Global Climate Change-the Quantifiable Sustainability Challenge

Supercritical CO_2 Power Cycles

4th Annual Symposium

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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.

Office of Research and Development
National Risk Management Research Laboratory

September 9, 2014

Climate Change; the Sustainability Elephant in the Room

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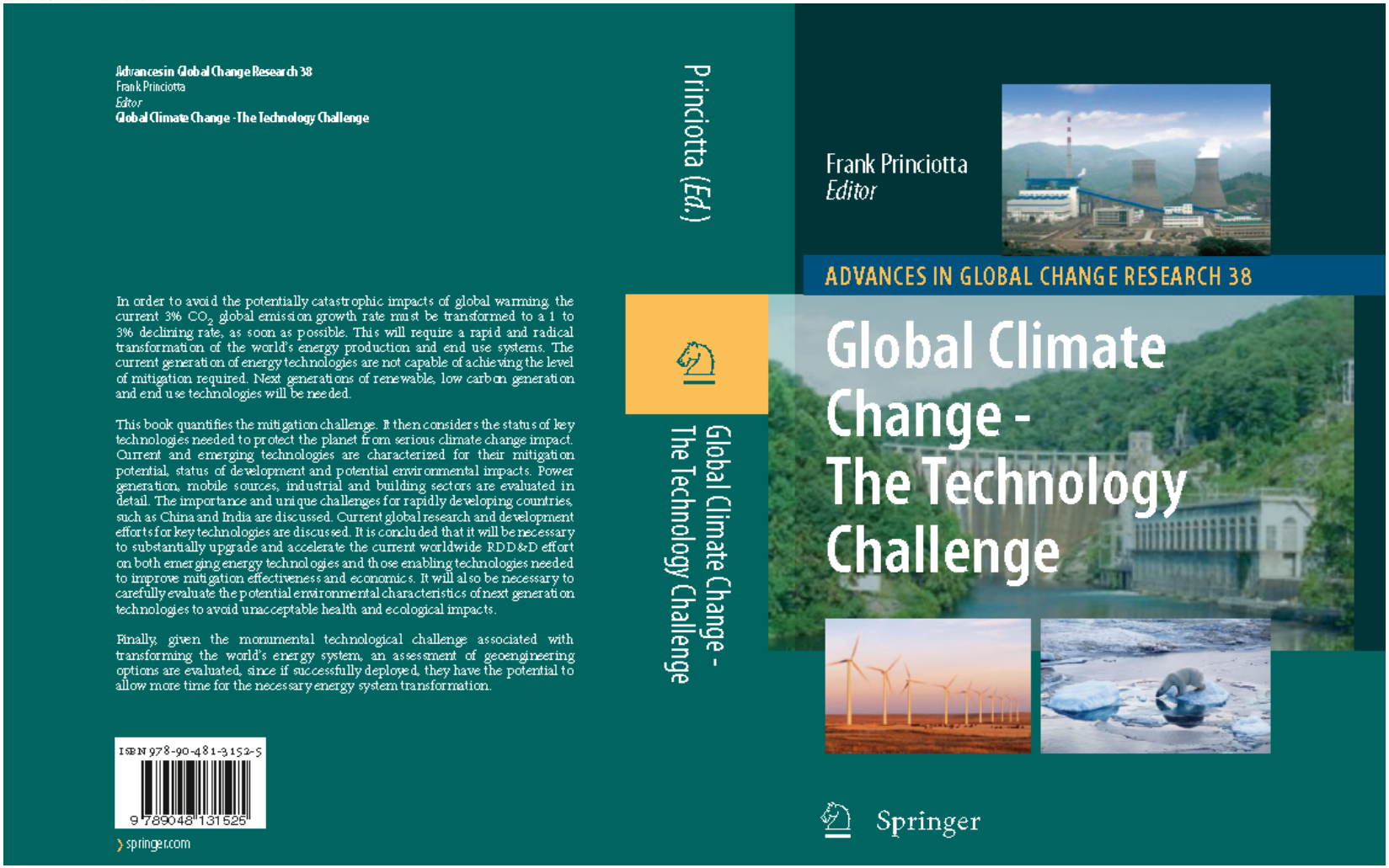

Just published in JA&WMA 9/2014; Climate Change the Quantifiable Sustainability Challenge> http://www.tandfonline.com/doi/full/10.1080/10962247.2014.923351

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Major Issues Discussed

- Is the planet warming & is humanity the cause? *(IPCC: Yes is the answer)*
- What are the fundamental drivers
- What will it take to avoid catastrophic climate change in terms emission reductions via low C technology globally and nationally
- *Note cultural changes & geological engineering options may be needed but are not covered due to time constraints*

IPCC Fifth Assessment Report (AR5); Summary for Policymakers *September 2013*

-Warming of climate system unequivocal, since 1950s many changes unprecedented over decades to millennia; atmosphere & ocean warmed, amounts of snow & ice diminished, sea level has risen

- *Extremely likely that human influence dominant cause of warming since mid-20th century*; evident from increasing GHG concentrations, positive radiative forcing, observed warming, and understanding of the climate system

-Concentrations of CO_2, methane, & nitrous oxide increased to unprecedented levels in last 800,000 years. The ocean has absorbed about 30% of emitted CO_2, causing ocean acidification

-Each of last 3 decades successively warmer at Earth's surface than any preceding decade since 1850. In Northern Hemisphere,1983–2012 *likely warmest 30-year period of last 1400 years*

GHG Forcing Needed to Explain Observed Warming

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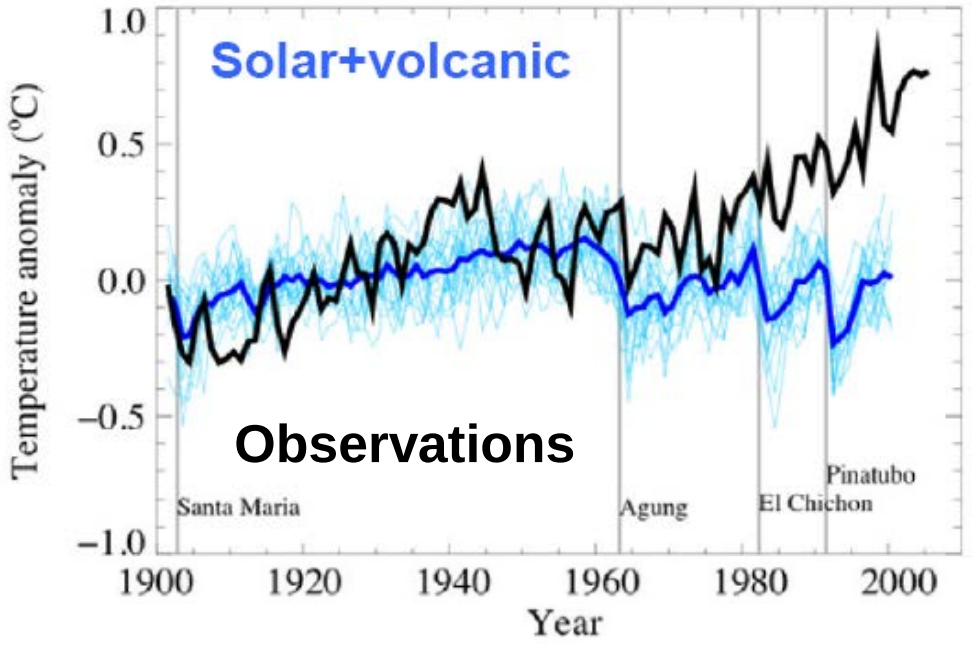
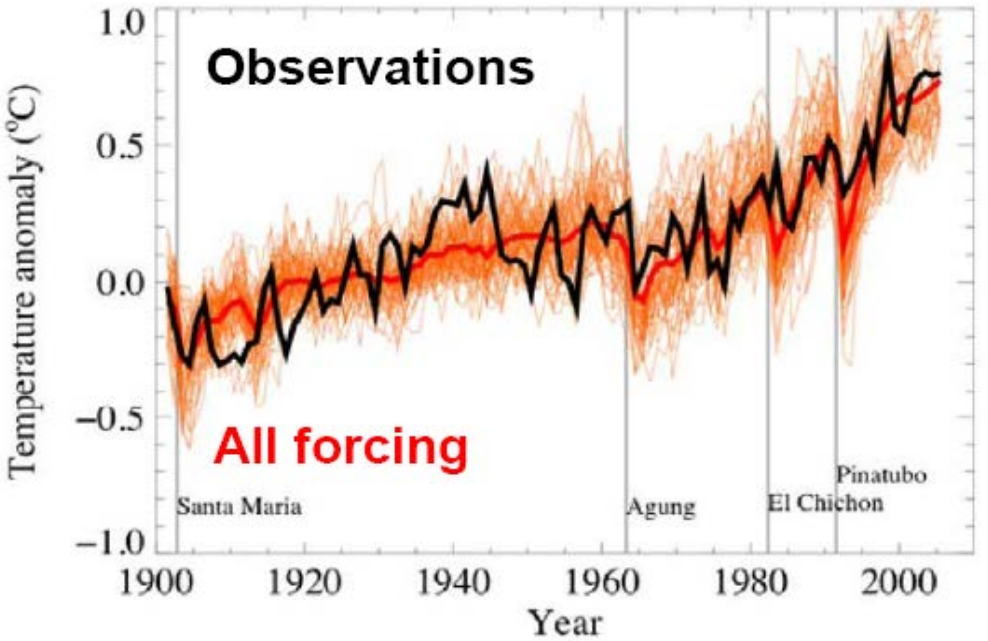
Solar + Volcanic Forcings ***DO NOT*** explain **Observed Warming**



