The Context for Advanced Coal and CCS in the United States and China

John P. Holdren

Assistant to the President for Science and Technology and Director, Office of Science and Technology Policy
Executive Office of the President of the United States

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Why is the energy problem so difficult?

- It's a "rate problem", not an "equilibrium problem".

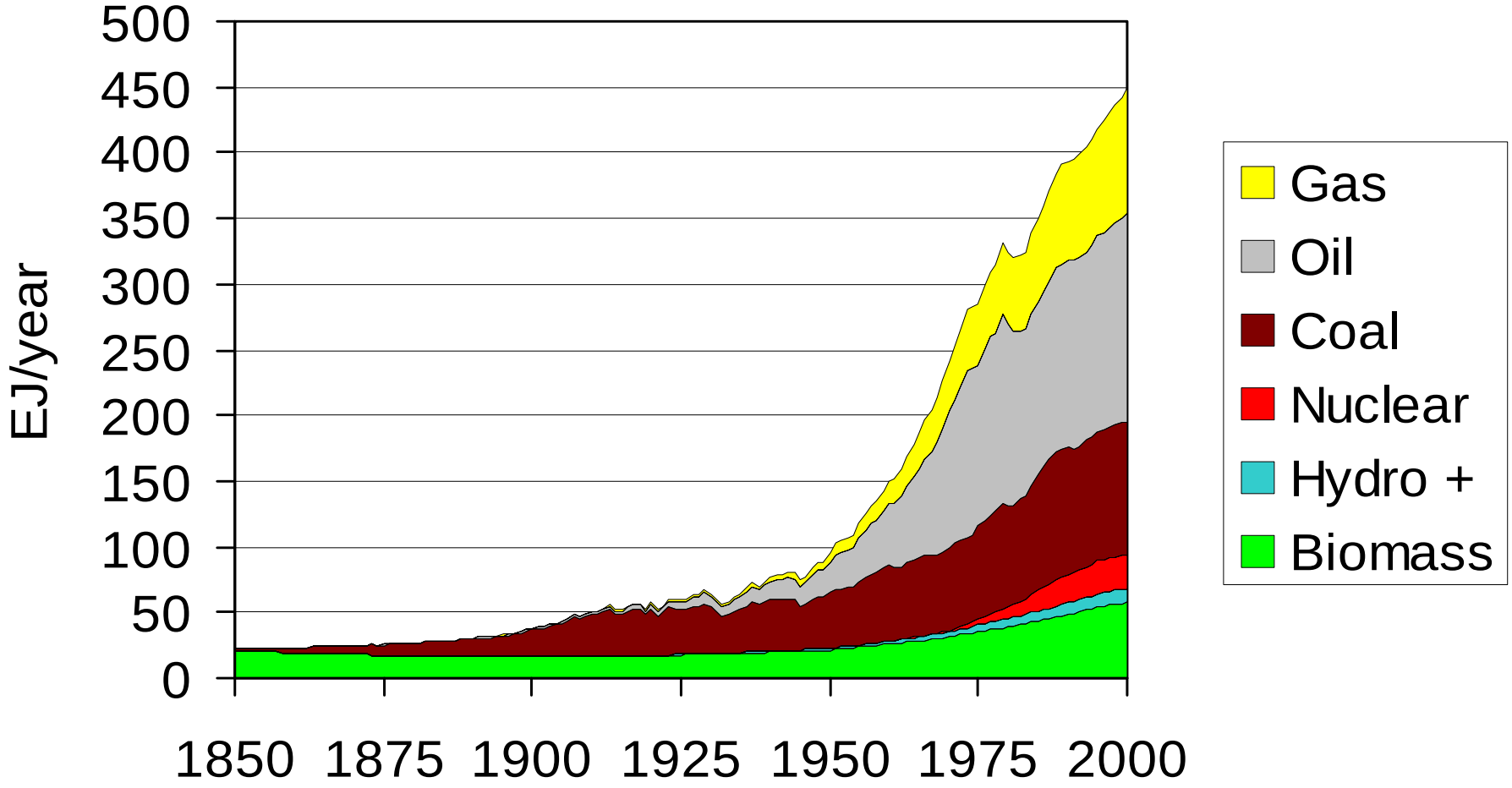
  Not how to match a portfolio of static supply options to static demand...

  Rather: how to keep up with rapidly rising demand for energy services, using changing technologies under changing constraints

- Economic, environmental, and political objectives of energy policy are often in tension.

