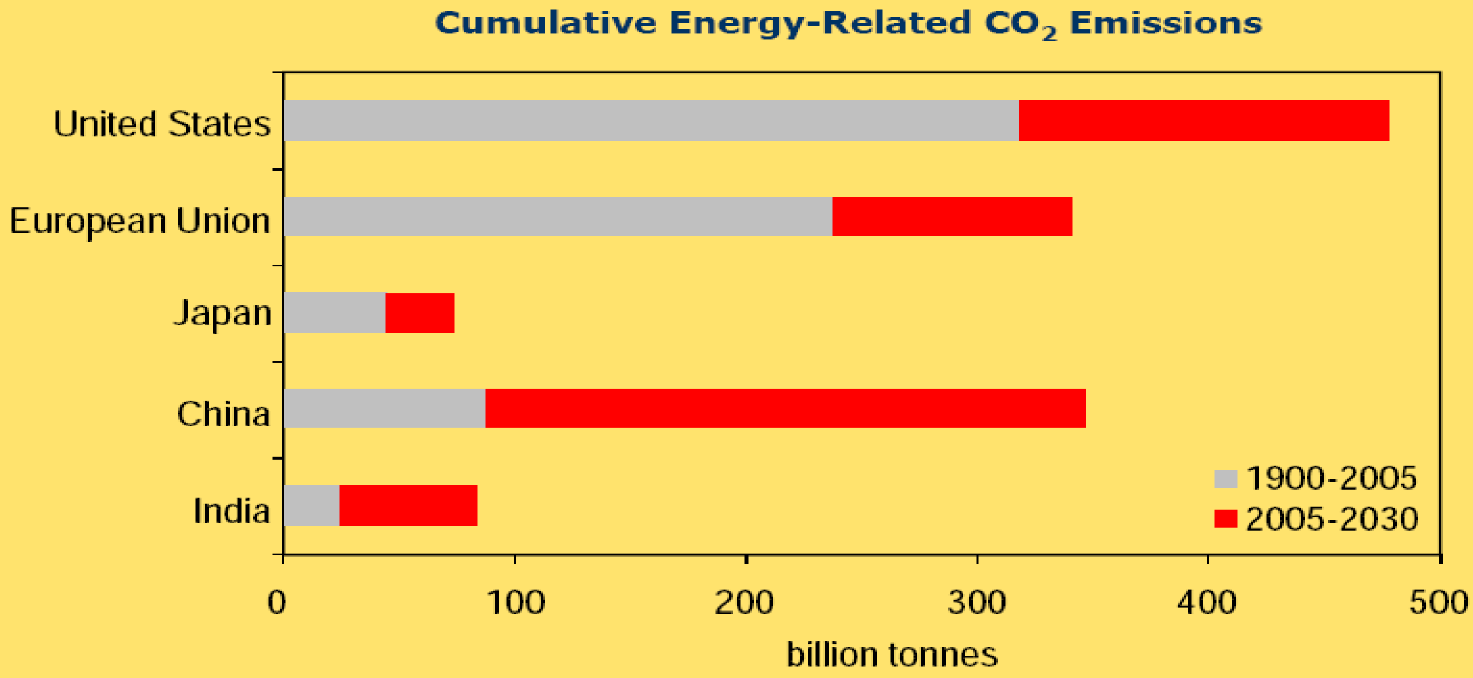
China & India in Global CO_2 Emissions WEO2007 Reference Scenario

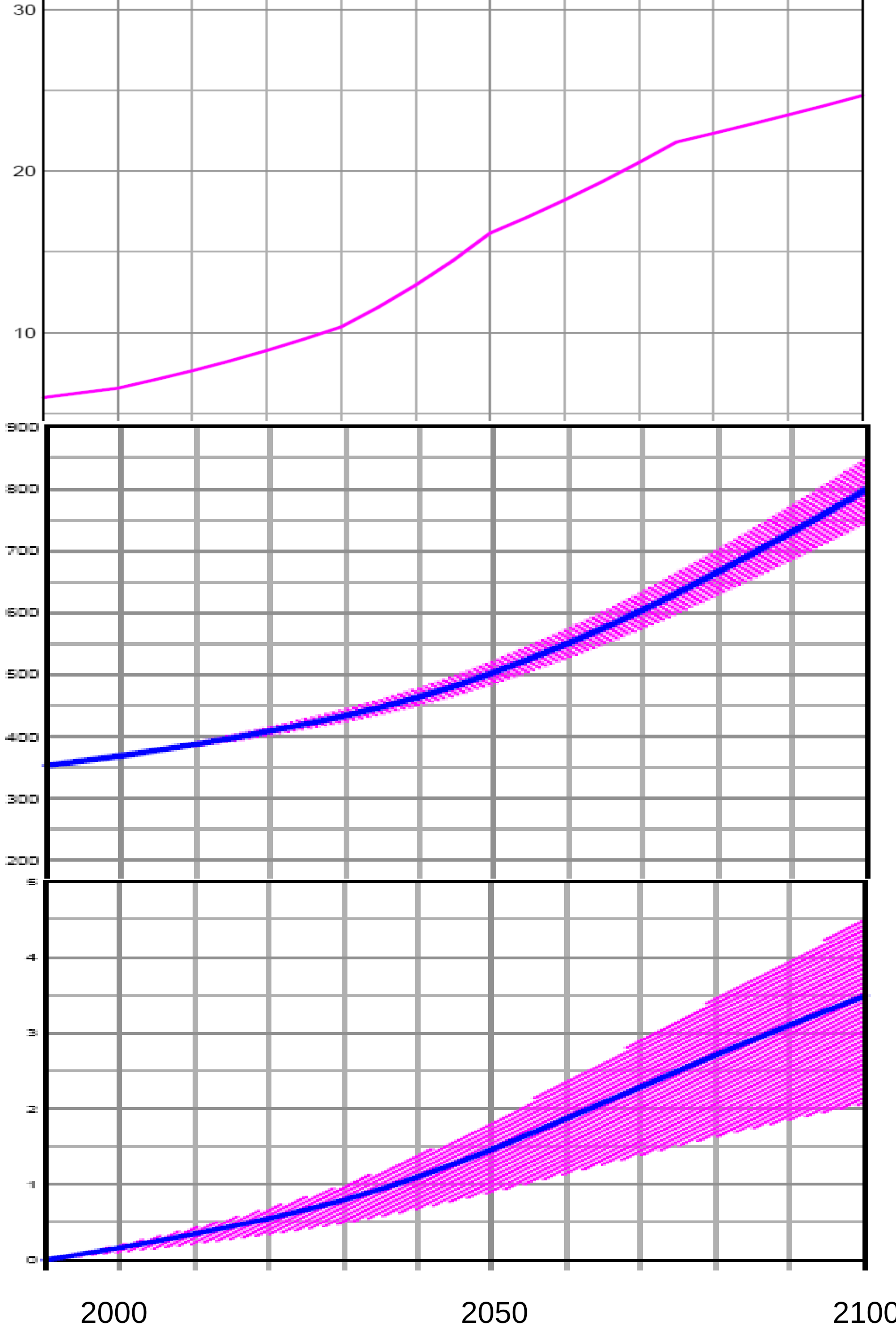


Around 60% of the global increase in emissions in 2005-2030 comes from China & India

CO_2 Emissions
Gt C per Year

CO_2 ppm

Warming
from 1990, C
degree



Assumed Business as Usual emission scenario per IEA (to 2050) extended to 2100 by author, concentration and warming calculations via MAGICC 4.1

Atm. Sensitivity =3.0 C

Equilibrium warming range from pre-industrial; **Low: 2.4 C**, **Best Guess: 4.9 C**, **High: 7.5 C** deg.

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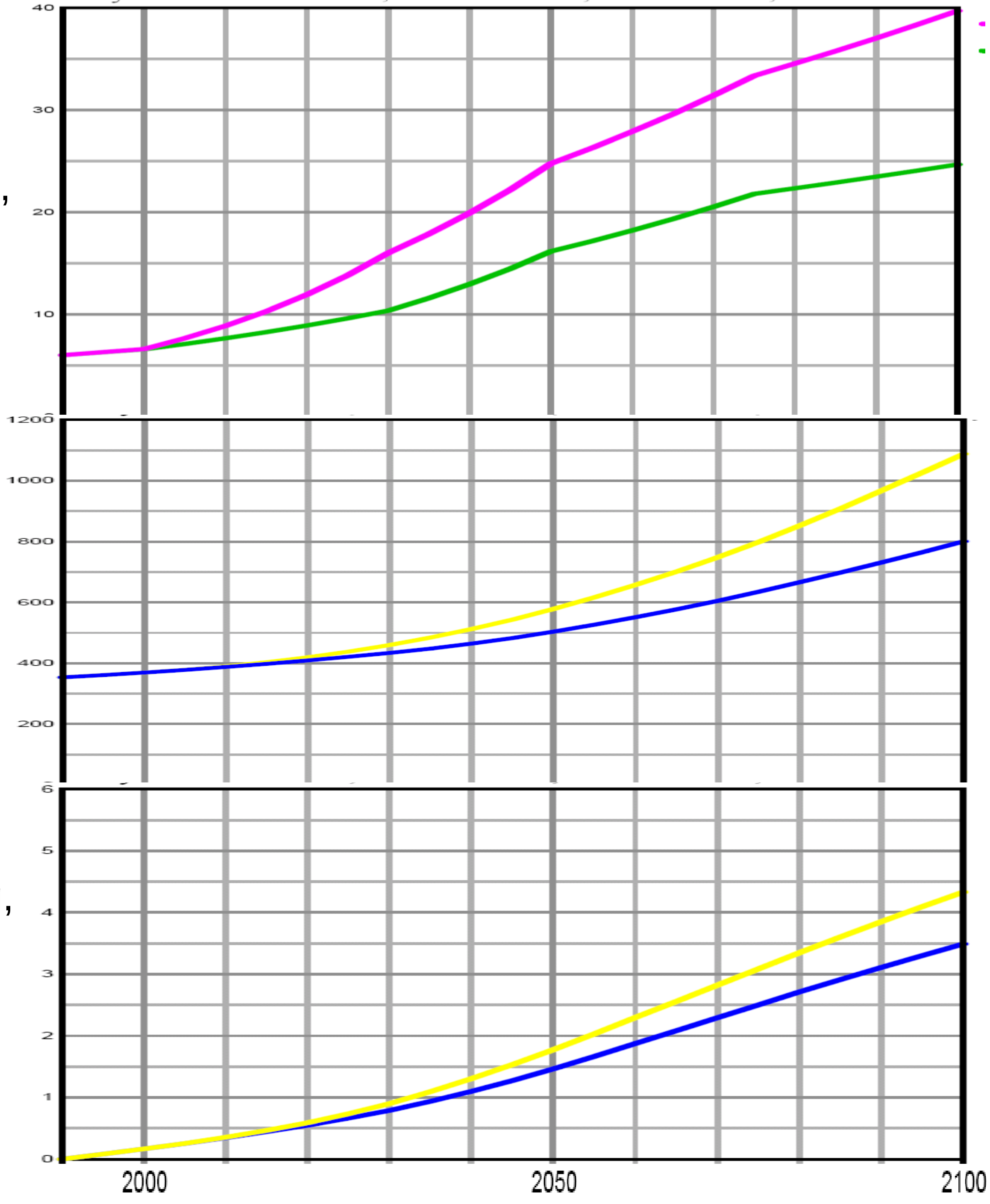
Emissions, Gt C