GHG + Solar + Volcanic Forcings ***DO*** explain **Observed Warming**



Source: IPCC Fourth Assessment Report, 2007

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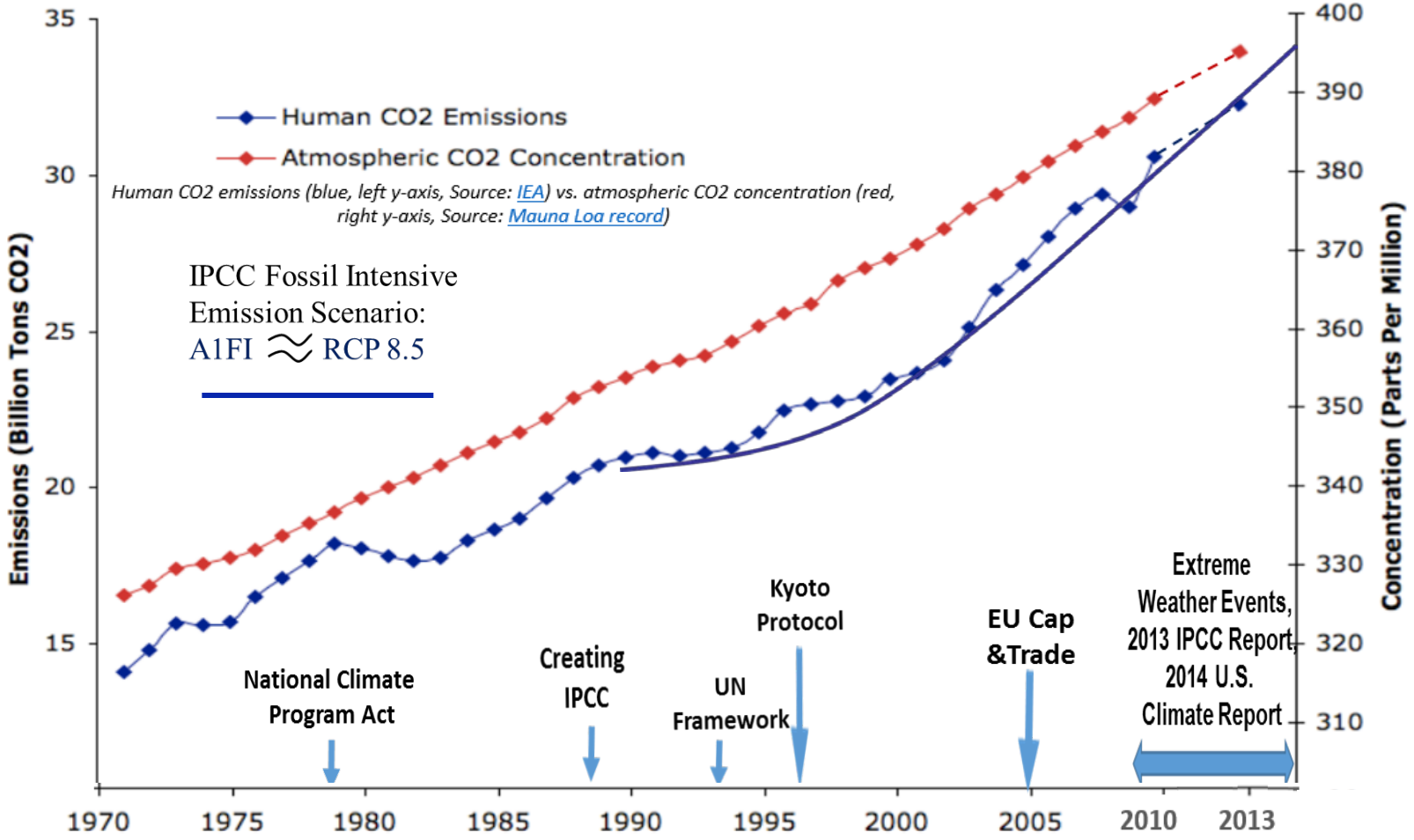
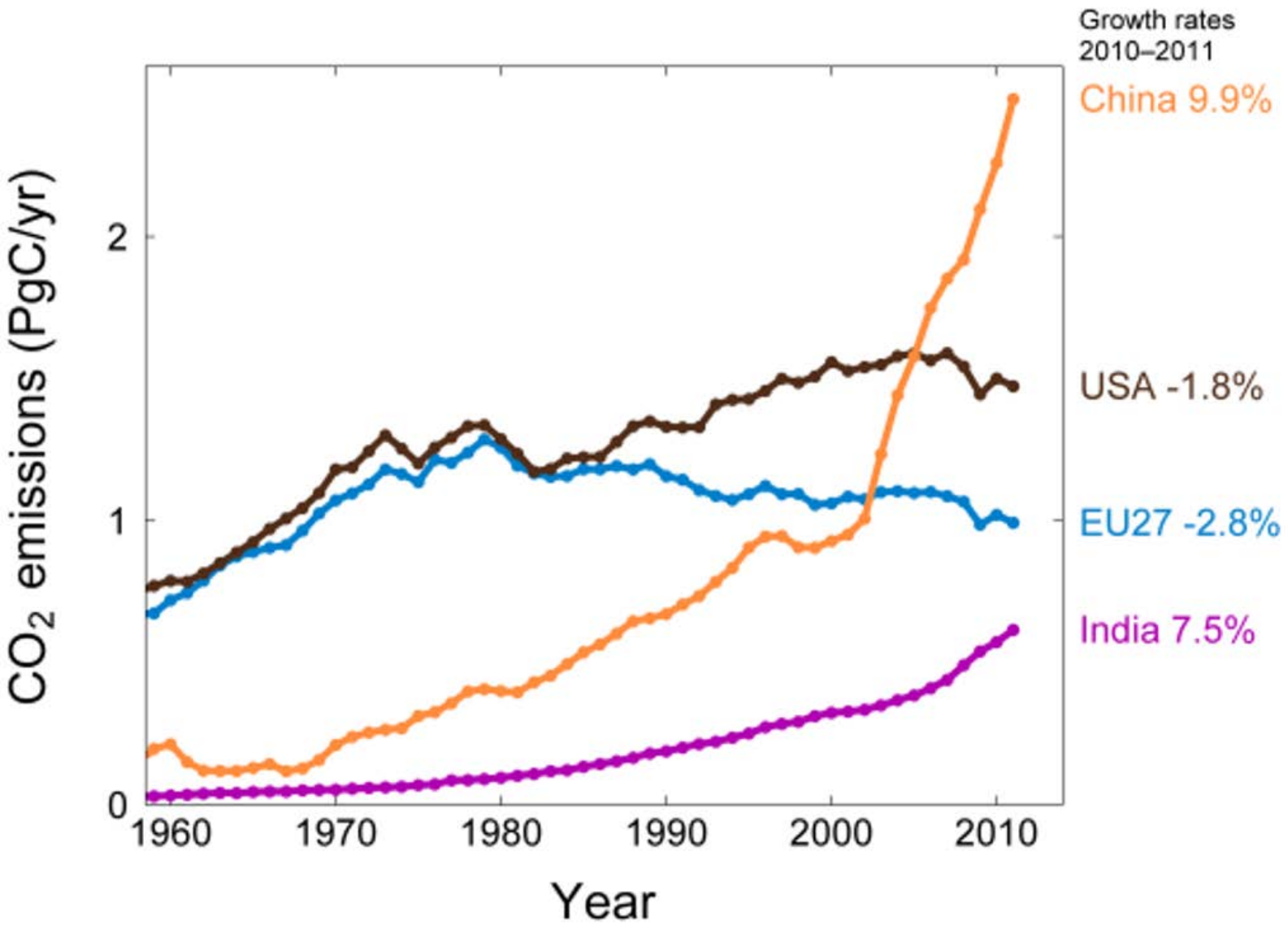
1)Despite Studies, Frameworks & Treaties CO_2 Emissions & Atm. Concentration Continue to Grow

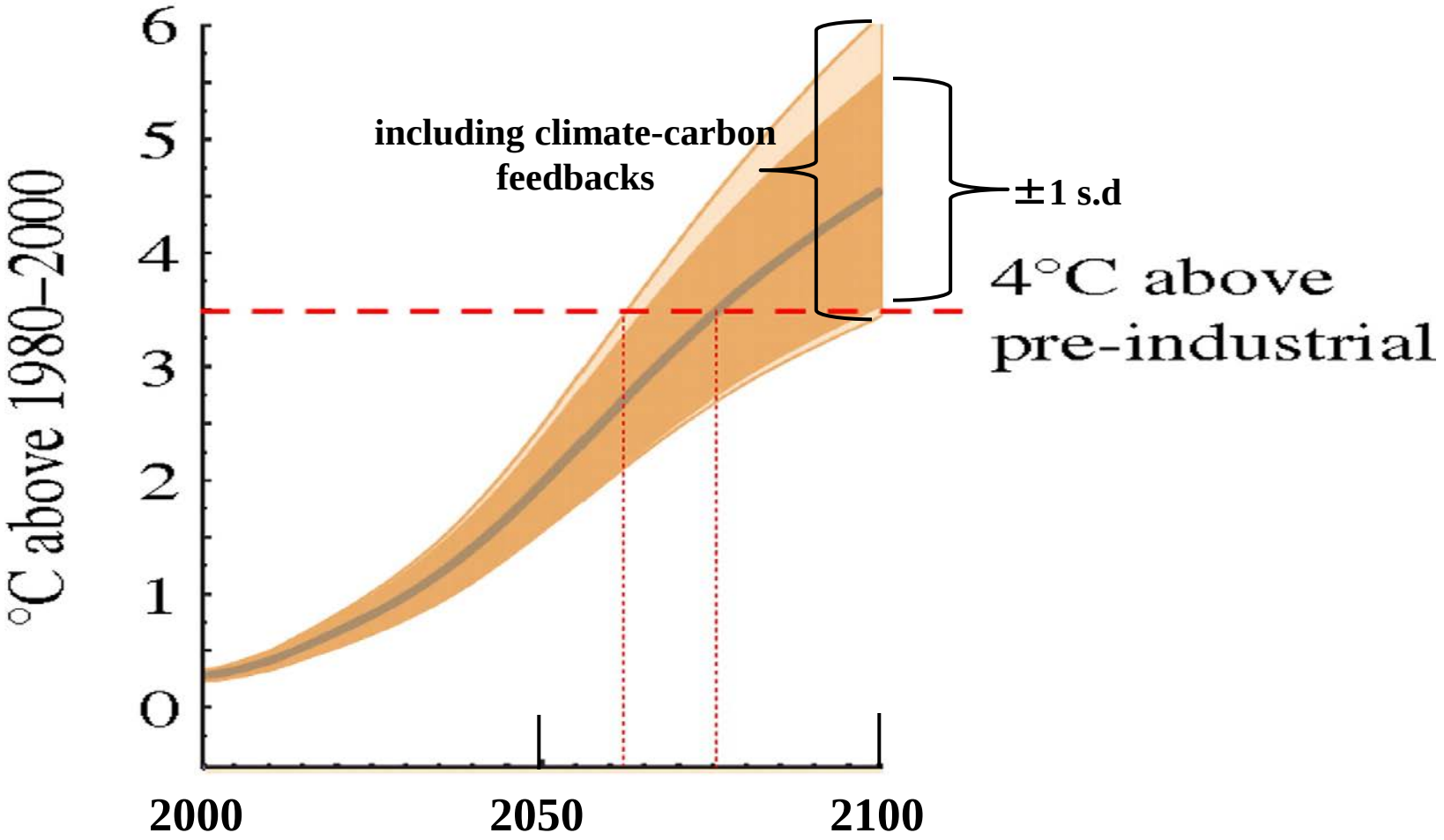
2) Emission Growth Rate Consistent with Most Extreme IPCC Scenarios



Fossil Fuel CO_2 Emissions: Top Emitters

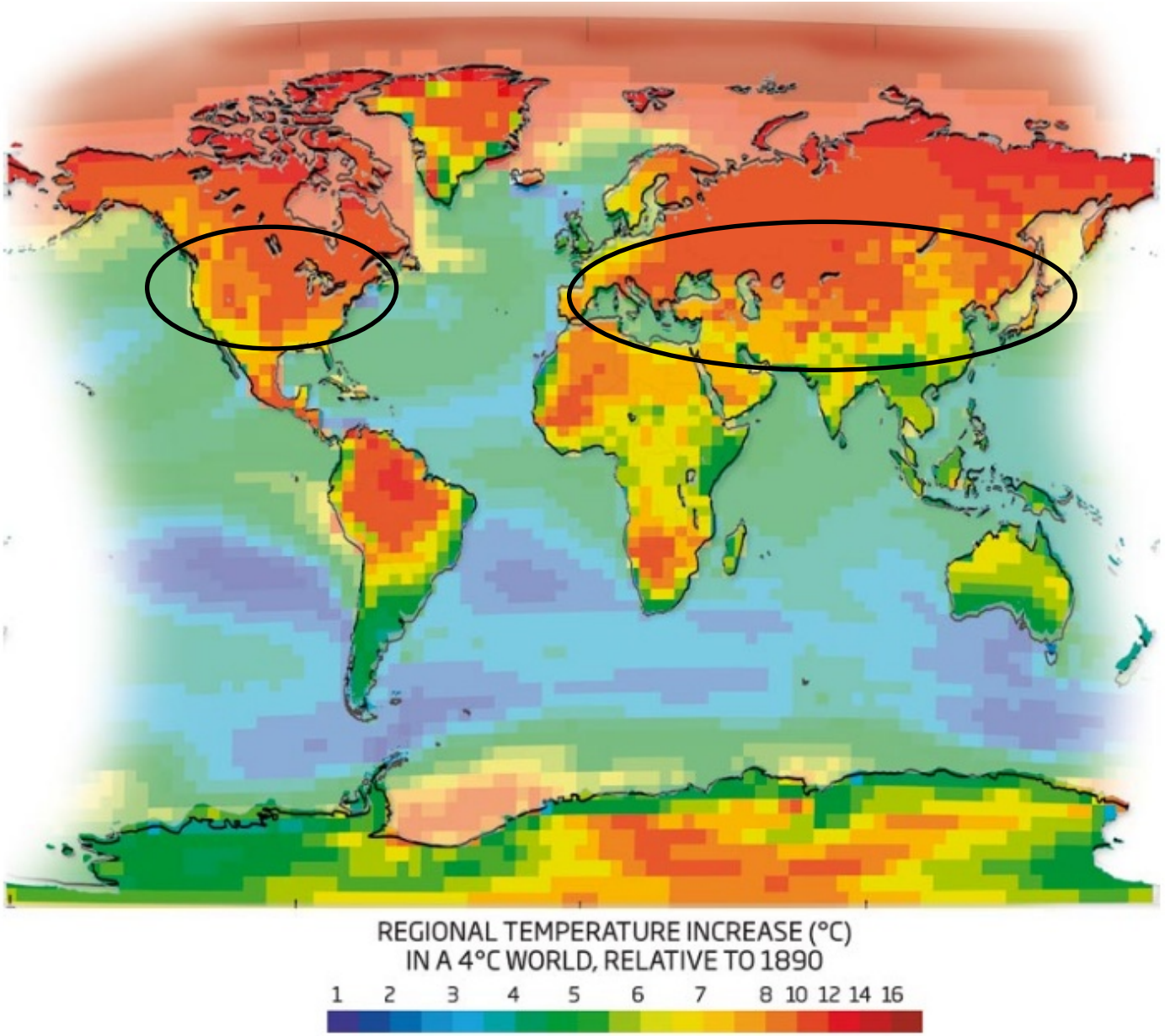


Jan 2011 Warming Projections by The Royal Society (UK): Global Warming Relative to Pre-Industrial for the IPCC A1FI Emissions Scenario, Using an Ensemble of Model Simulations