- All energy technologies have shortcomings vis-a-vis one or more of these objectives

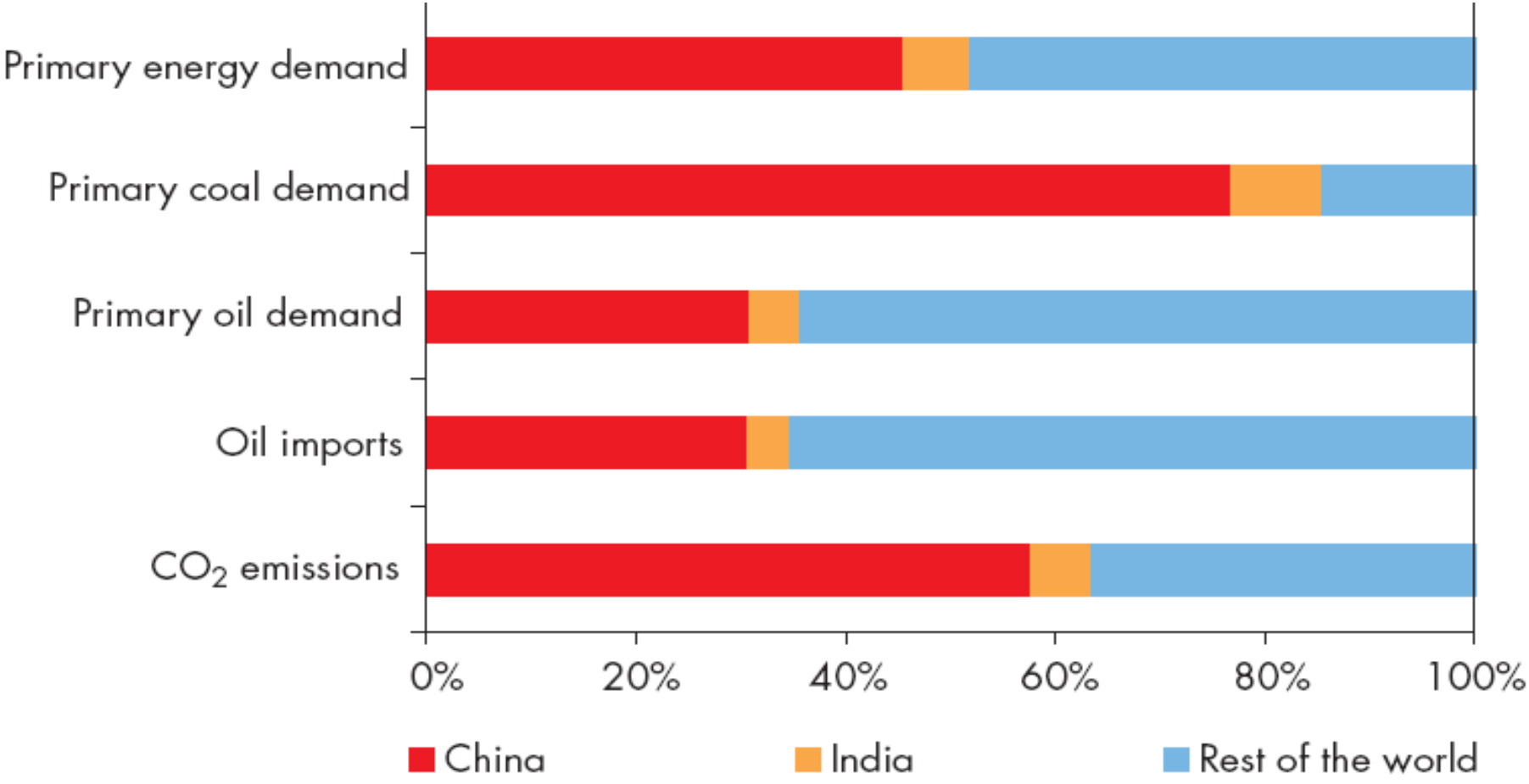
Rates: Growth of world population & prosperity 1850-2000 ➔ brought 20-fold growth in energy use



Growth rate 1850-1950 was 1.45%/yr, driven mainly by coal.
From 1950-2000 it was 3.15%/yr, driven mainly by oil & natural gas.

Much of the recent growth has been in Asia

Bars show role of China & India in growth 2000-2006



* Based on preliminary estimates for 2006.