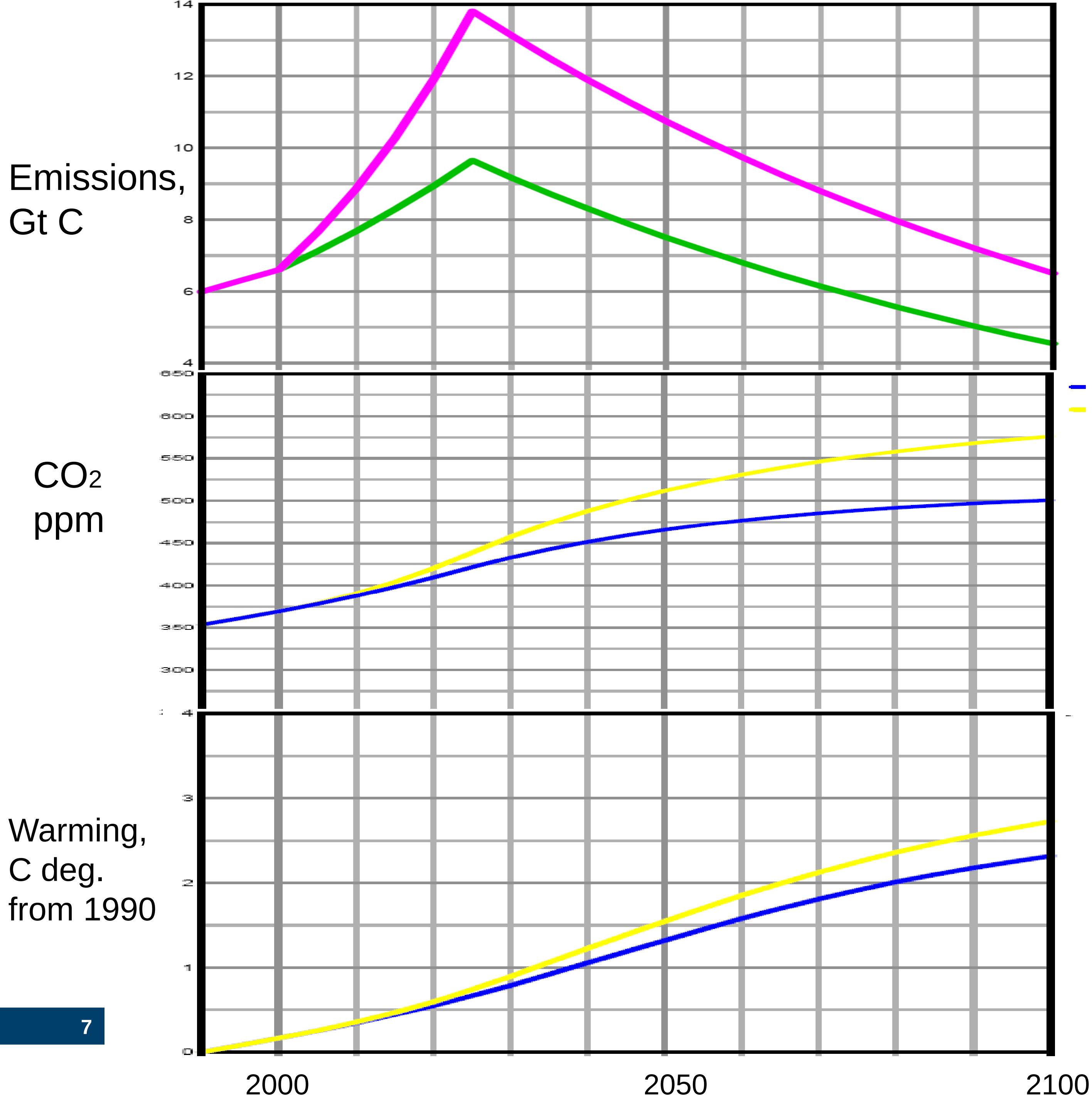
CO2 ppm

Warming, C deg. from 1990



Two Emission Scenarios: IEA base: Original assumed growth rate from 2000 to 2030 of 1.6%; Revised growth rate from 2000 to 2030 of 3.0%

Atm. Sensitivity =3.0 C



Two Mitigation Scenarios: Original assumed emission 2000 to 2025 growth rate of 1.6%, then a 1% annual reduction; Revised 2000 to 2025 growth rate of 3.0%, then an annual 1% reduction

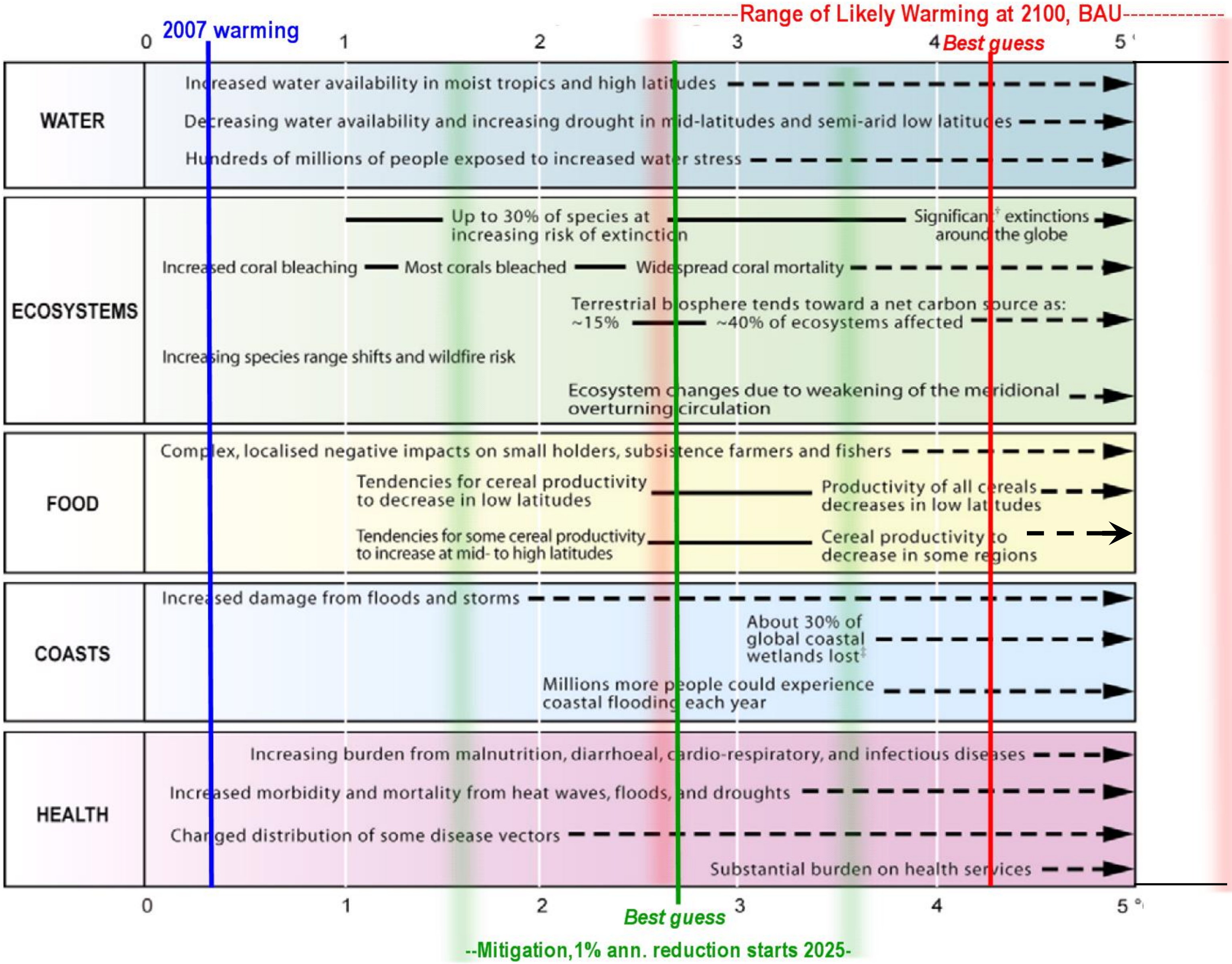
Atm. Sensitivity =3.0 C

IPCC Projected impacts as function of 1990 to 2100 warming, deg. C

BAU case: 3% CO_2 growth to 2030 then moderates,

Mitigation case: 3% growth then 1%/yr. decrease starts in 2025 for 75 years

(Atmospheric Sensitivity: 1.5/3.0/4.5 C deg.)



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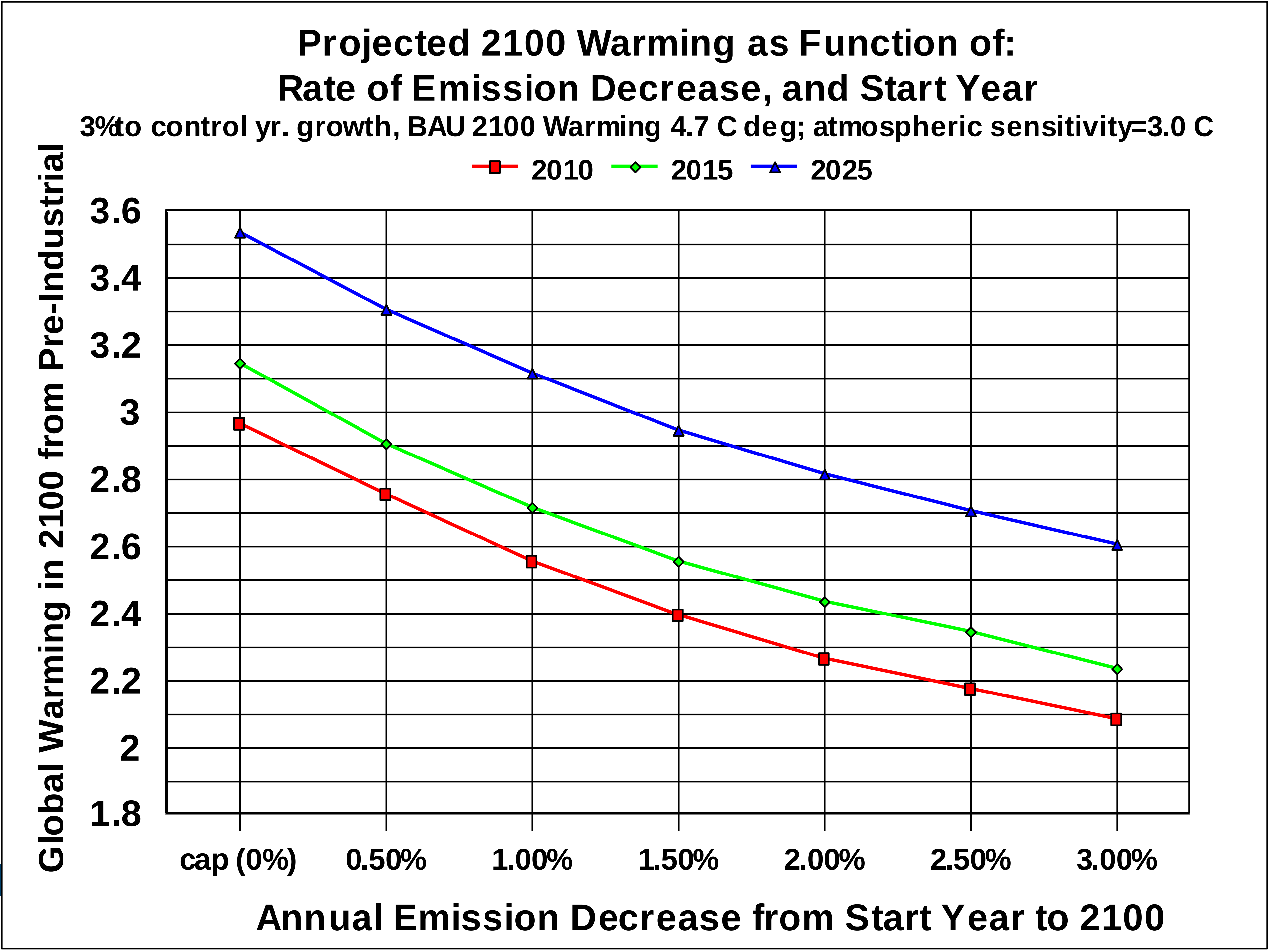
IPCC Fourth Assessment Report Impacts