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

Royal Society: Global Warming in a “4ºC World”

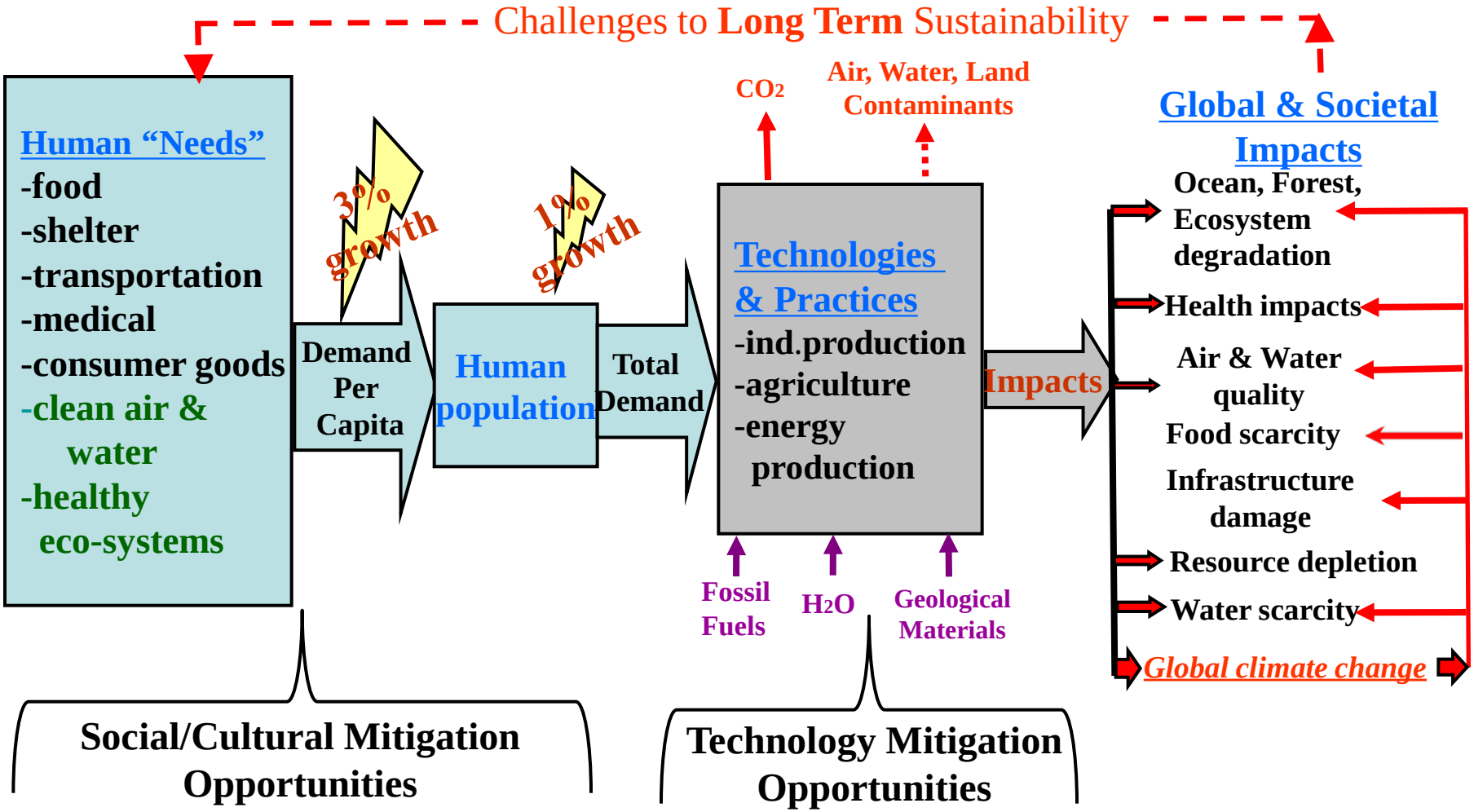


Royal Society (Jan/2011): Implications of 4 deg. Warming

- ***"Enormous adaptation challenges in the agricultural sector, with large areas of cropland becoming unsuitable for cultivation…"***
- ***"…this world would … rapidly be losing its ecosystem services, owing to large losses in biodiversity, forests, coastal wetlands…supported by an acidified and potentially dysfunctional marine ecosystem."***
- ***"…drought and desertification would be widespread, with large numbers of people experiencing increased water stress…."***
- ***"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. …"***

The Macro View of Humanity's Sustainability Challenge

F. Princiotta 2010



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

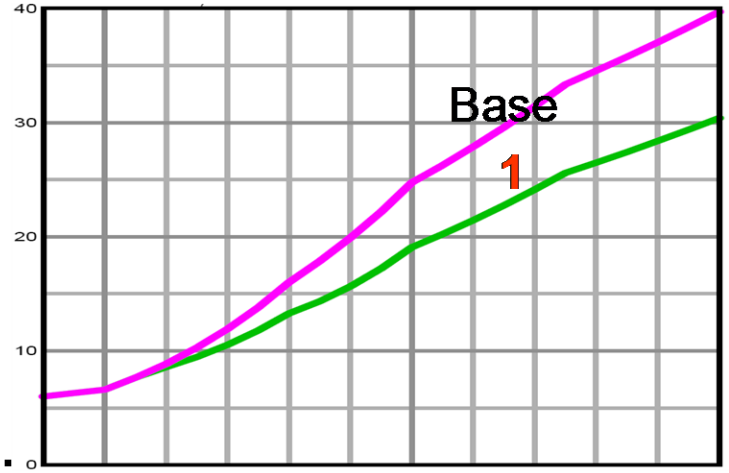
Base Case

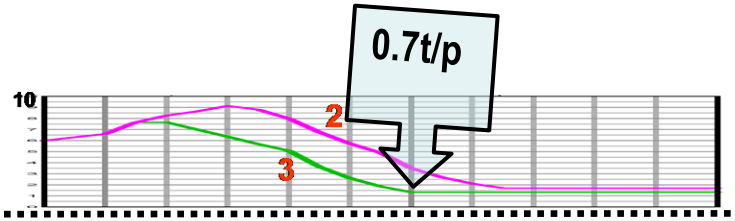
1) US only

2) All developed countries + developing countries> ***delayed*** 15 yrs.