WEO 2007

Some comparative data for 2007

	population (millions)	ppp-GDP (trillion $)	energy (EJ)	fossil E (percent)	fossil CO_2 (MtC)
World	6625	65.2	536	82%	8250
China	1320	7.1	93	85%	1790
USA	302	13.8	106	88%	1720
Russia	142	2.1	30	90%	440
India	1123	3.1	28	61%	355
Brazil	192	1.8	9	61%	100

But Brazil adds 200-400 MtC/yr from deforestation.

Continued high growth is expected to 2030

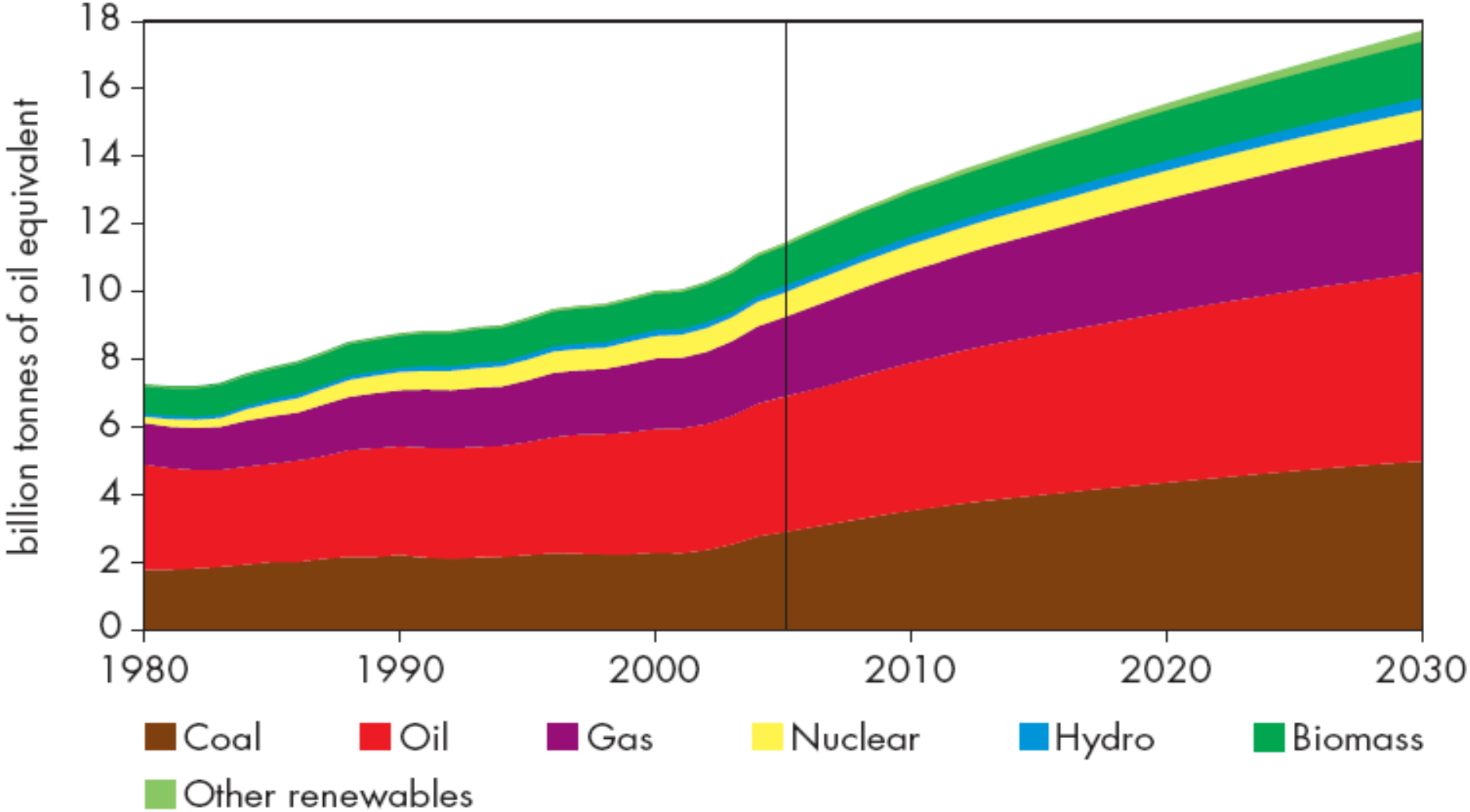
US EIA 2007 and IEA WEO 2007 “reference” forecasts