- **Water:** Water supplies stored in glaciers and snow coverage projected to decline, reducing water availability in regions supplied by melting water from major mountain ranges, where more than one-sixth of the world population currently lives.
- **Ecosystems:**~20-30% of plant and animal species assessed so far are likely to be at increased risk of extinction if warming exceeds1.5-2.5^{o} C.
- **Food:** At lower latitudes, crop productivity is projected to decrease for even small local temperature increases (1-2° C). At higher latitudes crop productivity is projected to increase for increases of 1-3° C, then decrease beyond that.
- **Coasts:** Many millions more people are projected to be flooded every year due to sea-level rise by the 2080s.
- **Human Health:** Projected climate change-related exposures are likely to affect the health status of millions of people, particularly those with low adaptive capacity.


Projected 2100 Warming as Function of:
Rate of Emission Decrease, and Start Year
3% to control yr. growth, BAU 2100 Warming 4.7 C deg; atmospheric sensitivity=3.0 C
2010
2015
2025
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
Global Warming in 2100 from Pre-Industrial
cap (0%)
0.50%
1.00%
1.50%
2.00%
2.50%
3.00%
Annual Emission Decrease from Start Year to 2100

IEA Accelerated Technology (ACT) Scenarios

- Mandate by G-8 Leaders and Energy Ministers
- Assumes aggressive R,D&D Program
- Major mitigation starts in 2030
- Assumes policies in place to encourage technology use in accelerated time frame
  - CO_2 reduction incentives of up to $25 per ton
  - Policies include regulation, tax breaks, subsidies and trading schemes

Reference: International Energy Agency, Energy Technology Perspectives 2006, OECD-IEA, **2006**

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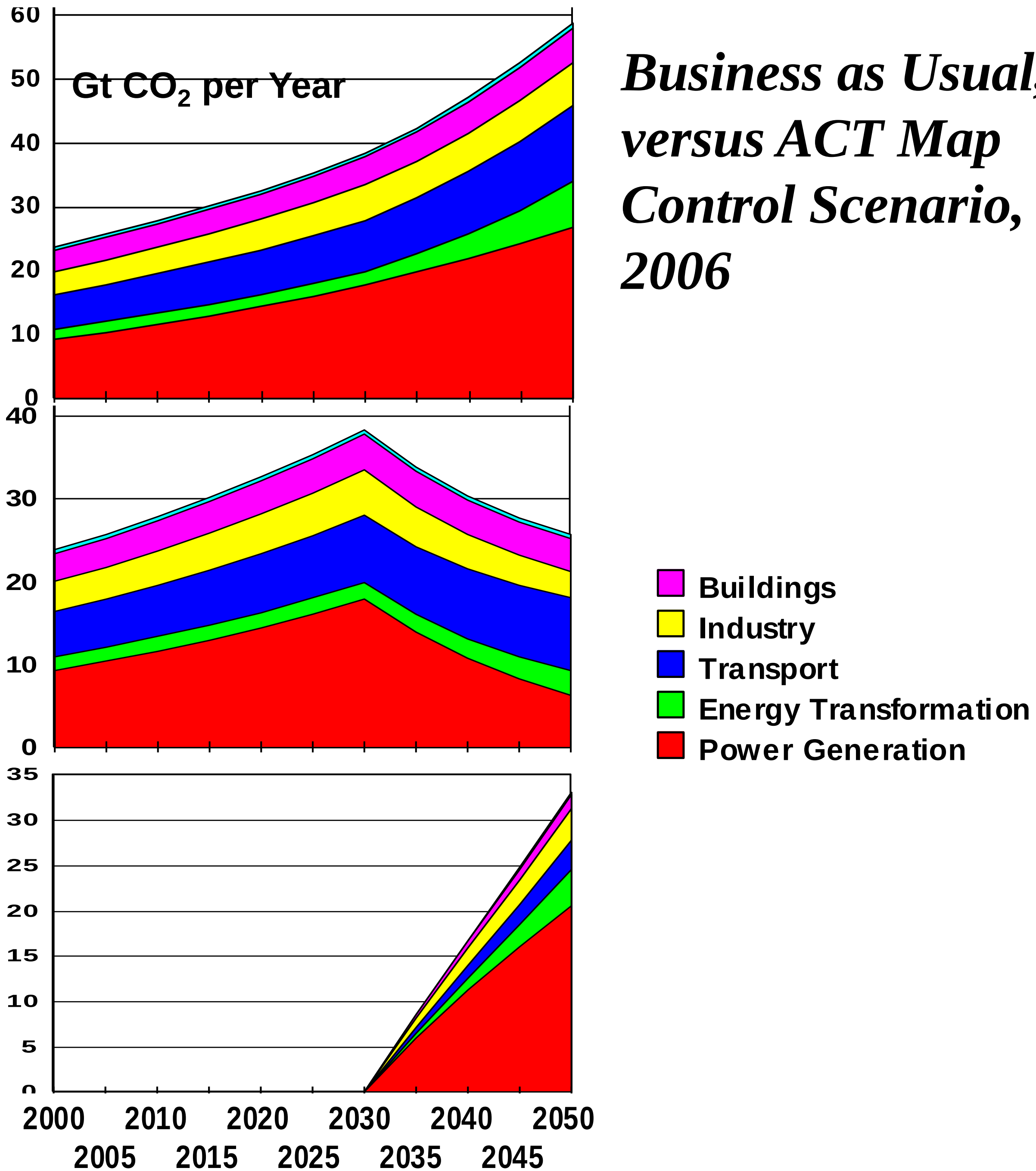
Business as Usual, versus ACT Map Control Scenario, IEA 2006

World Projection of CO_2 Emissions by Sector (IEA, 2006)