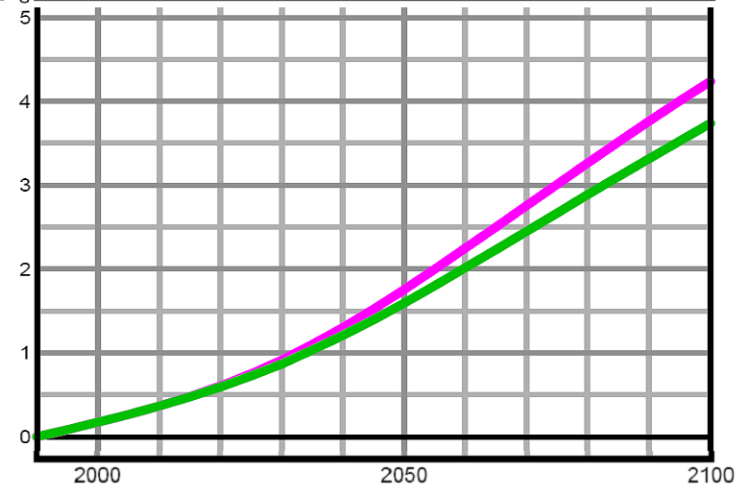
3) World, all countries

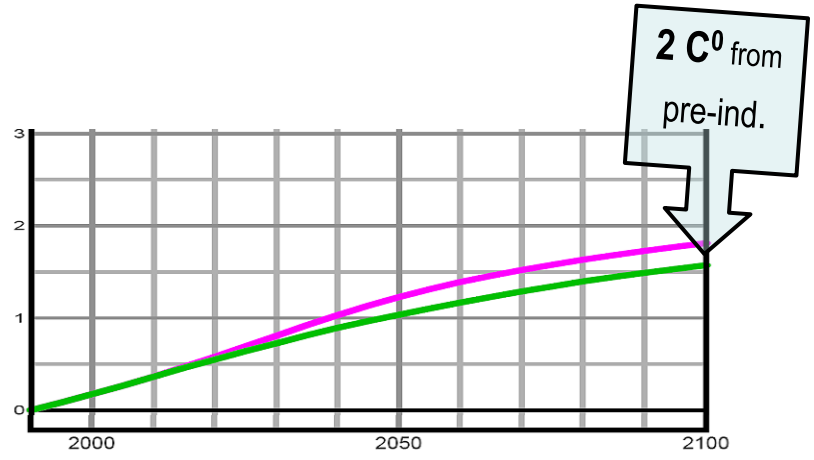
CO_2 Emissions Gt C per Year





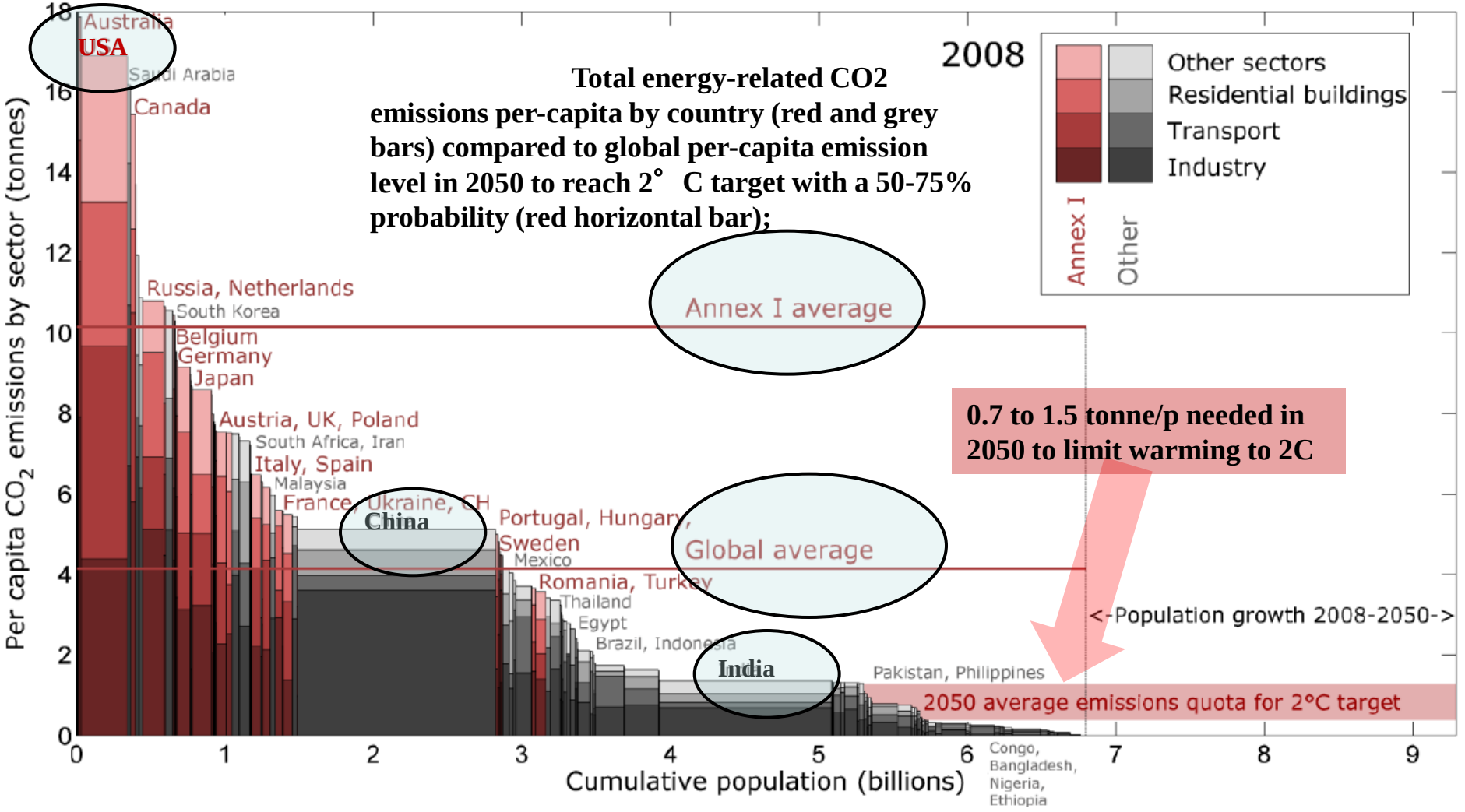
Warming from 1990, C degree



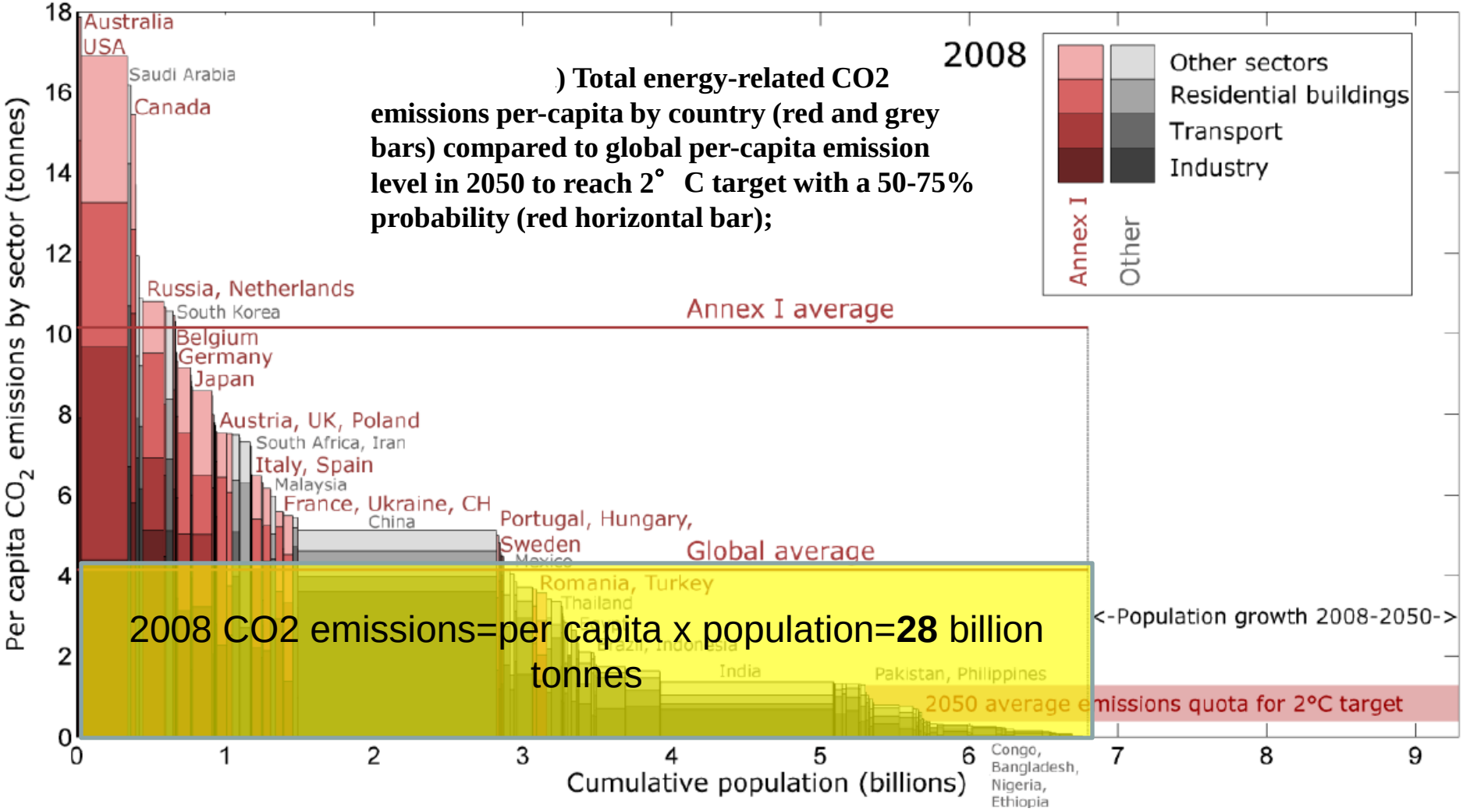


Assumed aggressive mitigation: 2005 to 2012:capped; 2005 to 2020:-17%,2005to2030:-34%;2005 to 2050:-83%

2008 Per Capita CO_2 Emissions by Country Versus That Required to Limit Warming to 2 ^{0}C



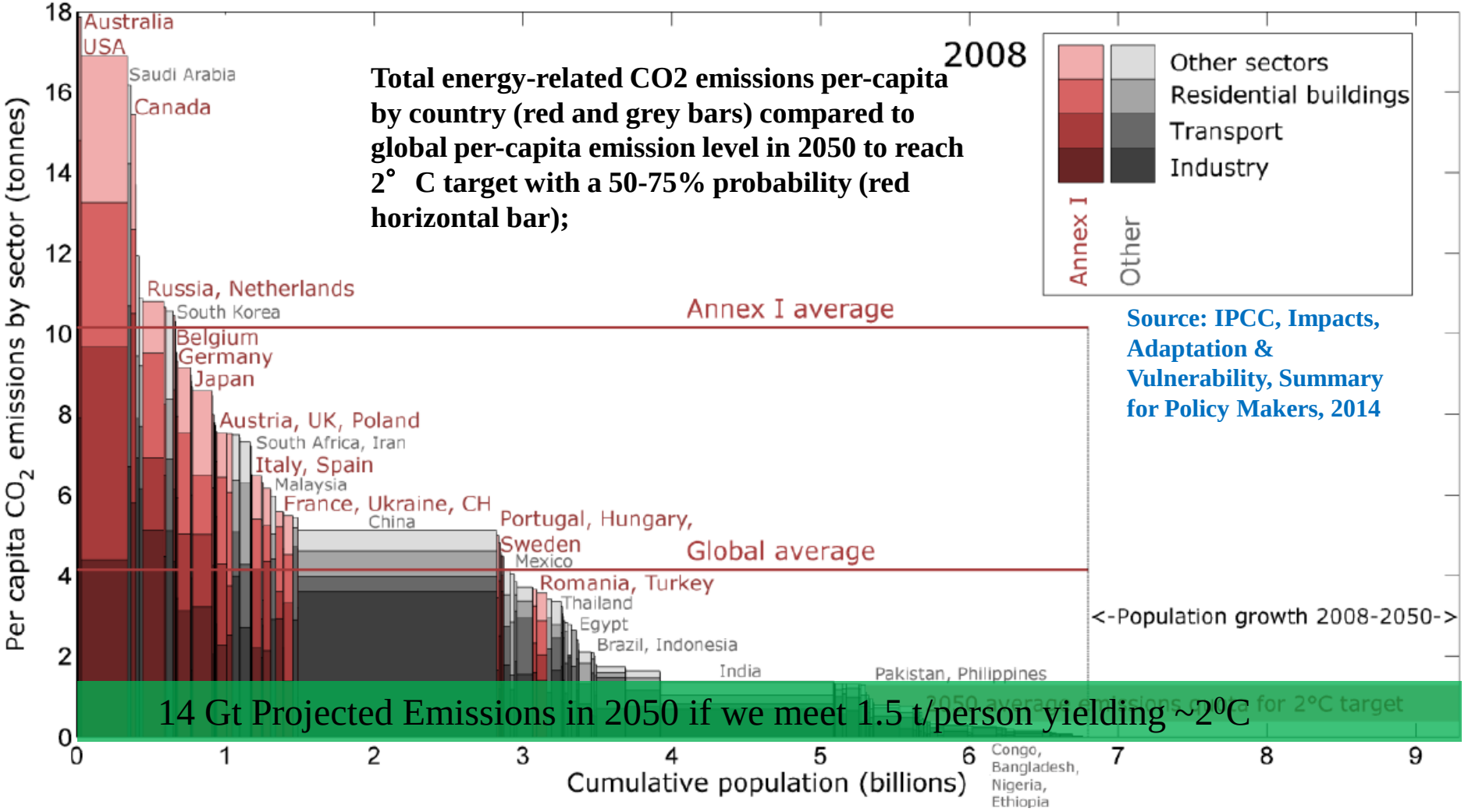
2008 Per Capita CO_2 Emissions by Country Versus That Required to Limit Warming to 2 ^{0}C



) Total energy-related CO2 emissions per-capita by country (red and grey bars) compared to global per-capita emission level in 2050 to reach 2° C target with a 50-75% probability (red horizontal bar);

2008 CO2 emissions=per capita x population=**28** billion tonnes

2008 Per Capita CO_2 Emissions by Country Versus That Required by 2050 to Limit Warming to 2 ^{0} C



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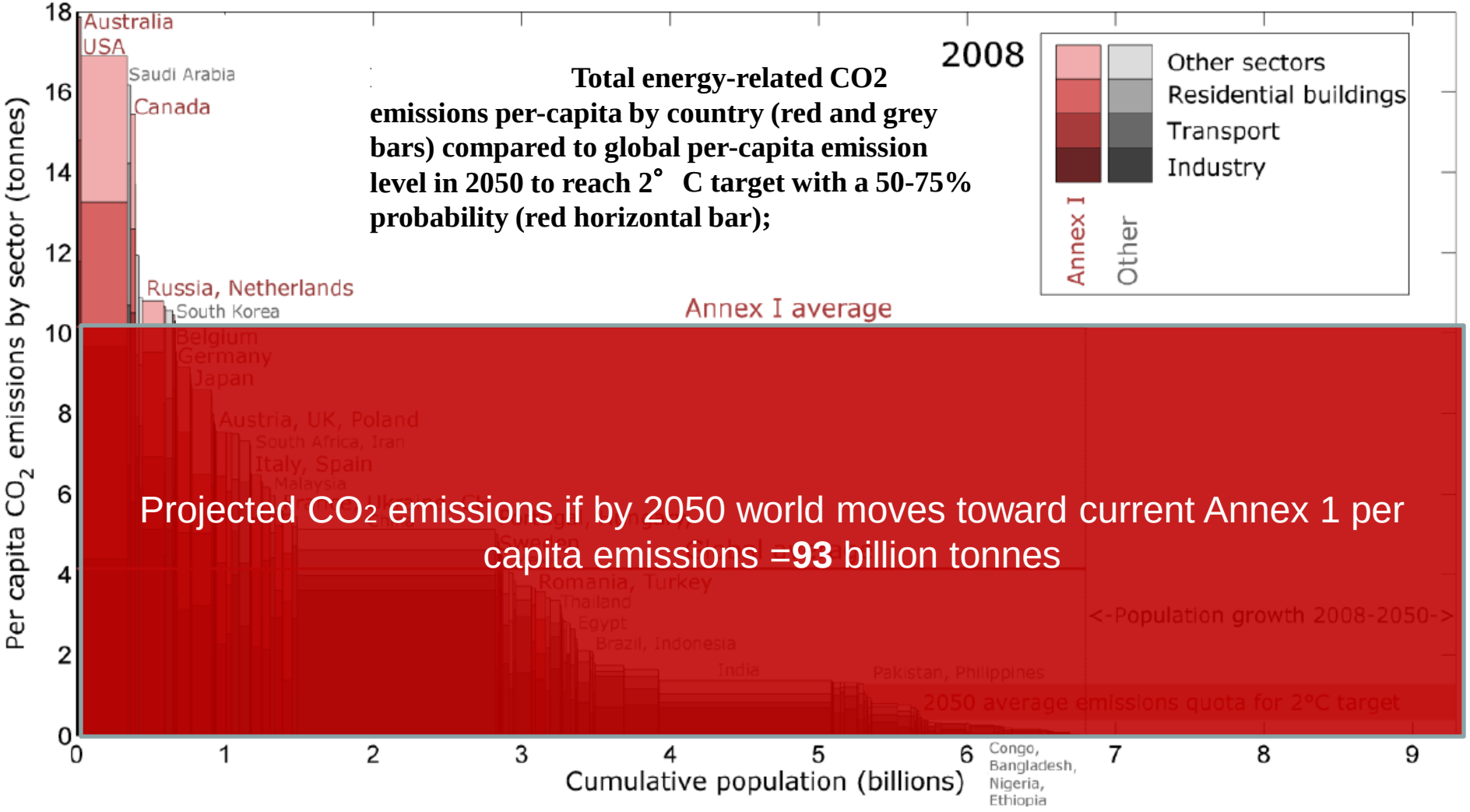
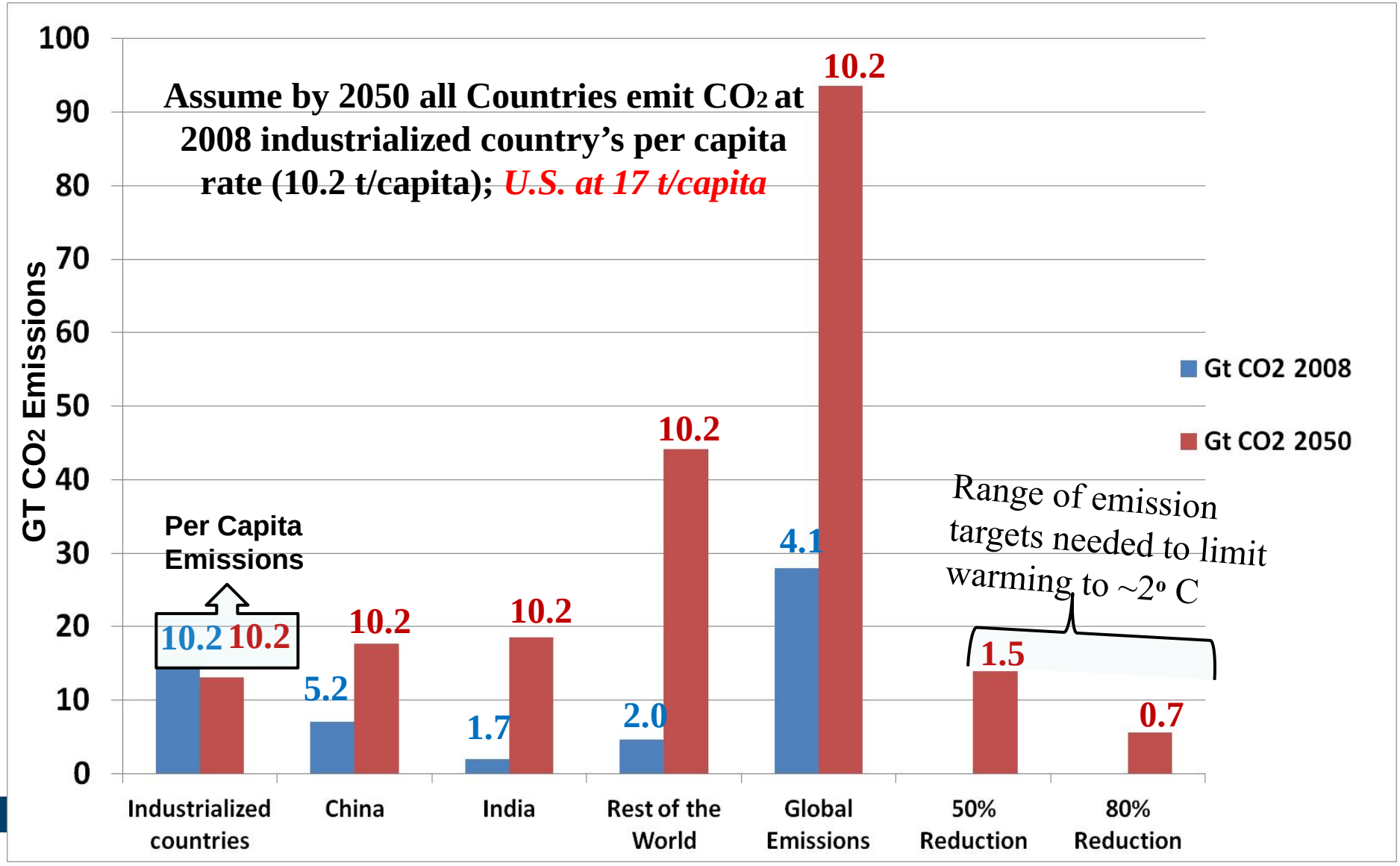


Industrialized Countries' Per Capita Emissions Unsustainable Globally



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

- Develop/utilize low carbon/low resource intensive technologies; transformational technologies appear necessary
- Societies Makes Fundamental Changes
- For climate change, modify Earth's solar radiation balance or remove CO_2 from atmosphere to compensate for GHG emissions, i.e., geoengineering

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IEA Energy Technology Perspectives; a Global Perspective (2010)

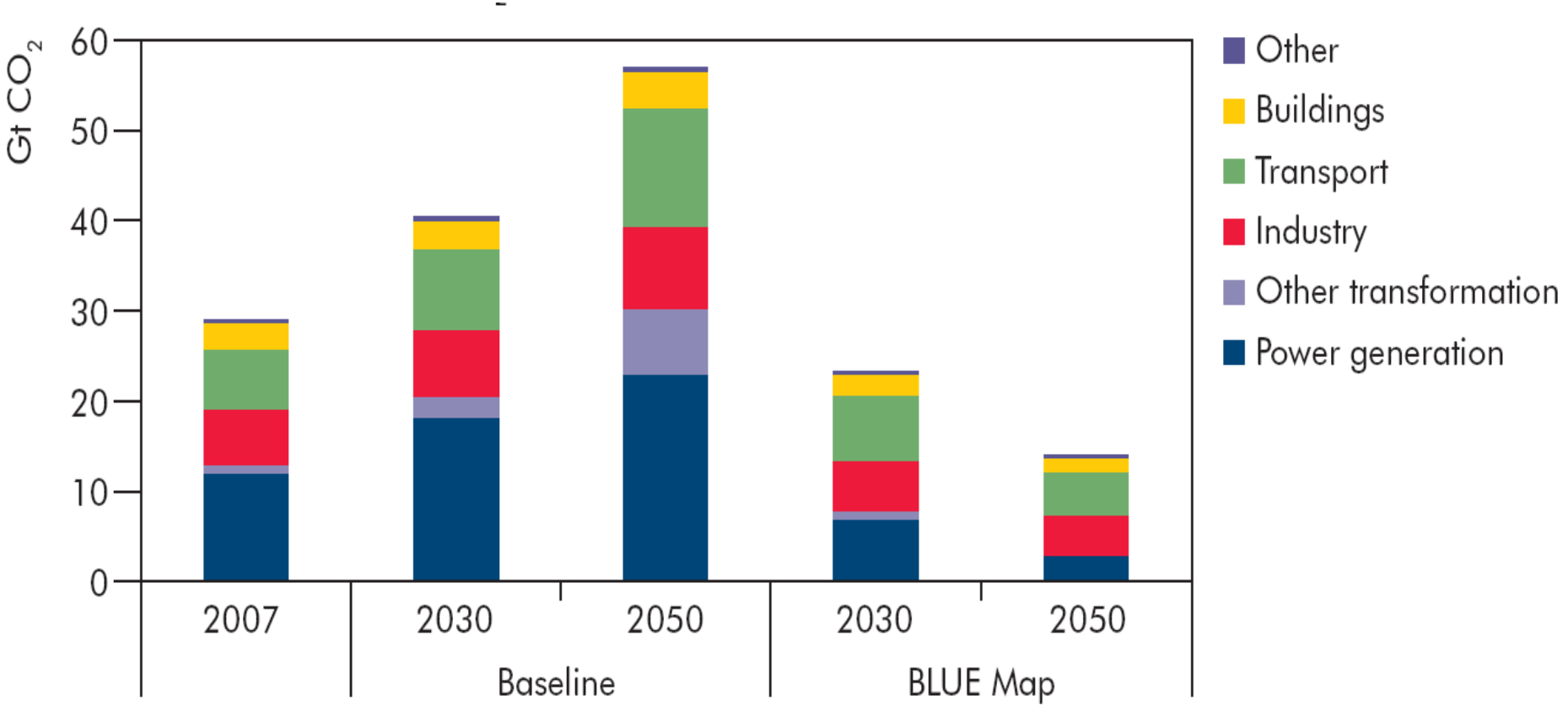
- Mandate by G-8 Leaders and Energy Ministers
- Analyzed *Blue* scenario to limit warming to ~ 2.5 C; this requires 2050 emissions to be 1/2 of 2005 values (~2% annual reduction for 45 years)
- They concluded:

  "We are facing serious challenges in energy sector"

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

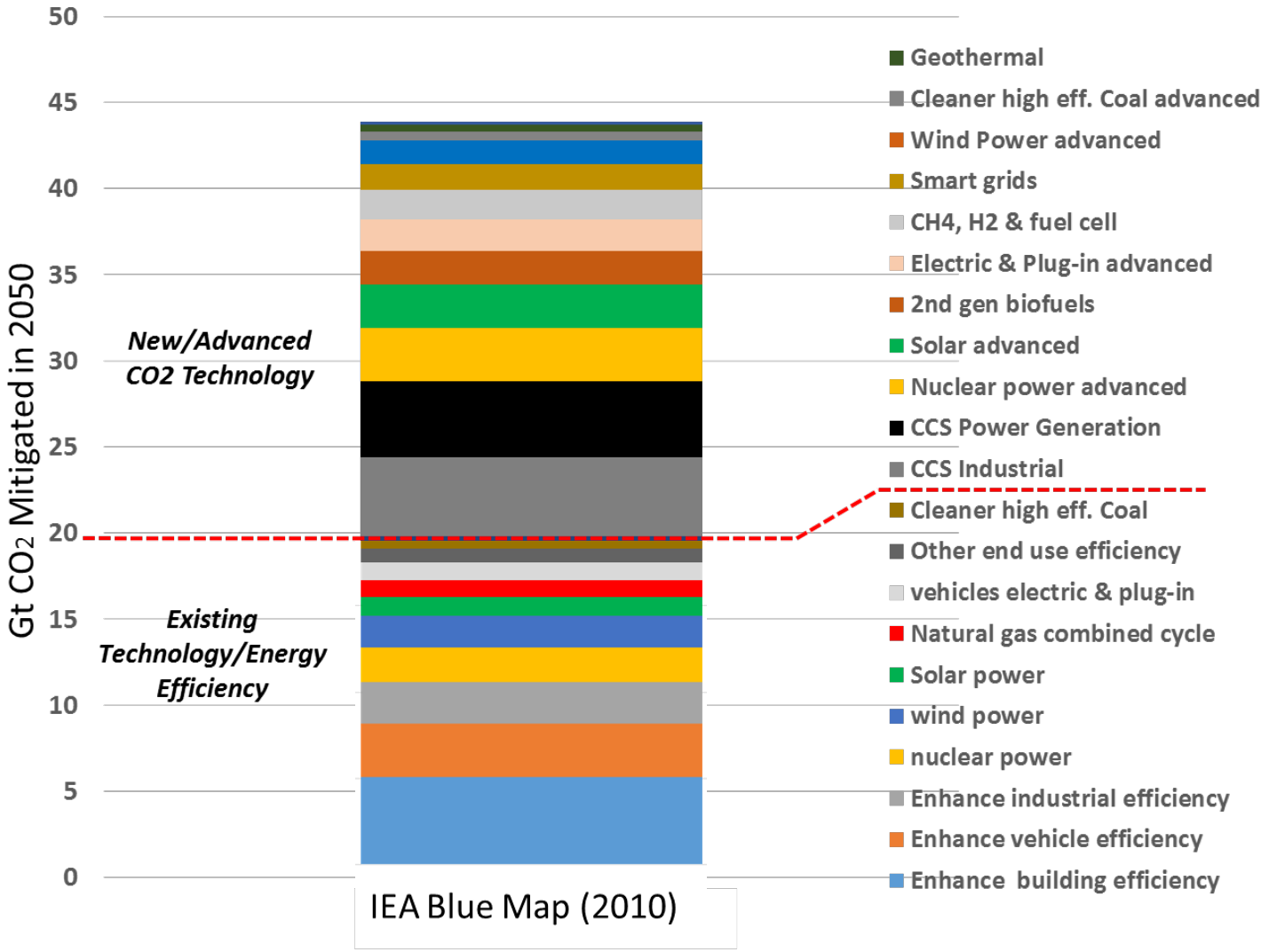
  "The Blue scenarios require urgent implementation of unprecedented and far reaching new policies in the energy sector"