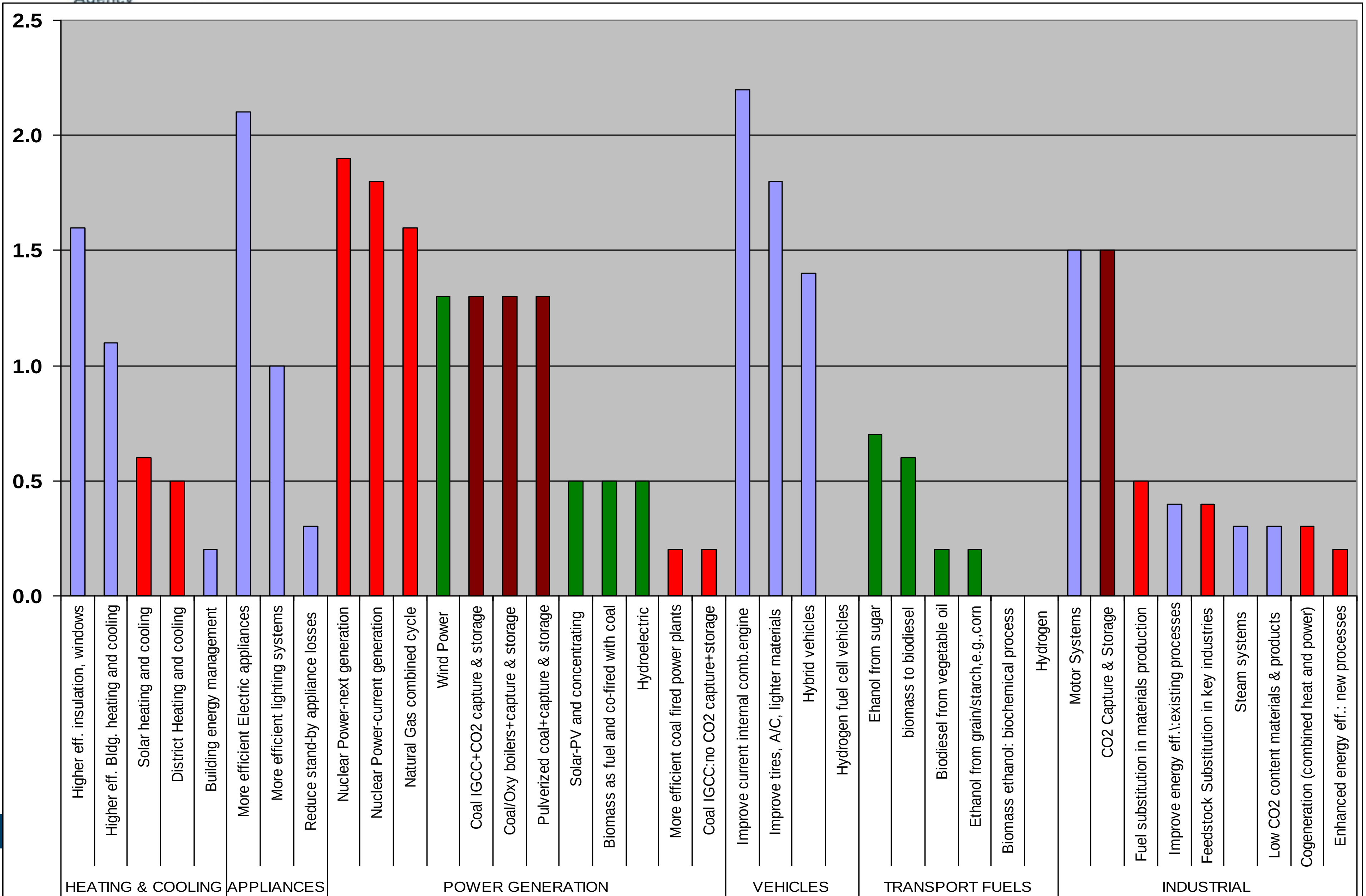
IEA Baseline ACT Map Scenario

IEA ACT Map Scenario, CO2 Reductions by Sector

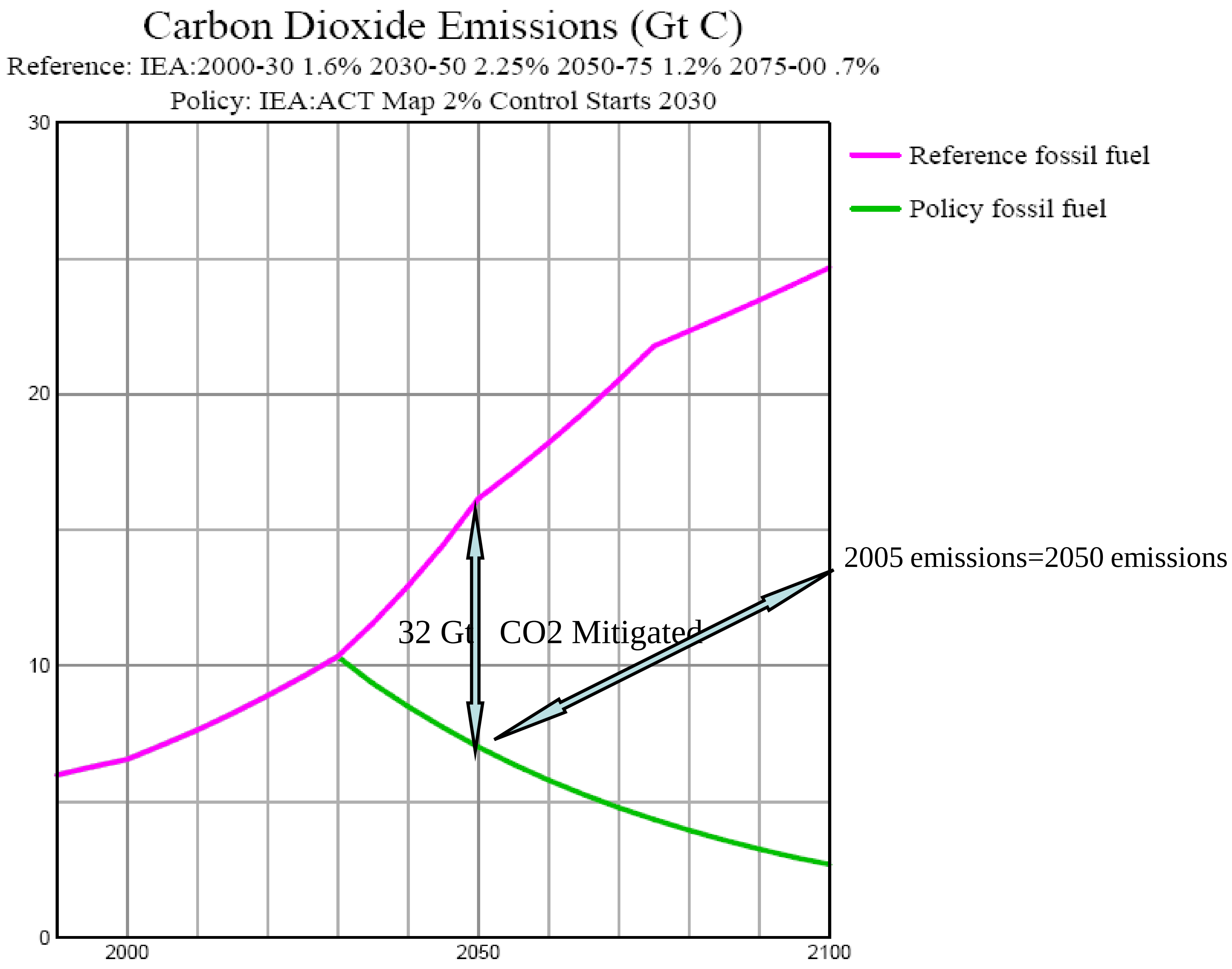


Summary Of IEA Technology Analysis; Total: 32 Gt in 2050

End Use   Power Generation/Other   CO2 Storage   Renewables

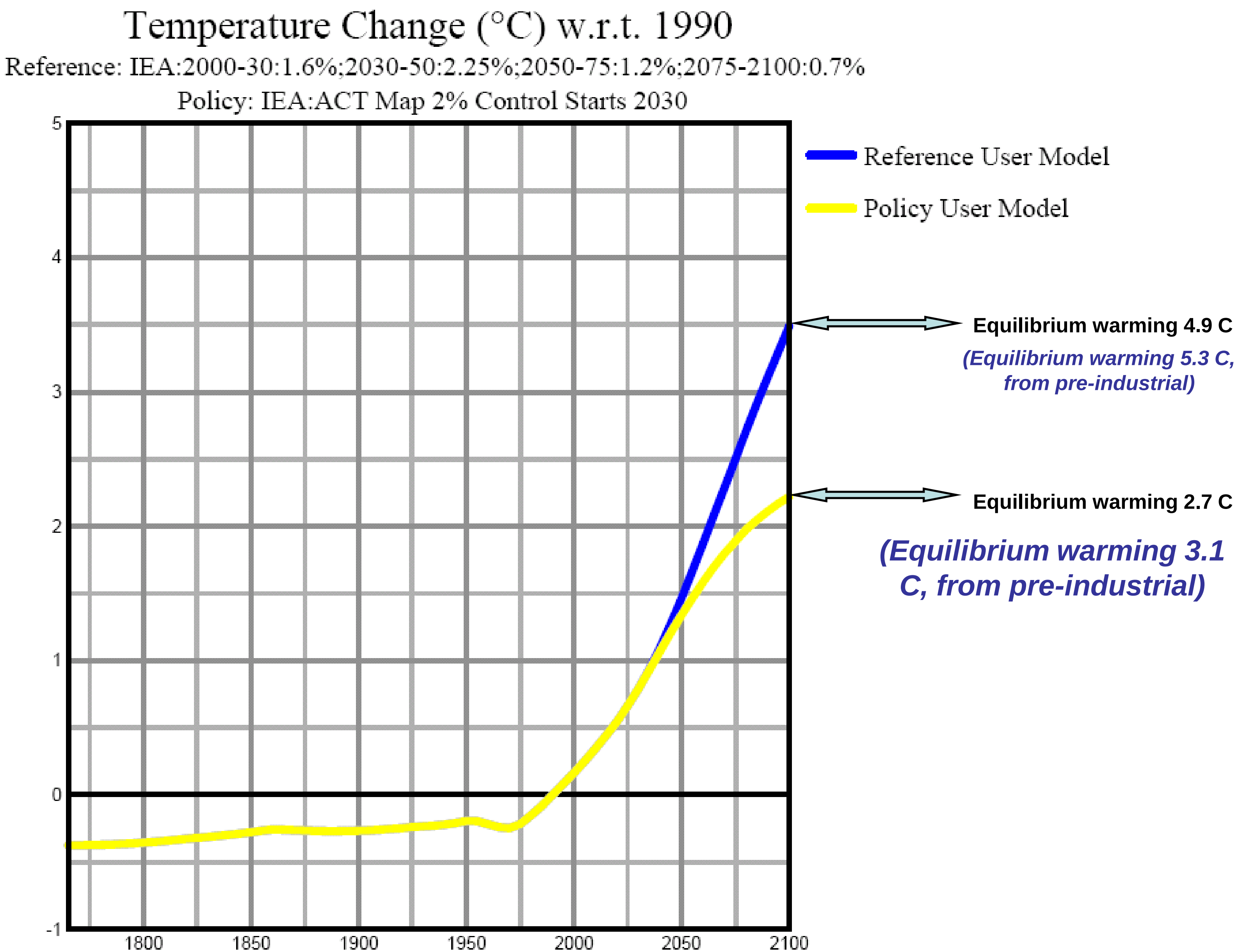


CO_2 Emissions for IEA Base Case and ACT Map Scenario



Projected Warming for IEA Base Case & ACT Map Scenario

Atm. Sensitivity =3.0 C



Power Generation Sector-Key Technologies

Technology	Current State of the Art	2050 Impact per IEA	Issues	Technology R,D&D Needs
Nuclear Power-next generation	Developmental, Generation **III+ and IV**: e.g. Pebble Bed Modular Reactor and Supercritical Water Cooled Reactor	1.9	Deployment should be targeted to no later than 2030 with a focus on lower cost, minimal waste, enhanced safety and resistance to proliferation	**High**, Demonstrations of key technologies with complimentary research on important issues
Nuclear Power-current generation	Commercial, Pressurized Water Reactors and Boiling Water Reactors (Generation **III**)	1.8	Plant siting, high capital costs, levelized cost 10 to 40% higher than coal or gas plants, potential U shortages, safety, waste disposal and proliferation	**Medium,** Waste disposal research
Natural Gas Combined Cycle	Commercial, 60% efficiency	1.6	Limited by natural gas availability, which is major constraint; high efficiency & low capital costs	**Medium**, higher efficiencies with new materials desirable
Wind Power (renewable)	Commercial	1.3	Costs very dependent on strength of wind source, large turbines visually obtrusive, intermittent power source	**Medium**, higher efficiencies, off-shore demonstrations, storage

Power Generation Sector-Key Technologies, Continued

Technology	Current State of the Art	2050 Impact	Issues	Technology R,D&D Needs
Coal IGCC with CO2 Capture and Storage	*IGCC* : early commercialization, Underground storage *(US)* : early development.	1.3	*IGCC* :High capital costs, questionable for low rank coals, complexity and potential reliability concerns; *US* : Cost, safety, efficacy	**High**, *IGCC* : demos on a variety of coals; *US* : major program with long term demo**s** evaluating geological formations to evaluate environmental impact, efficacy, cost and safety
Pulverized Coal/Oxygen combustion with CO2 Capture and Storage	Developmental, underground storage developmental;	1.3	Oxygen combustion allows lower cost CO2 scrubbing, but oxygen production cost is high; *US* : Cost, safety and permanency	**High**, large pilots followed by full scale demos needed, low cost O_2 production needed, *US* requires major program (see write-up above)
Pulverized Coal with CO2 Capture and Storage	MEA scrubbing near commercial but expensive, NH3 & NaSO3 developmental, underground storage developmental	1.3	*US* : Cost, safety and efficacy issues, CO_2 scrubbing energy intensive: yielding major cost penalties	**High,** affordable CO2 removal technologies need to be developed and demonstrated, *US* requires major program (see above);
Solar-Photovoltaic and concentrating (renewable)	First generation commercial, but very high costs	0.5	Costs unacceptably high, solar resource intermittent in many locations	**High**, breakthrough R,D&D needed to develop & demo cells with higher efficiency and lower capital costs, energy storage
Biomass as fuel and co-fired with coal (renewable)	Commercial, steam cycles	0.5	Biomass dispersed source, limited to 20% when co-fired with coal, food and sustainability concerns	**Medium,** biomass/IGCC would enhance efficiency and CO_2 benefit; also genetic engineering to enhance biomass plantations

Power Generation Sector-Environmental Issues for Key Technologies

Technology	Potential Environmental Impacts/ *R&D Needs*
Coal IGCC with CO_2 Capture and Storage	Lower power plant efficiency yields greater emissions of SOx, NOx, Fine PM and coal mining impacts, including acid mine drainage. Sequestration could impact groundwater quality/ *High*
Pulverized Coal/Oxygen combustion with CO_2 Capture and Storage	Same as above
Pulverized Coal with CO_2 Capture and Storage	Same as above
Solar-Photovoltaic and concentrating (renewable)	Reduction in emissions of SOx, NOx, Fine PM; fewer mining impacts and Residues for disposal or use. Potential upstream emissions/effluents associated with manufacturing cells /*Medium*
Biomass as fuel and co-fired with coal (renewable)	Reduction in emissions of SOx, NOx, Fine PM; fewer mining impacts and residues for disposal or use; however potential eco impacts and excessive water use from biomass plantations/ *Medium*