IEA CO2 Projections: Baseline and Blue (50% reduction 2050 from 2007) Scenarios



Source: IEA Energy Technology Perspectives 2010

For Global 50% CO_2 Reduction Scenario (Blue, IEA ETP 2010); New & Advanced Technologies Needed



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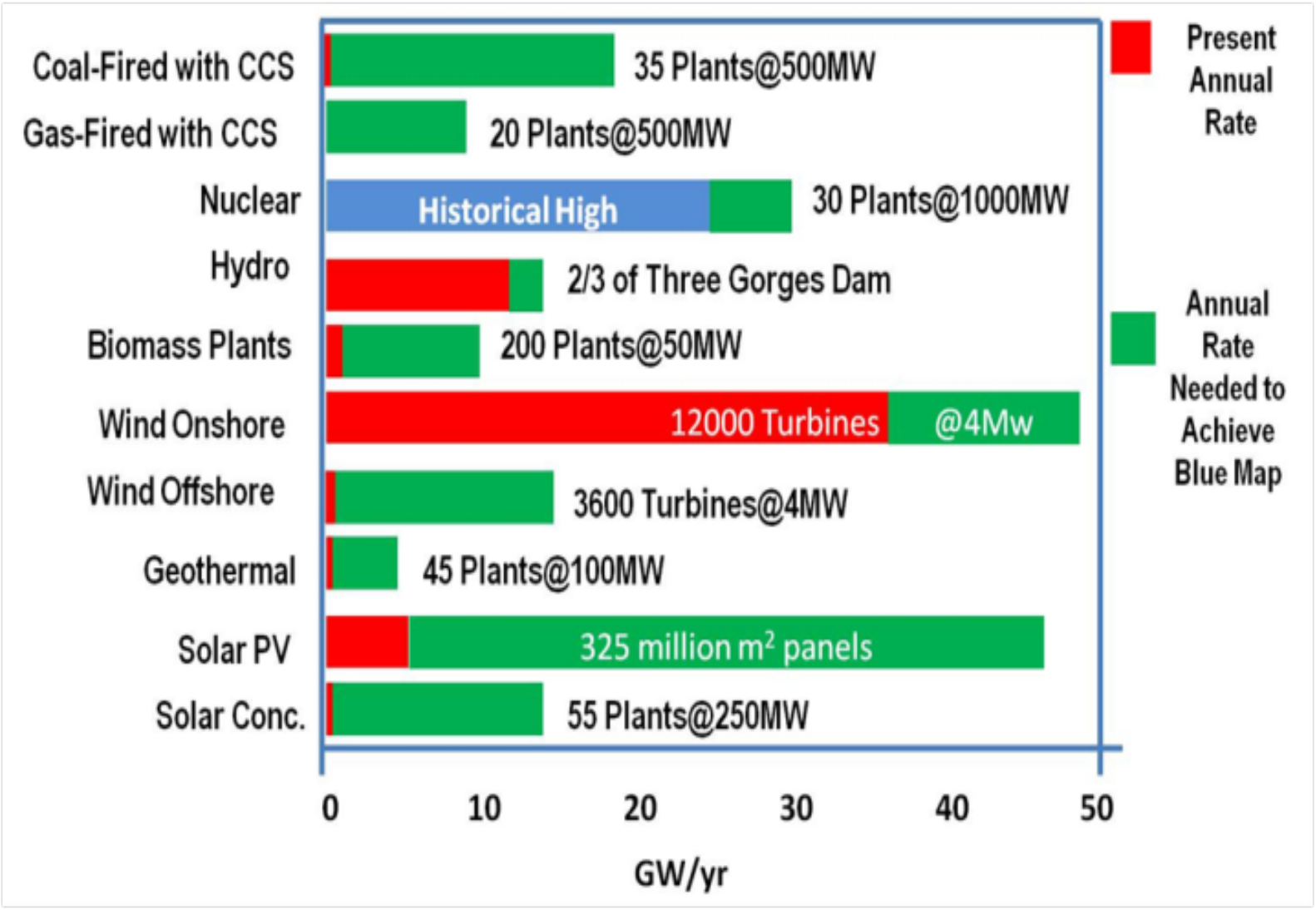
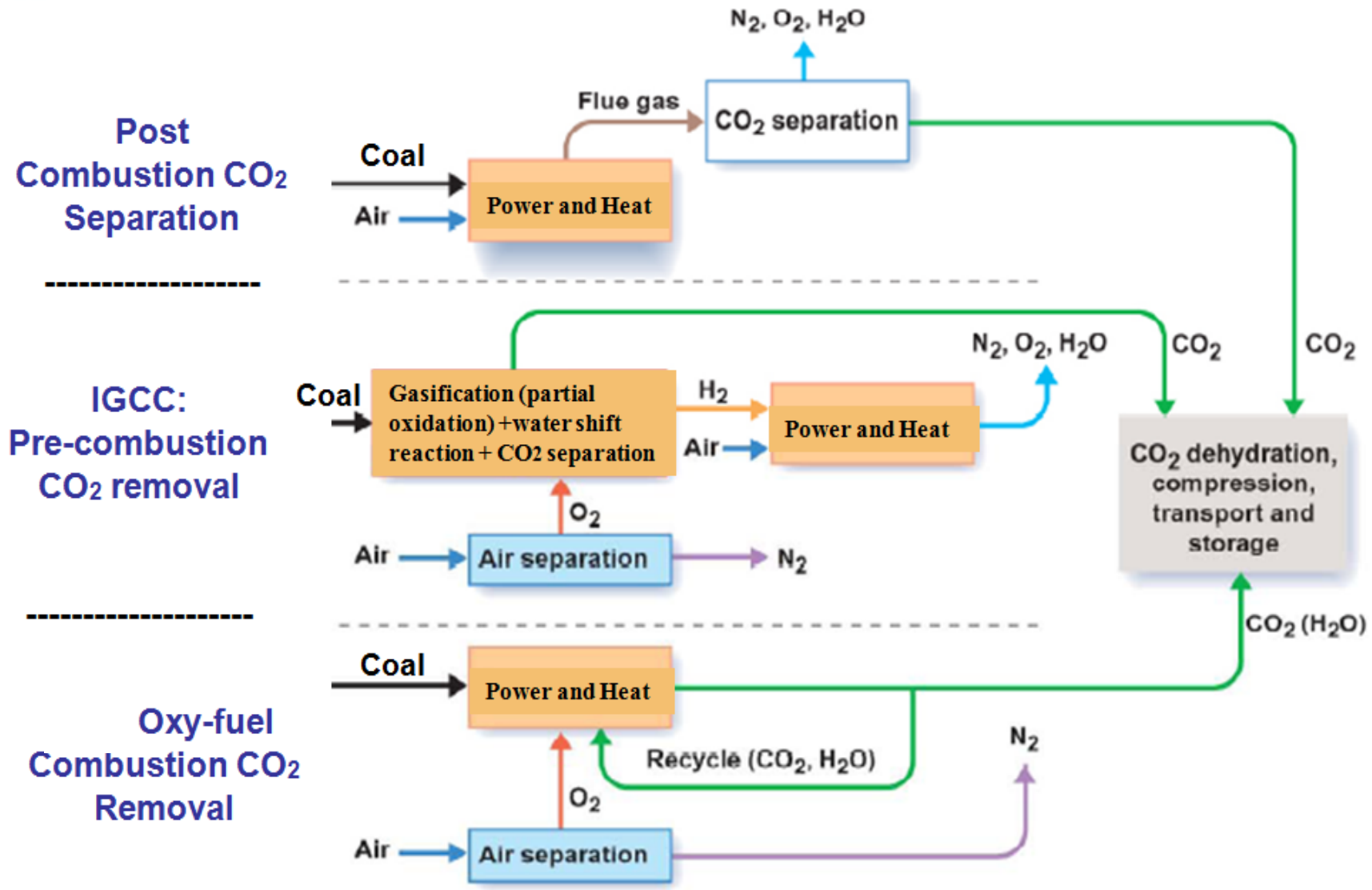
Additional **Annual** capacity needed in global power generation sector for IEA **Blue 50% Reduction Scenario**



The three key CCS Technologies



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

Large Scale Power Plant CCS Projects Planned or Under Construction in U.S. and Canada

Project	Private-Sector Project Leader	Fuel	Location	Size (Mw)	DOE Funding (Millions Dollars)	Planned Start Date	Technology	Readily Retrofitted	Storage
Kemper County	Mississippi Power/Southern Co.	Coal	Kemper County, Miss.	582	270	2015	IGCC	No	EOR
Texas Clean Energy	Summit Power Group	Coal	Ector County, Tex.	400	450	2015	IGCC	No	EOR
Boundary Dam	Sask Power	Coal	Estunam, *Canada*	110	N/A	2016	Amine	Yes	DSA
FutureGen 2.0	FutureGen Industrial Alliance	Coal	Meredosia, Ill.	200	1000	2017	Oxy Fuel	Yes	DSA
Hydrogen Energy California	SCS Energy	Pet coke	Kern County, Calif.	300	408	2017	IGCC	No	EOR
W.A. Parish Plant	NRG Energy	Coal	Thompsons, Tex.	60	154	2017	Amine	Yes	EOR
Bow City	BC P&L	Coal	Bow City, *Canada*	500-**1000**	N/A	2017	Amine	Yes	EOR

Source: MIT Data Base

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Evaluating a U.S. mitigation strategy

- Modeling performed with MARKAL model
  - U.S. EPA ORD's 9-region MARKAL model/database; *such models they do not attempt to predict, they generate credible scenarios consistent with input assumptions*
  - Baseline scenario:
    - Calibrated to Annual Energy Outlook 2010 through 2035
  - *Hypothetical* GHG mitigation scenario:
    - Selected energy system-wide limit on CO_2 emissions: **50%** reduction by 2050 from 2005 levels