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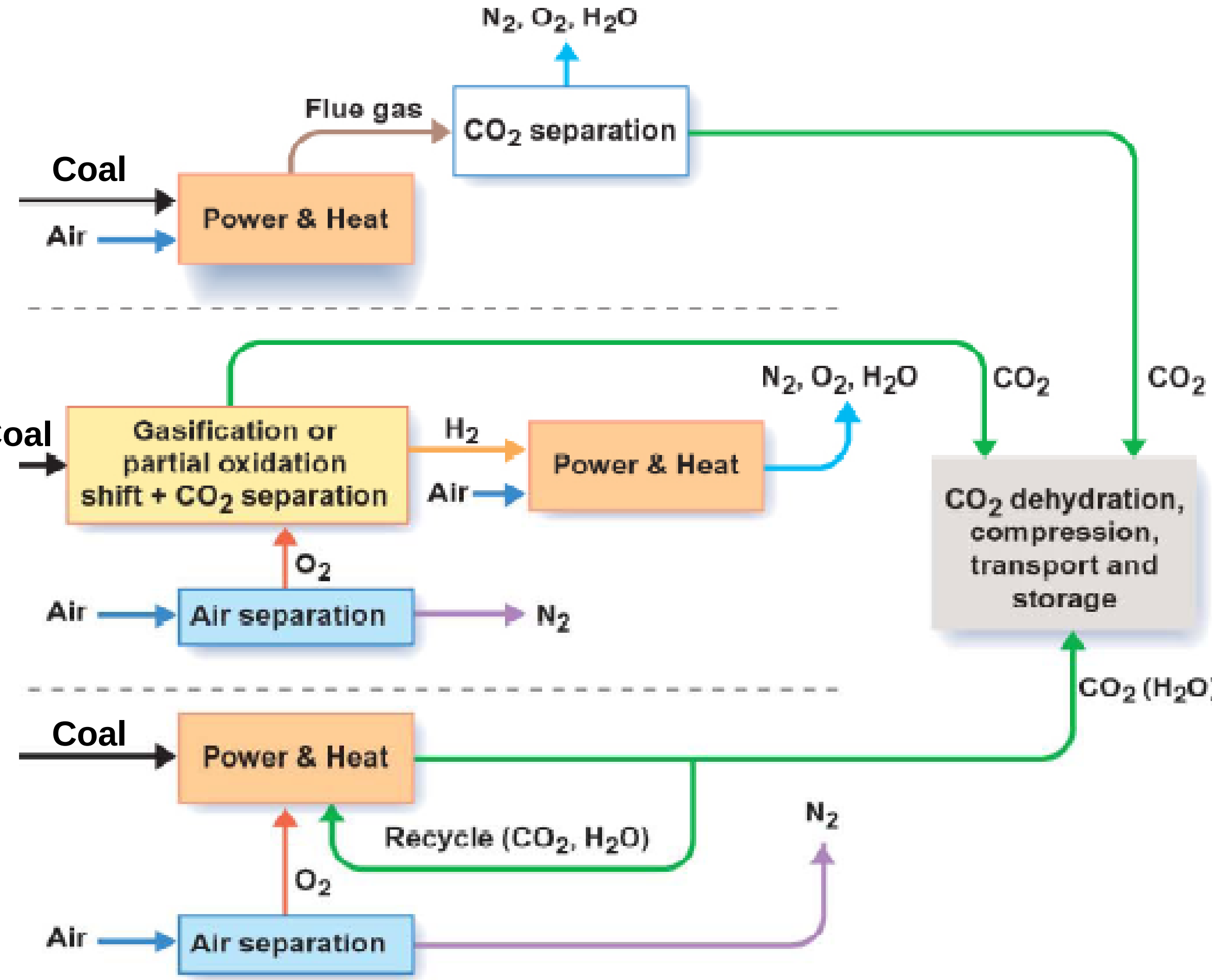
Three Options for CO_2 Capture from Coal Power Generation Plants

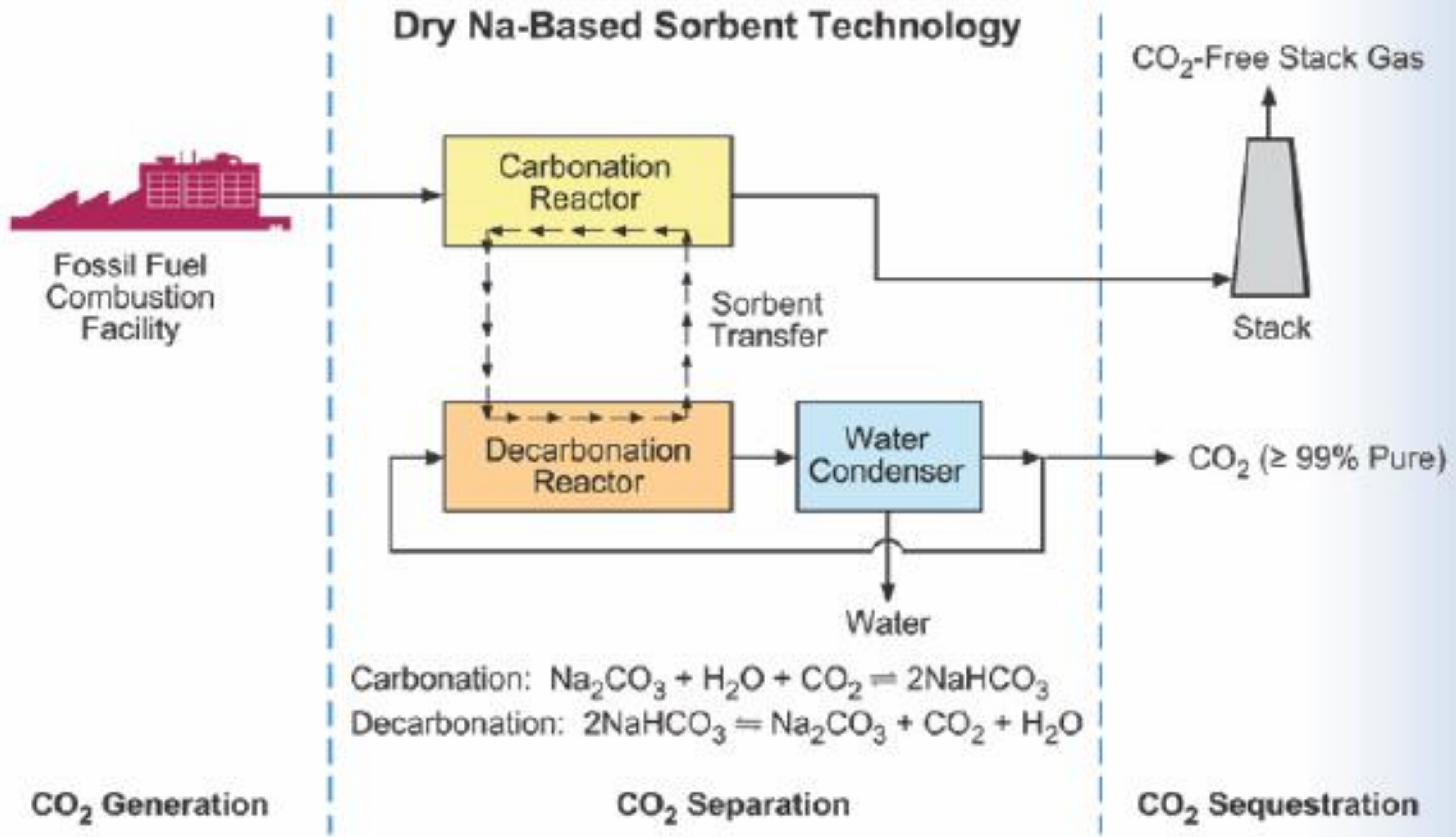
Post Combustion CO_2 Separation

IGCC: Pre-combustion CO_2 removal

Post Oxy-fuel Combustion CO_2 Removal



RTI "Dry Carbonate Process" for CO2 Capture from Power Plants



Power Generation Sector

- Projected to grow from large base at 3% annually, China and India critical; offers greatest opportunity for reductions; 38% of US CO_2
- Coal combustion key source, important to develop CO_2 **CCS** technologies and alternatives to coal-based systems.
- 3 major candidates for CO_2 capture: PC boilers/advanced CO_2 scrubbing, IGCC/carbon capture and oxygen-fed PC combustors. Only IGCC funded at significant levels
- Underground storage in deep geological formations an unproven technology at scale needed for coal-fired boilers, with serious cost, efficacy, & safety issues.
- Nuclear power plants; accelerated R, D and D program is important for advanced reactors, given high mitigation potential, yet serious cost, safety, proliferation and waste disposal concerns.
- Natural gas/combined cycle plants, wind turbines also have potential to decrease dependence on coal

Transportation Sector-Key *Vehicle* Technologies

Technology	Current State of the Art	2050 Impact	Issues	R,D&D Needs
Improvements: Current Internal combustion engine components	First generation: commercial	2.2	Lack of customer incentive major problem; trend to larger vehicles in US and recently Europe counter-productive	**Medium**; Transmission and drive train improvements
Non-engine Improvements: Current Vehicles; tires, A/C, light materials	First generation: commercial	1.8	Lack of customer incentive major problem; trend to larger vehicles in US and recently Europe counter-productive	**Medium**, Lower weight construction, improved tires and more efficient A/Cs
Hybrid vehicles	First generation: commercial	1.4	Higher costs (about $3000),"light" hybrids not as efficient as full hybrids, some newer models yield power over mileage benefits	**Medium/High**, Minimize incremental cost and enhance efficiency
Hydrogen fuel cell vehicles	Developmental	0	Fuel cell costs and fuel cell stack life; also hydrogen storage, safety and lack of infrastructure	**High**, Breakthrough R,D&D needed to develop cost competitive, long lived fuel cells. Hydrogen storage R,D&D also needed

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Transportation Sector-Key *Fuel* Technologies

Technology	Current State of the Art	2050 Impact	Issues	R,D&D Needs
Ethanol from sugar	Commercial	0.7	Limited by land capable of high sugar yields, e.g., sugar cane	**Medium**, develop sugar cane cultivars with higher yield and more frost tolerant
Biodiesel & other fuels from biomass; thermo chemical processes	Developmental	0.6	Developmental, yet potentially high production and lower cost via gasification/Fischer-Tropsch synthesis	**High,** Major R,D&D needed to develop and demonstrate viable technology for biomass feedstock
Biodiesel from vegetable oil	First generation: commercial	0.2	High costs, low yield from oil crops, limited waste cooking oils, low S a positive	**Low**
Ethanol from grain/starch, e.g.,corn	Commercial	0.2	Limited by grain supply; high costs, energy intensive production, food impacts	**Low**
Ethanol from biomass/lignocellulose; biochemical process	Early Developmental	**0**	Inability to convert wide range of biomass types, high production costs, dispersed biomass source	**High**, Breakthrough R,D&D needed to develop lower cost generally applicable process(es)
Hydrogen	Commercial from natural gas and electricity	**0**	Cost via electrolysis high, CO_2 benefits if produced via natural gas low	**High;** breakthrough research to generate H_2 at low cost from renewable or nuclear sources

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Transportation Sector-Environmental Issues for Key Technologies

	Technology	Potential Environmental Impacts/ *R&D Needs*
Vehicles	**Hybrid vehicles**	Lower emissions of VOCs, CO and Nox, uncertain impacts of battery production and disposal ***/Medium***
	Hydrogen fuel cell vehicles	On road emissions close to zero, H2 production emissions depends on feedstock & production process ***/High***
Fuels	**Ethanol from sugar**	Potential eco, soil and water impacts from biomass plantations, environmental studies would be useful /***High***
	Biodiesel & other fuels from biomass; thermo chemical processes	Potential eco, soil and water impacts from biomass plantations, production and combustion impacts unclear; environmental studies would be useful/ ***High***
	Biodiesel from vegetable oil	Not clear, environmental characterization would be useful/ ***High***
	Ethanol from grain/starch, e.g.,corn	Not clear, environmental characterization would be useful / ***High***
	Ethanol from biomass/lignocellulose; biochemical process	Potential eco, soil and water impacts from biomass plantations, production and combustion impacts unclear; environmental studies would be useful/ ***High***
	Hydrogen	Depends upon feedstock source and production process /***High***

Transportation Sector

- Growing at 2% per year, most difficult sector; 32% of US CO_2
- The first challenge: current propulsion systems all depend on fossil fuels with associated CO_2 emissions
- The second challenge: the automobile industry, driven by consumer preferences (especially in North America), have offered heavy, high emitting vehicles such as SUVs.
- The third challenge: increasing vehicle miles travelled (VMT)
- A review of evolving technologies suggests hybrids & biomass-to-diesel fuel via thermo chemical processing are most promising.
- However, cellulosic biomass-to-ethanol and hydrogen/fuel cell vehicles offer longer term potential, if key technical issues are resolved and, for hydrogen, renewable sources are developed.
- Ethanol from grain, e.g. corn, not an effective avoidance approach

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In June 2008 IEA Released the 2008 version of Energy Technology Perspectives

- **Mandate by G-8 Leaders and Energy Ministers**
- **Earlier graphic: in 2006 their *ACT* scenario (2050 =2005 emissions) still yielded ~3.1 C warming**
- **In light of IPCC (2007), they analyzed new *Blue* scenario to limit warming to ~ 2.4 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"

"The situation is getting worse"

"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"

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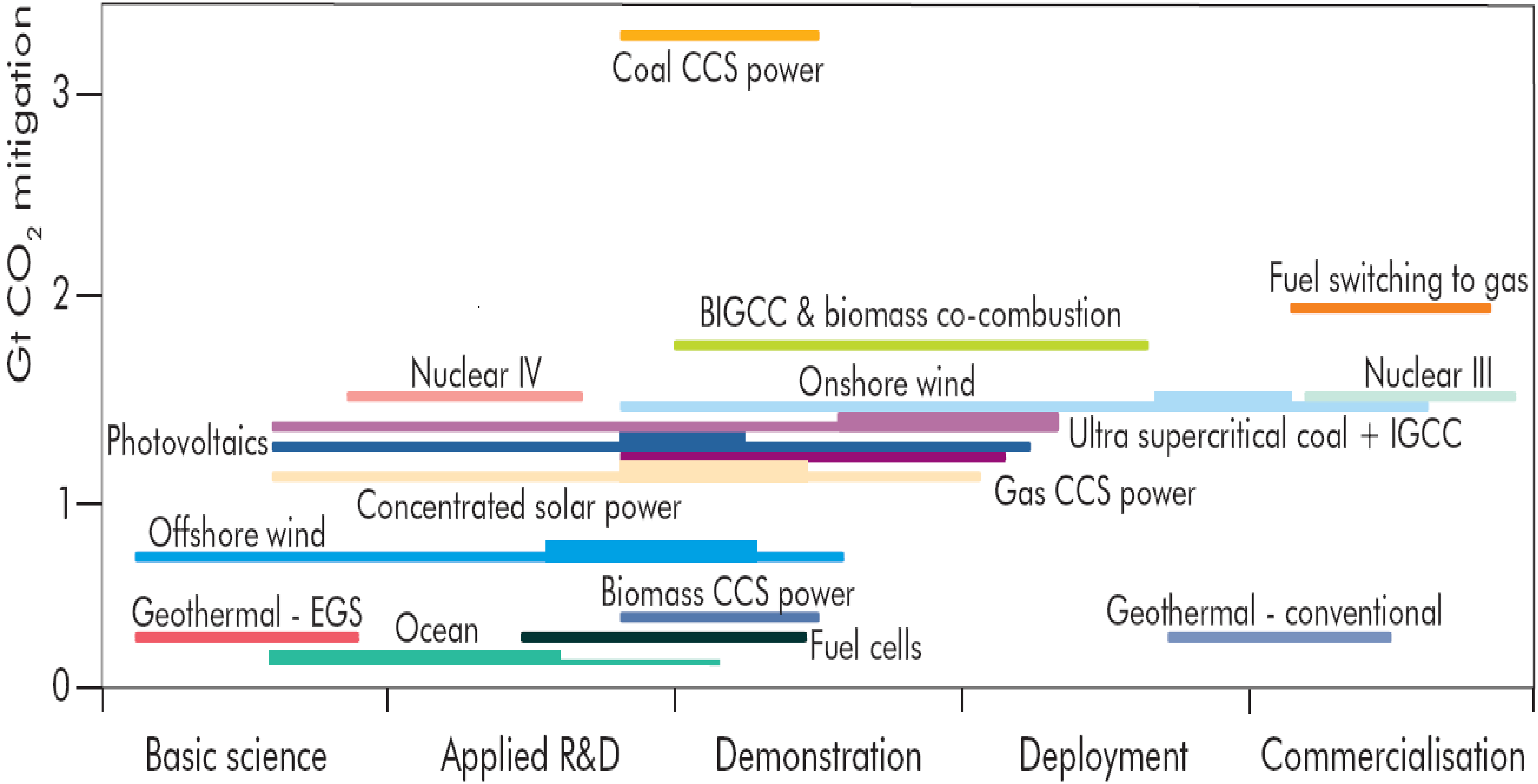
In June 2008 IEA Released the 2008 version of Energy Technology Perspectives (Continued)

- Key technologies not available: “a huge effort of RD&D will … be needed”
- “Critical technologies: solar PV, advanced coal and biomass, CCS, batteries, fuel cells and H_2”
- “There is an urgent need for full scale CCS demonstration”
- Blue scenario requires ***$13 to $16*** trillion for Research, Development Demonstration & Deployment (RDD&D)
- Blue scenario requires marginal costs up to **200 to 500 $/ton**; the more modest ACT scenario (2050 emissions=2005 emissions) *revised* from **$25 to 50$/ton**
- Additional *investment* needs in the Blue scenario is ***$45*** trillion
- IEA generated “Roadmaps” for key technologies indicating RDD&D needs and collaborative opportunities

Near-term technology development priorities and CO_2 mitigation for power generation technologies

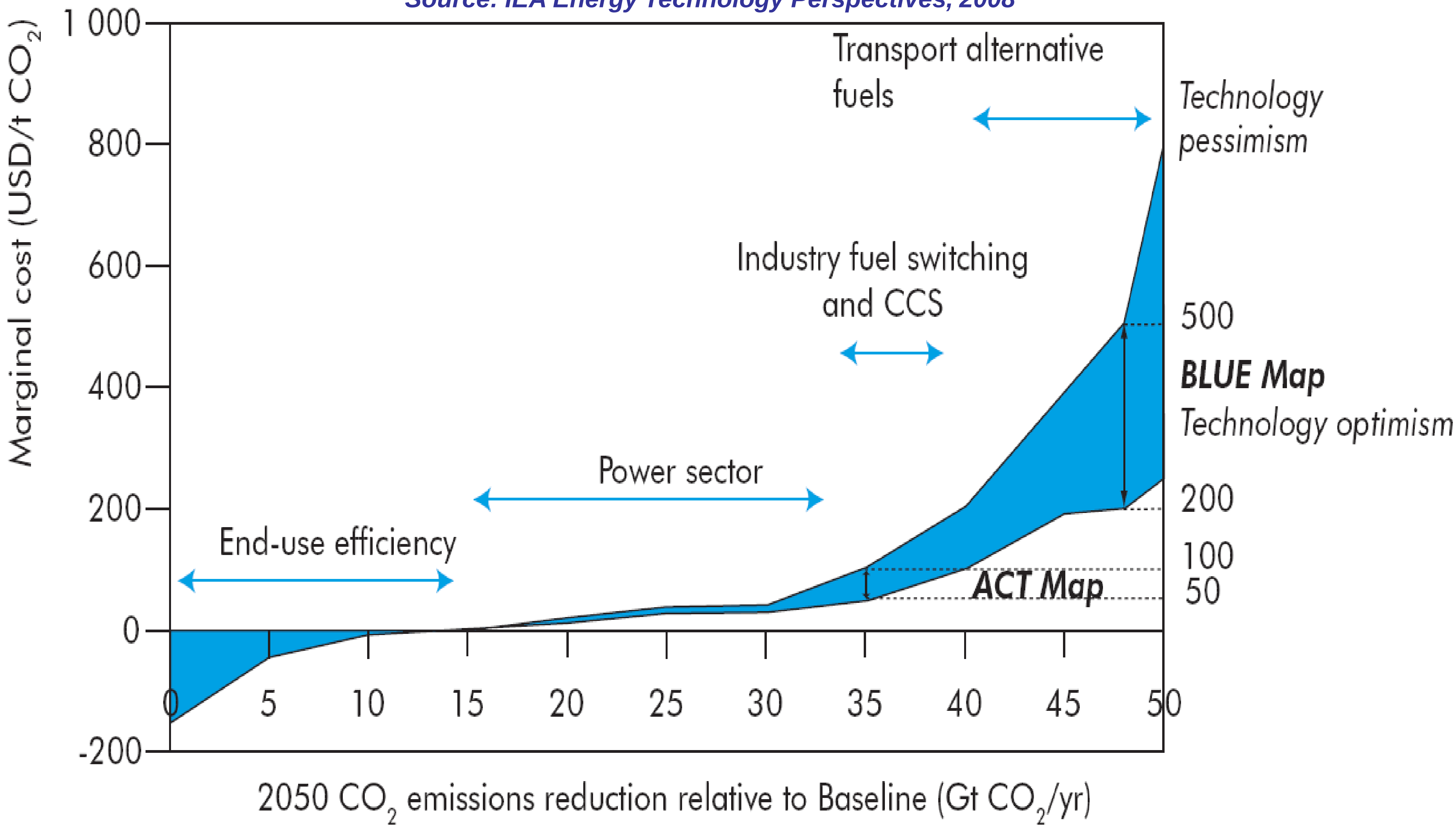
Source: IEA Energy Technology Perspectives, 2008



Notes: 1) See Annex C for detailed RD&D priorities for individual technologies. 2) Near-term indicates the next 10 to 15 years. 3) CO_2 emission mitigation in the BLUE Map scenario relative to the Baseline scenario.