For U.S. a Credible 50% CO_2 Reduction Scenario by 2050, Mt CO_2

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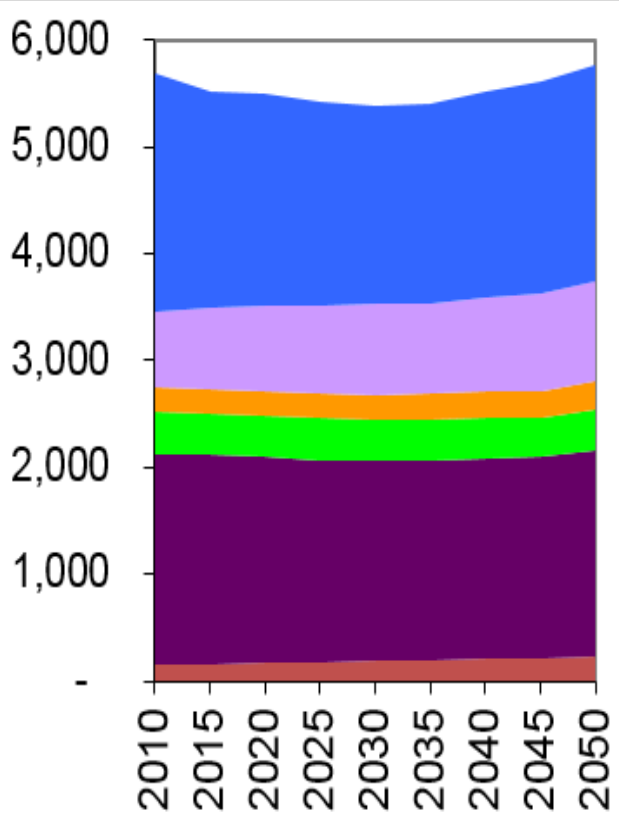
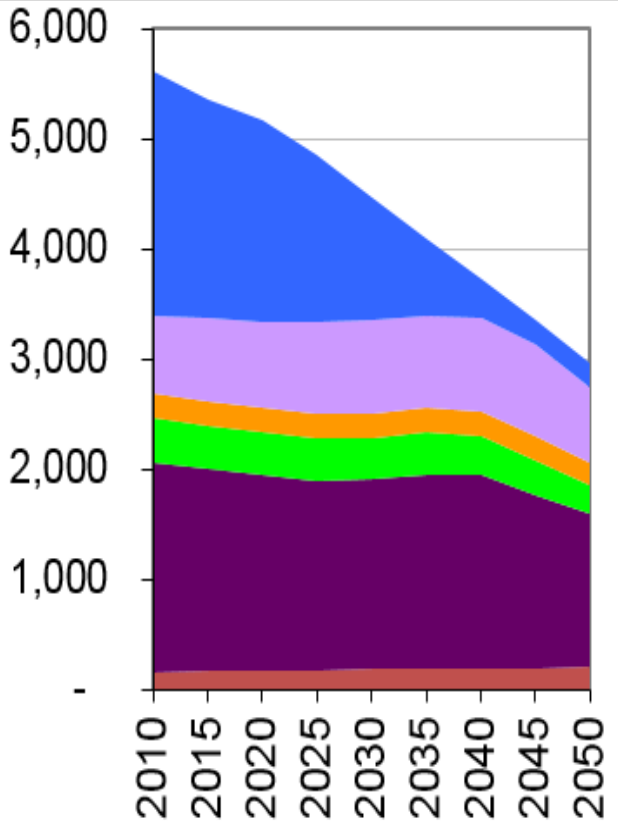
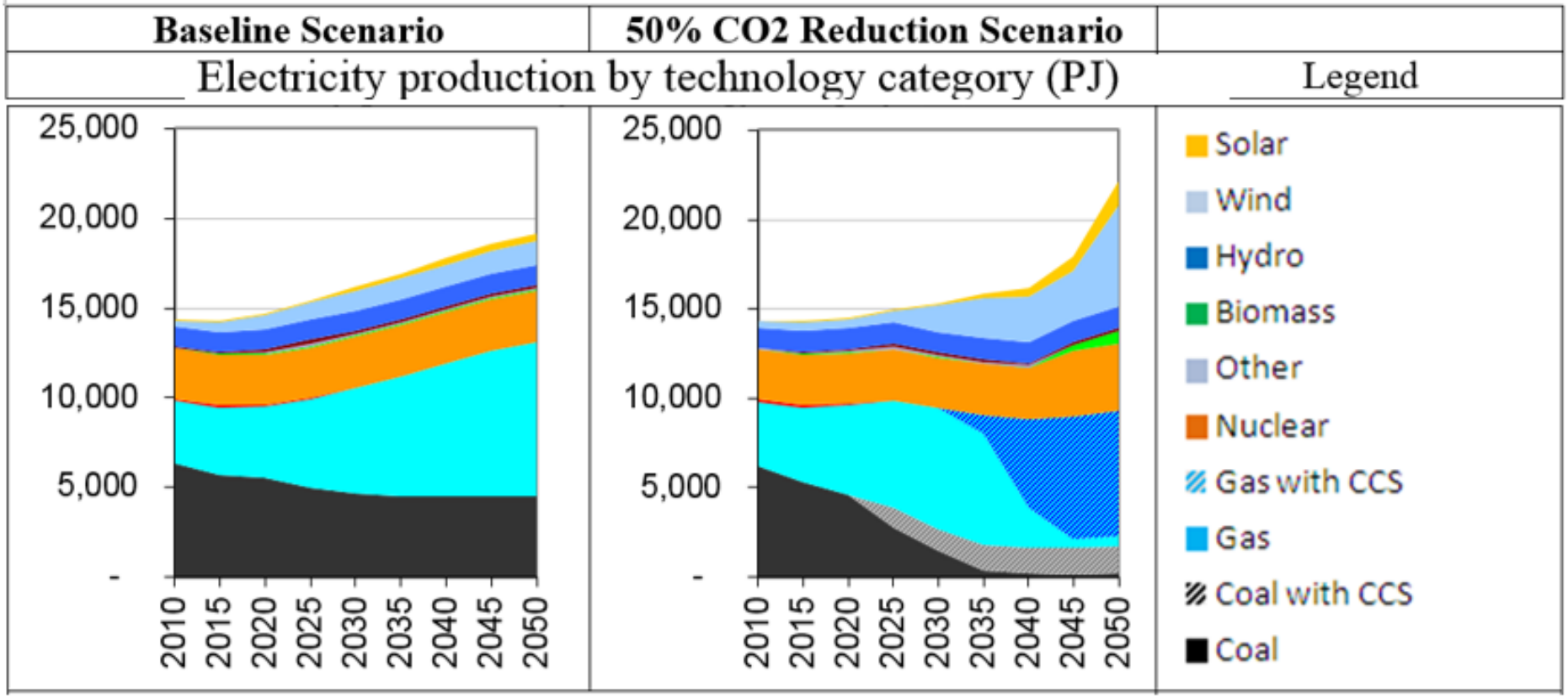
Baseline Scenario	50% CO2 Reduction Scenario	
Energy system CO_2 emissions by sector Mt		Legend





Electricity Production
Industry
Commercial
Residential
Transportation
Resources

For U.S. Power Generation a Credible 50% CO_2 Reduction Scenario by 2050, PJ



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	Current annual public RD&D spending	Estimated annual RD&D spending gap
	(USD million)[1]	(USD million)[2]	(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

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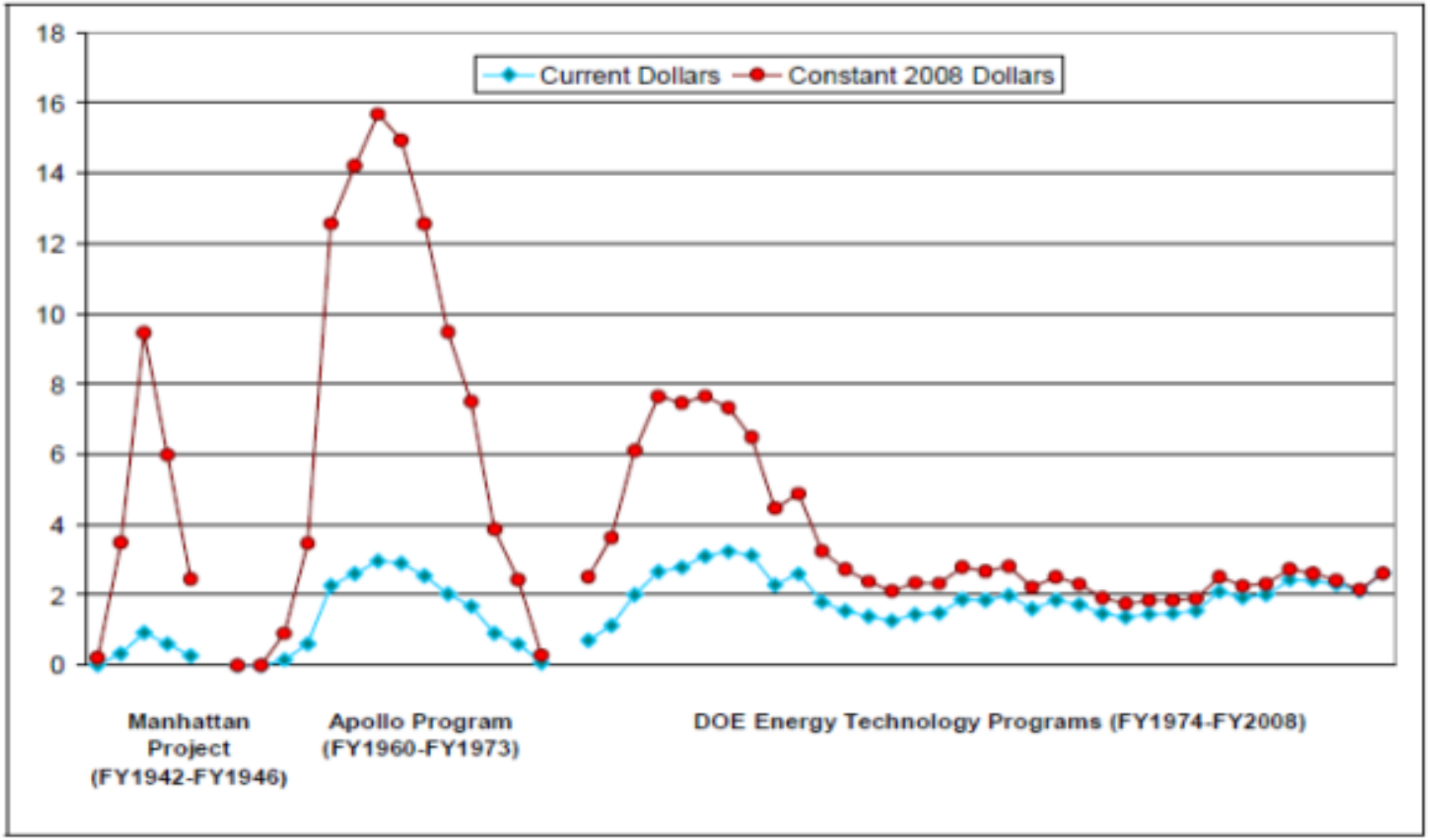
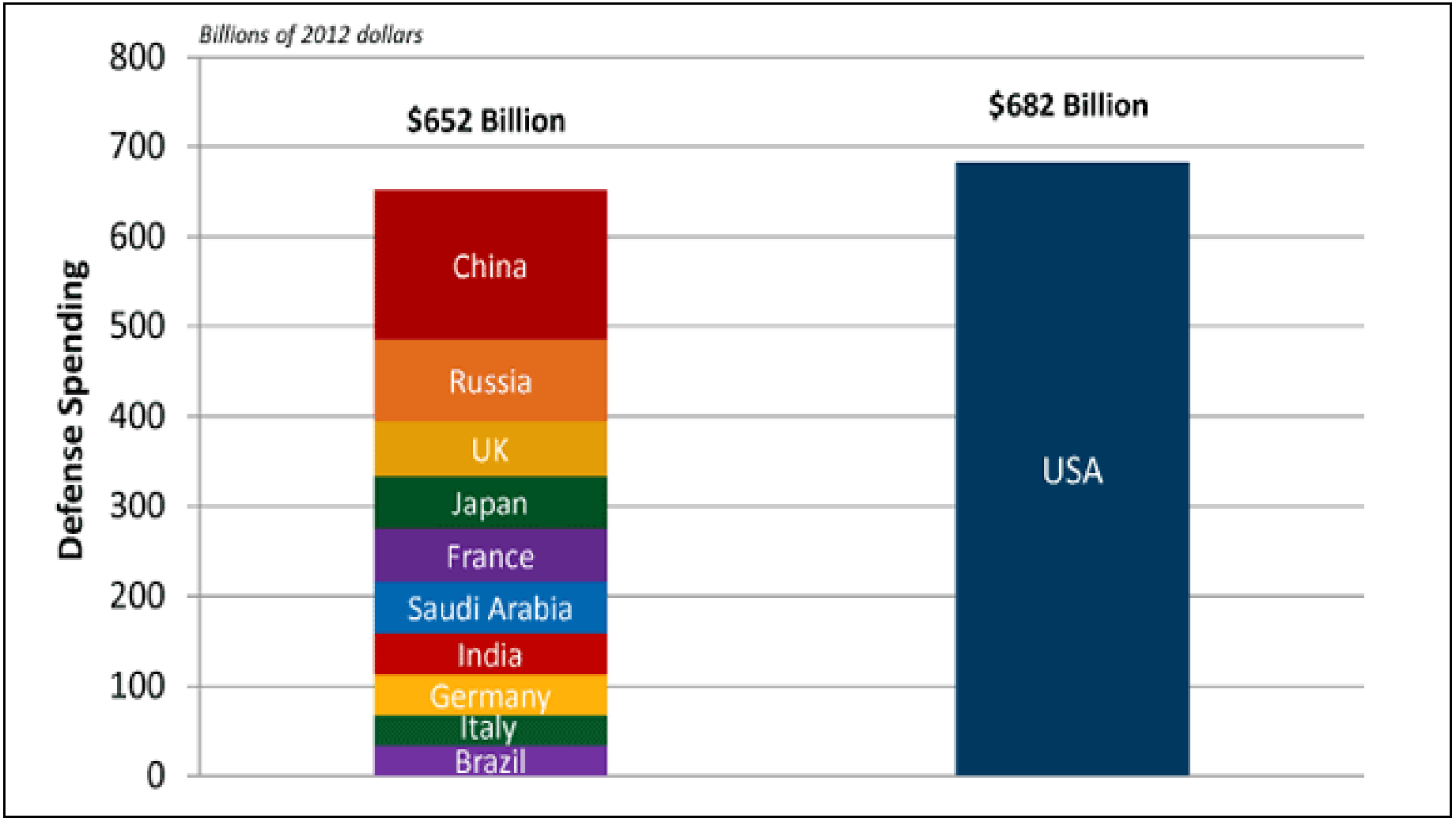
Annual Funding for Manhattan Project, Apollo Program, and DOE Energy Technology R&D Program