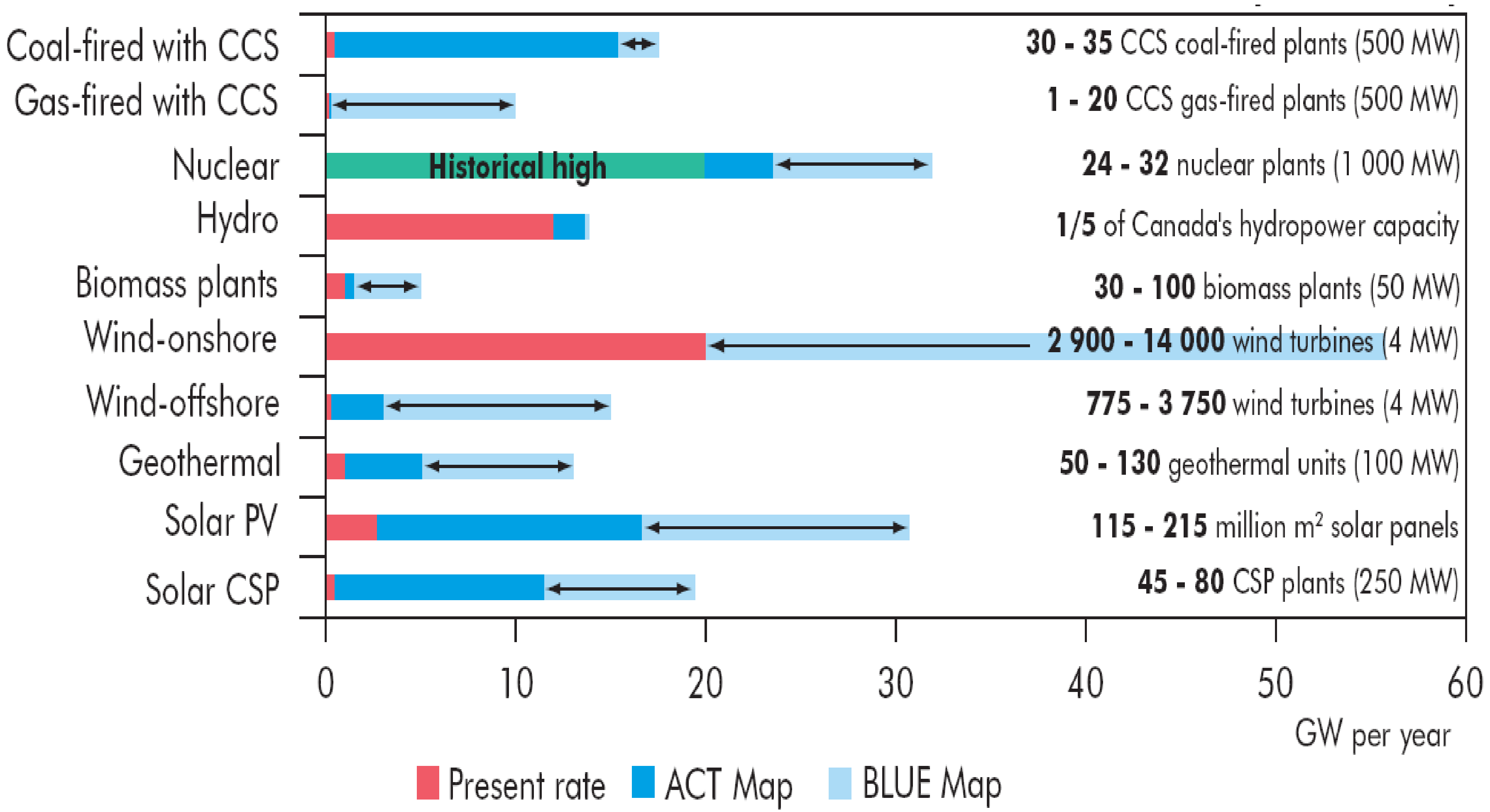
Marginal emission reduction costs for the global energy system, 2050

Source: IEA Energy Technology Perspectives, 2008



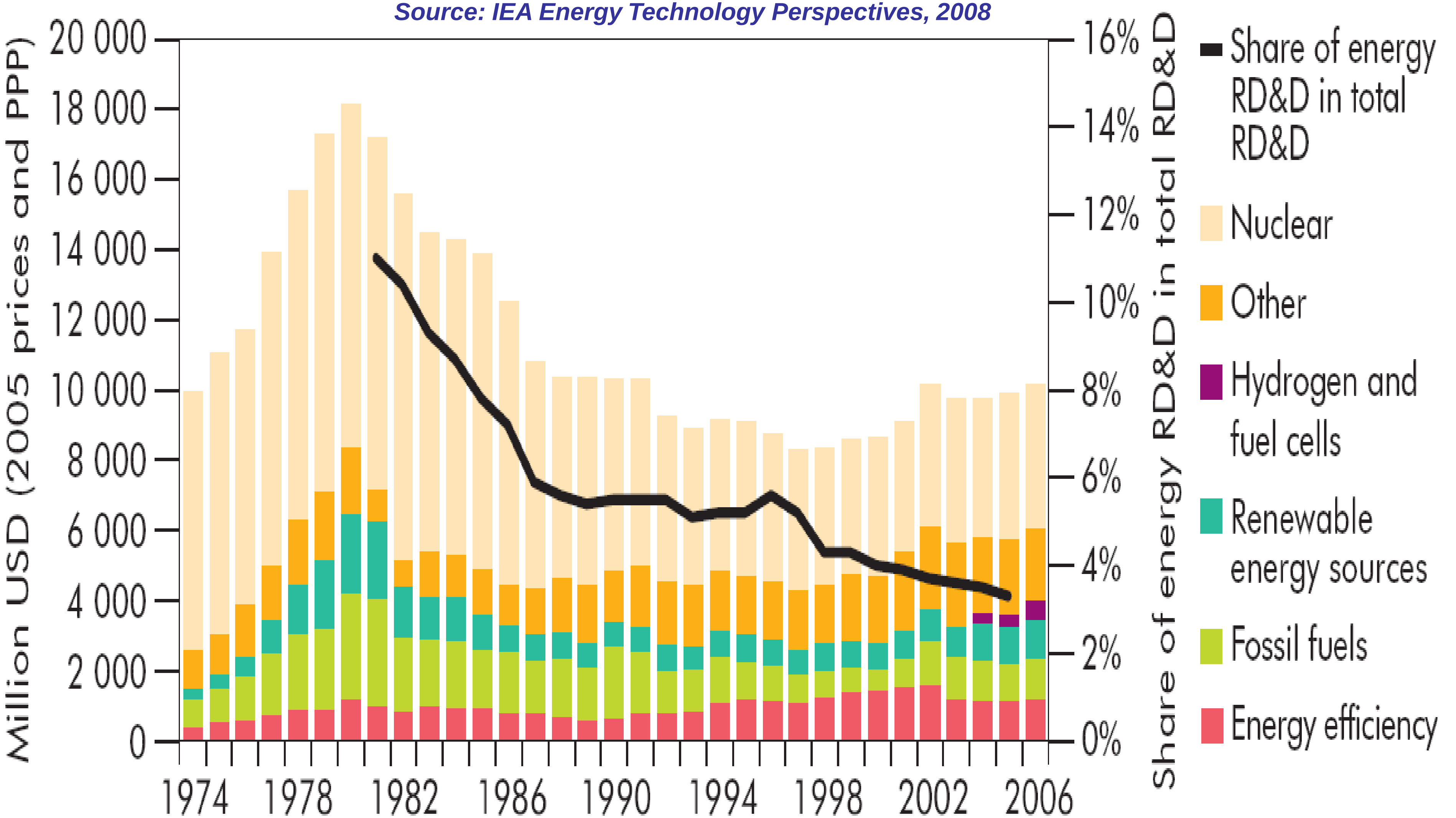
Additional **annual** capacity needed in power generation sector for ACT and Blue Scenarios (Relative to Baseline, 2005 to 2050)

Source: IEA Energy Technology Perspectives, 2008



Government budgets on energy RD&D of the IEA countries

Source: IEA Energy Technology Perspectives, 2008



Note: RD&D budgets for the Czech Republic not included due to lack of available data.

Source: IEA 2007a, OECD 2007a.

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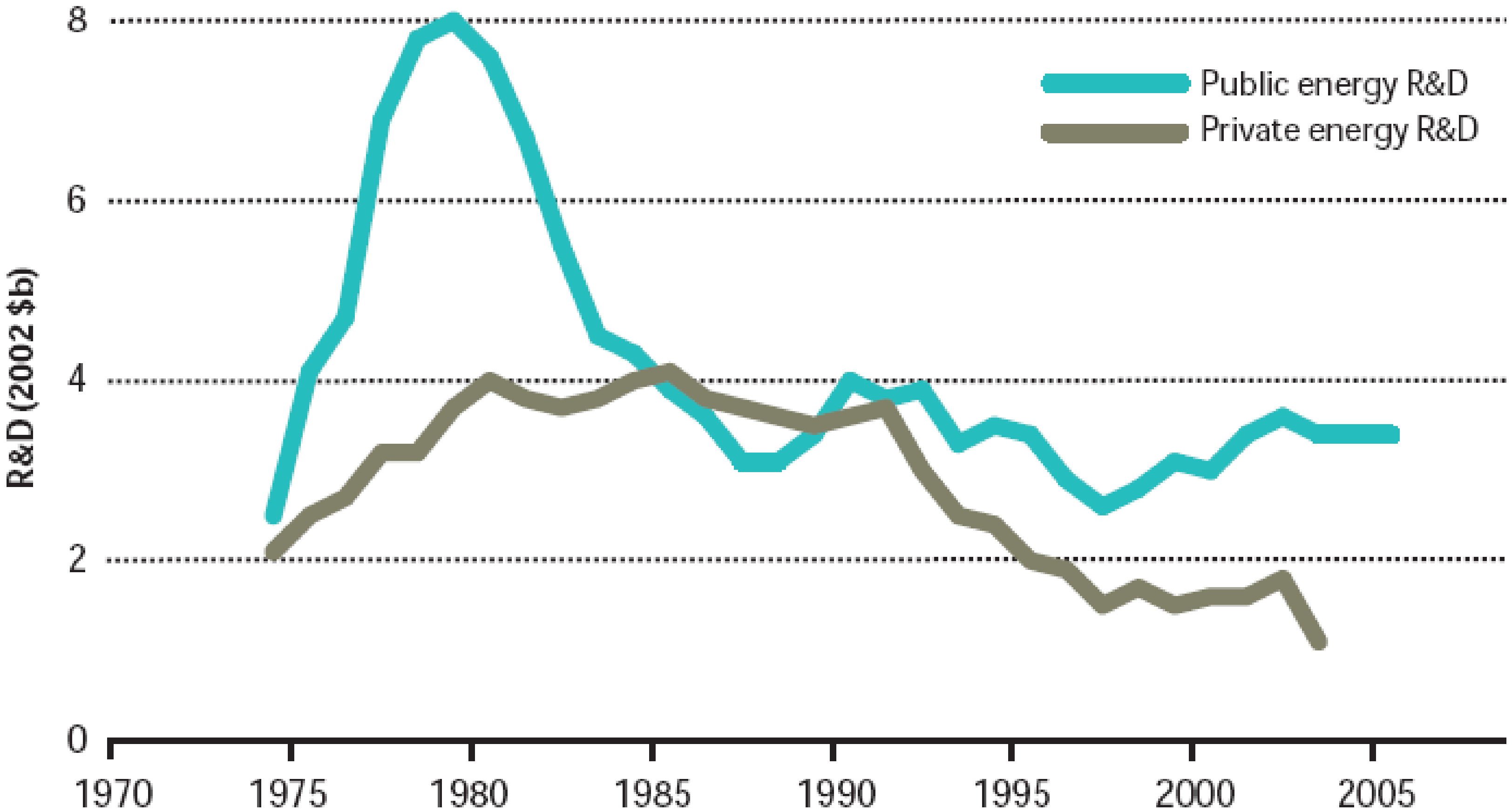
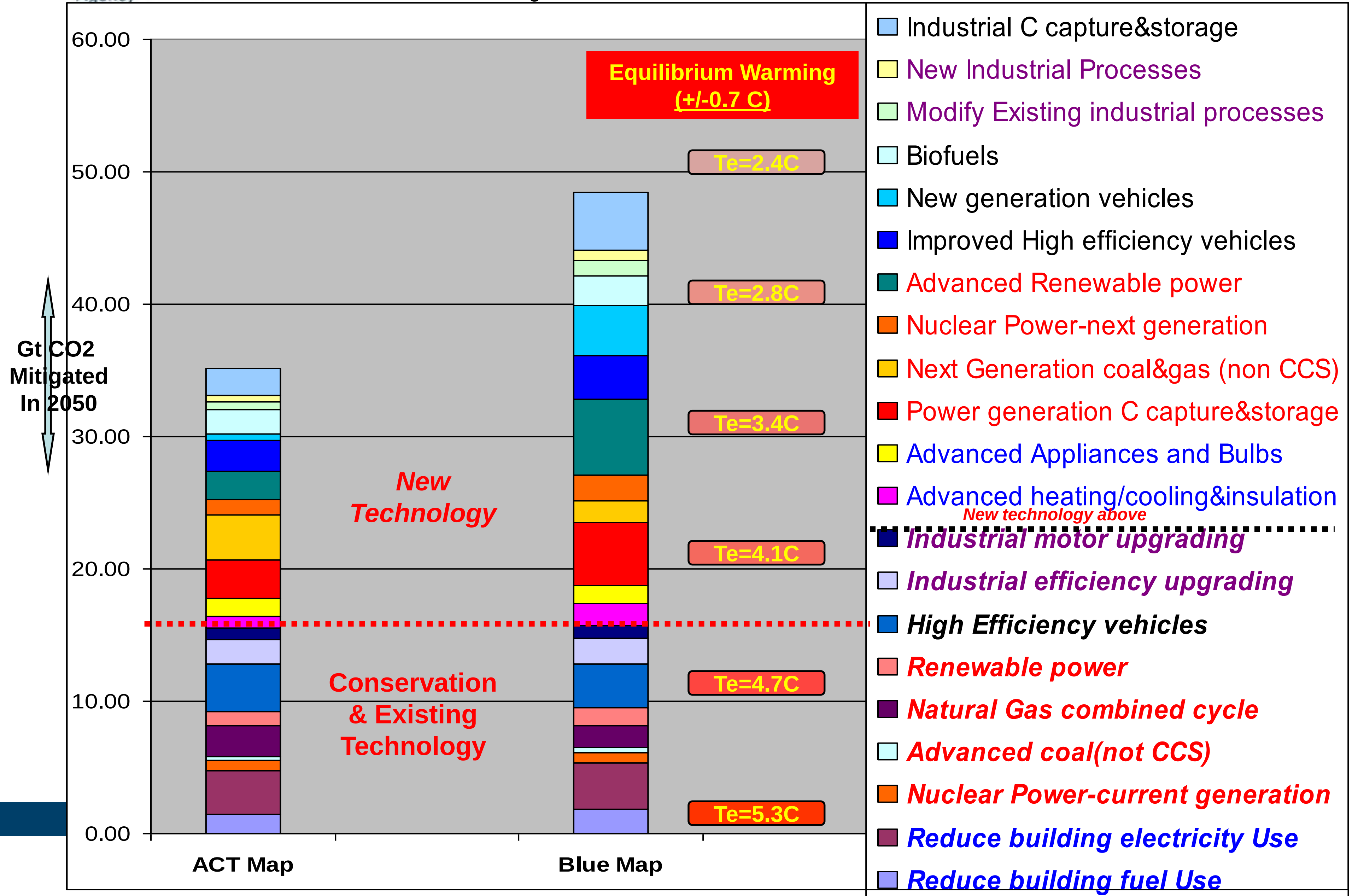
U.S. Federal Funding in Key Energy Areas per IEA in 2004 $



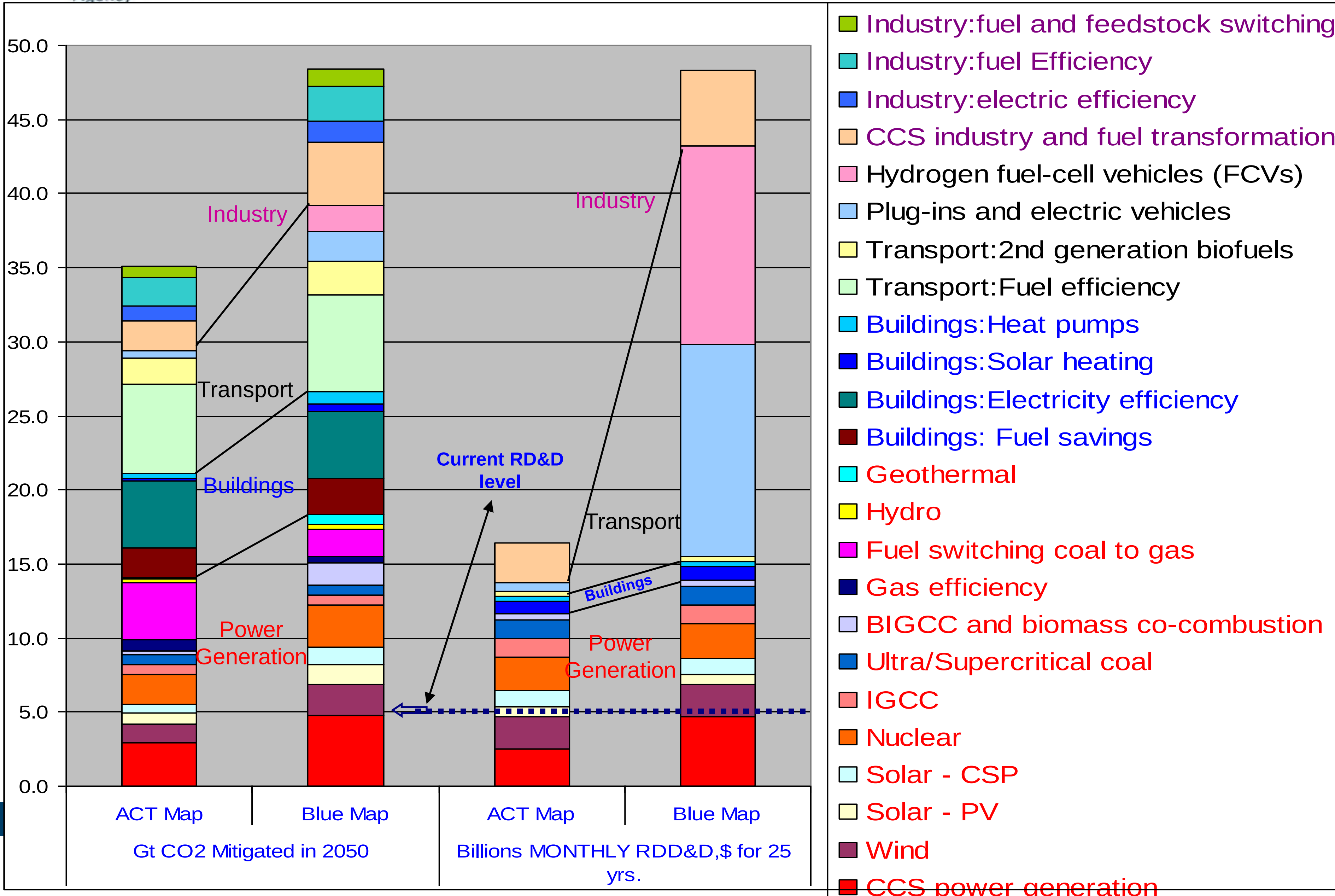
Sources: R. M. Wolfe, Resea rch and Development in Industry" (National Science Foundation, Division of Science Resources Statistics, 2004); M. Jefferson, *et al.*, "Energy Technologies for the 21st Century" (World Energy Council, 2001); R. L. Meeks, "Federal R&D Funding by Budget Function: Fiscal Years 2003-05" NSF 05-303 (National Science Foundation, Division of Science Resources Statistics, 20040; R. Margolis, and D. M. Kammen "Underinvestment: The energy technology and R&D policy challenge", *Science*, 285, 690-692 (1999).

ACT & Blue scenarios: existing & new technologies capable of reducing 2050 emissions & mitigate equilibrium warming +/- ~ 0.7 C (atmospheric sensitivity= 3.0 C)

1.6% annual growth rate, then mitigation, IEA Technology Perspectives 2008 until 2050 then mitigation continues at 1% annual reduction from 2050 to 2100



IEA Technology Perspectives *2008* for ACT and Blue scenarios: Gt CO2 mitigated in 2050 & Selective RDD&D needs; $Billions on ***monthly*** basis *multiply by 12x25yrs=300 for total dollars*



Major Increase in R,D,D &D Essential

- **If mitigation of one trillion tons of carbon is deemed a serious goal, a major increase in R,D,D&D needed. The Stern Report : "…support for energy R,D&D should at least double, and support for the deployment of new low-carbon technologies should increase up to five-fold."**
- **Currently world spends $1 trillion on military, $10 billion on all energy technologies, $1.5 billion on coal technologies**
- **R,D&D particularly important for coal generation technologies: IGCC, oxy-coal combustion, and CO_2 capture technology for PC boilers; all need to be integrated with underground storage, a key technology, but need numerous demos**
- **Also important; next generation mobile source technology and nuclear power plants**

The Climate Change Technology Challenge

- **Man is pumping CO_2 in the atmosphere at unprecedented rates; 30 billion tons last year, and growing at 3% annually from 2000 to 2006. Although US is largest 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 -1 to -2%; sooner control starts, the better**

The Climate Change Technology Challenge-continued

- **Available technology if aggressively utilized, will only avoid about 25 to 40%% of required CO_2 by 2050; *next generation low emission/high efficiency technologies need to be developed and utilized ASAP***
- **Major technology advances necessary, especially in critical power generation and mobile source sectors; *carbon capture and storage and nuclear reactors critical technologies***
- **No "silver bullets", all promising technologies should be pursued**
- **Research funding is grossly inadequate; "too few eggs in too few baskets"**
- **Focused fundamental research aiming at breakthrough technologies important**
- **Challenge is serious enough to warrant assessment of geoengineering options**
- **Technology necessary but not sufficient; utilization requires incentives/regulations**

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