FY 2012 US Military Spending Greater Than the Next Ten Countries Combined



Presentation Summary

- Population growth & developmental pressures spawned by increasing demand for energy & resource intensive goods, foods & services are driving exponential growth in GHG emissions
- The developing world is moving toward the unsustainable energy/resource intensive path pioneered by the developed world
- If GHG emissions will continue to grow at 2 to 3% annually for decades> yielding warming of 4 C as soon as 2065 (6 C over land)
- Per capita CO_2 emissions must reduce from 5 (2013) to ~1 tonne/person by 2050; US currently at 17, China at 7 (2013) & growing
- IEA: “A global revolution is needed in ways that energy is supplied and used”

Presentation Summary, continued

- Major technology advances necessary. Power generation & mobile source sectors; carbon capture and storage, renewables, nuclear reactors, and low emission vehicles are critical technologies.
- Current research program woefully underfunded
- Geoengineering, although problematic, offers the possibility of buying us time to allow necessary energy infrastructure/cultural changes
- Although a transformational change in the energy sector is necessary, it may not be sufficient. Cultural changes aimed at reducing humanity's resource/energy intensive footprint may be needed
- In June 2013, President Obama announced Climate Action Plan with Three Major Components: Cut U.S. Carbon Emissions, Prepare the U.S. for Climate Change Impacts & Lead International efforts on Mitigation & Adaptation

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

Electricity production for 50% CO_2 reduction scenario by Region

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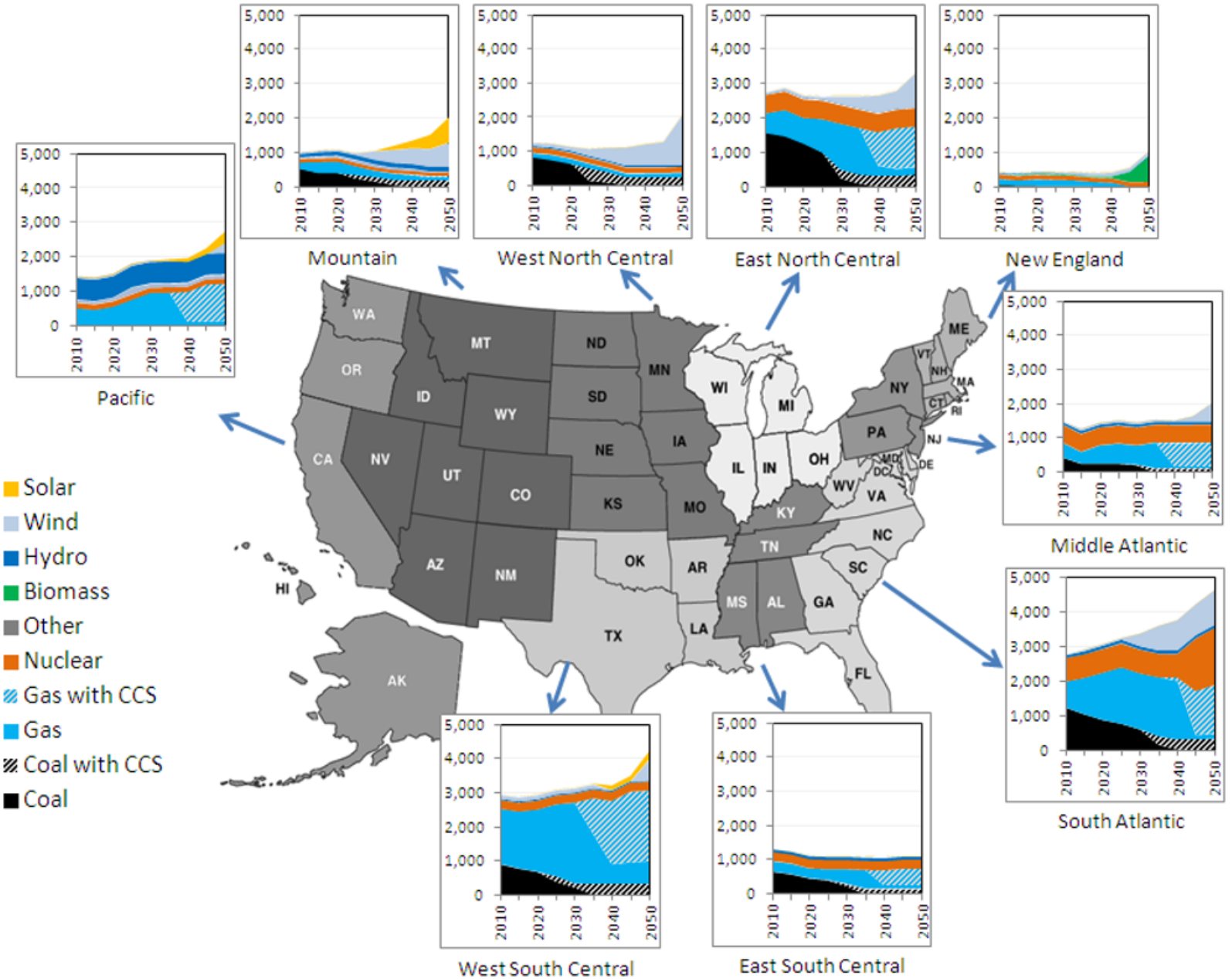

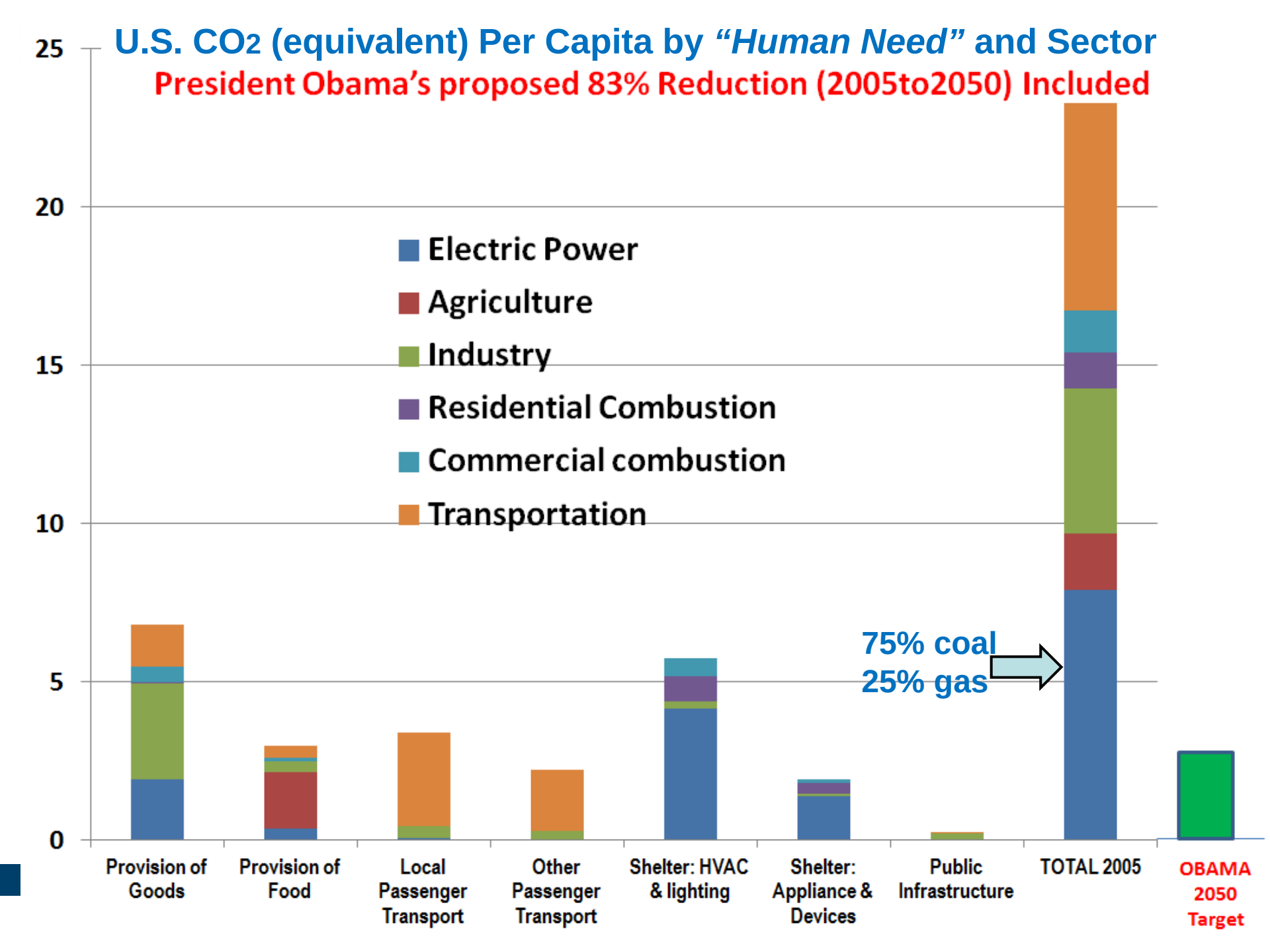
U.S. CO2 (equivalent) Per Capita by "Human Need" and Sector
President Obama's proposed 83% Reduction (2005to2050) Included
25
20
15
10
5
0
Electric Power
Agriculture
Industry
Residential Combustion
Commercial combustion
Transportation
75% coal
25% gas
Provision of Goods
Provision of Food
Local Passenger Transport
Other Passenger Transport
Shelter: HVAC & lighting
Shelter: Appliance & Devices
Public Infrastructure
TOTAL 2005
OBAMA 2050 Target

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Recent Trends are Deepening the Challenge

- Atmospheric concentration of CO2 approaches 400 ppm, & CO2 (e) ~450 ppm; >2 C warming appears inevitable
- Nature Article (Dec. 2013): Based on new cloud study atmospheric sensitivity to CO_2 may be greater than current models assume
- Following the tsunami damage at Fukushima, Japan and Germany are reconsidering their nuclear programs
- United Nations-led negotiations on a new global treaty on climate change have been unproductive
- U.S. budget battles don't bode well for an expanded energy technology program