	2006	2030
Primary energy, exajoules		
World	526	800
United States	106	150
China	86	175
Electricity, trillion kWh		
World	19.3	35
United States	4.3	6.0
China	2.8	7.5

…and beyond, if “business as usual” continues

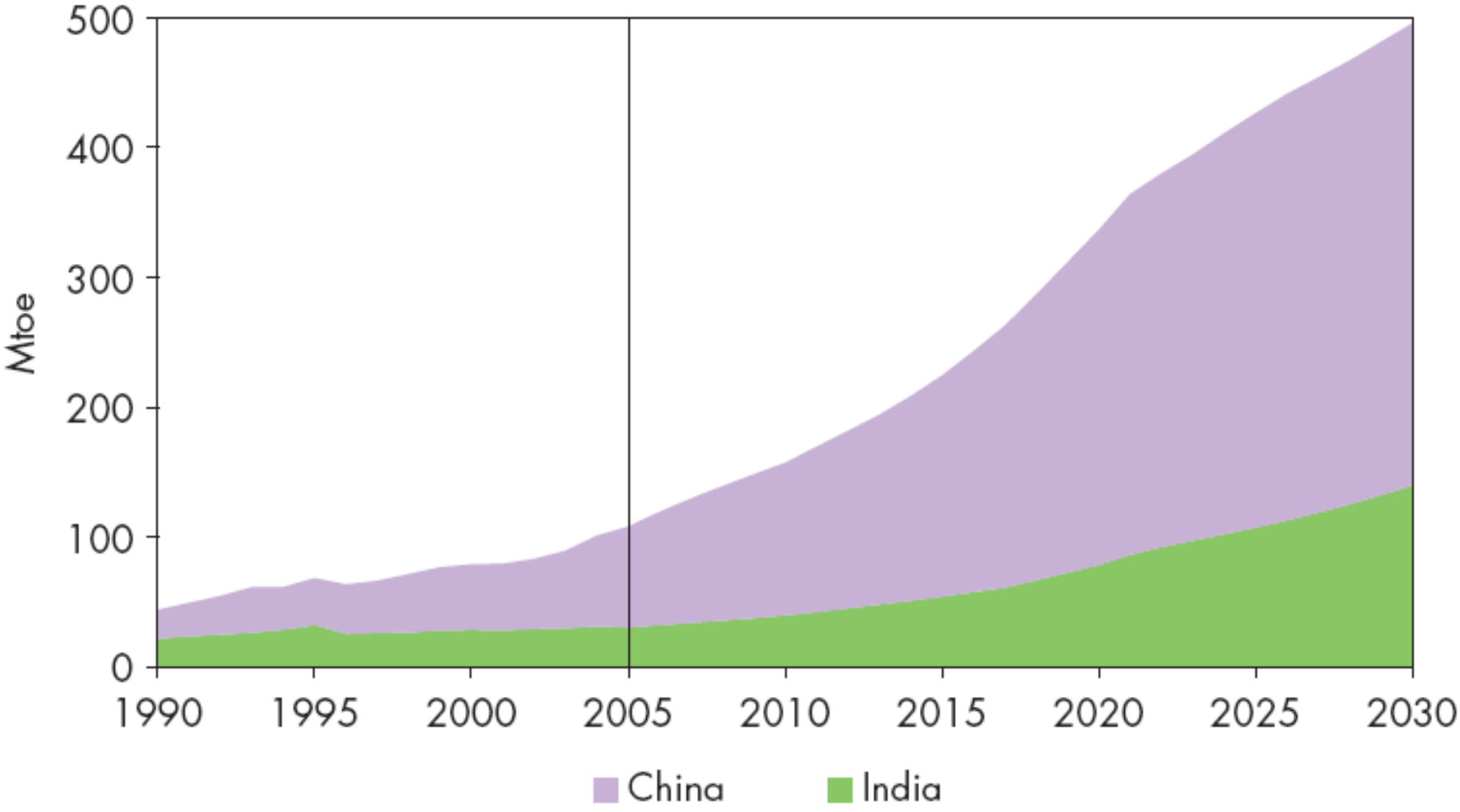
- World use of primary energy reaches
  - 2.5 times the 2000 level by 2050,
  - 4 times by 2100.
- World electricity generation reaches
  - 3 times the 2000 level by 2050,
  - 5 times by 2100.

Fossil fuels are expected to continue to dominate supply in the decades immediately ahead



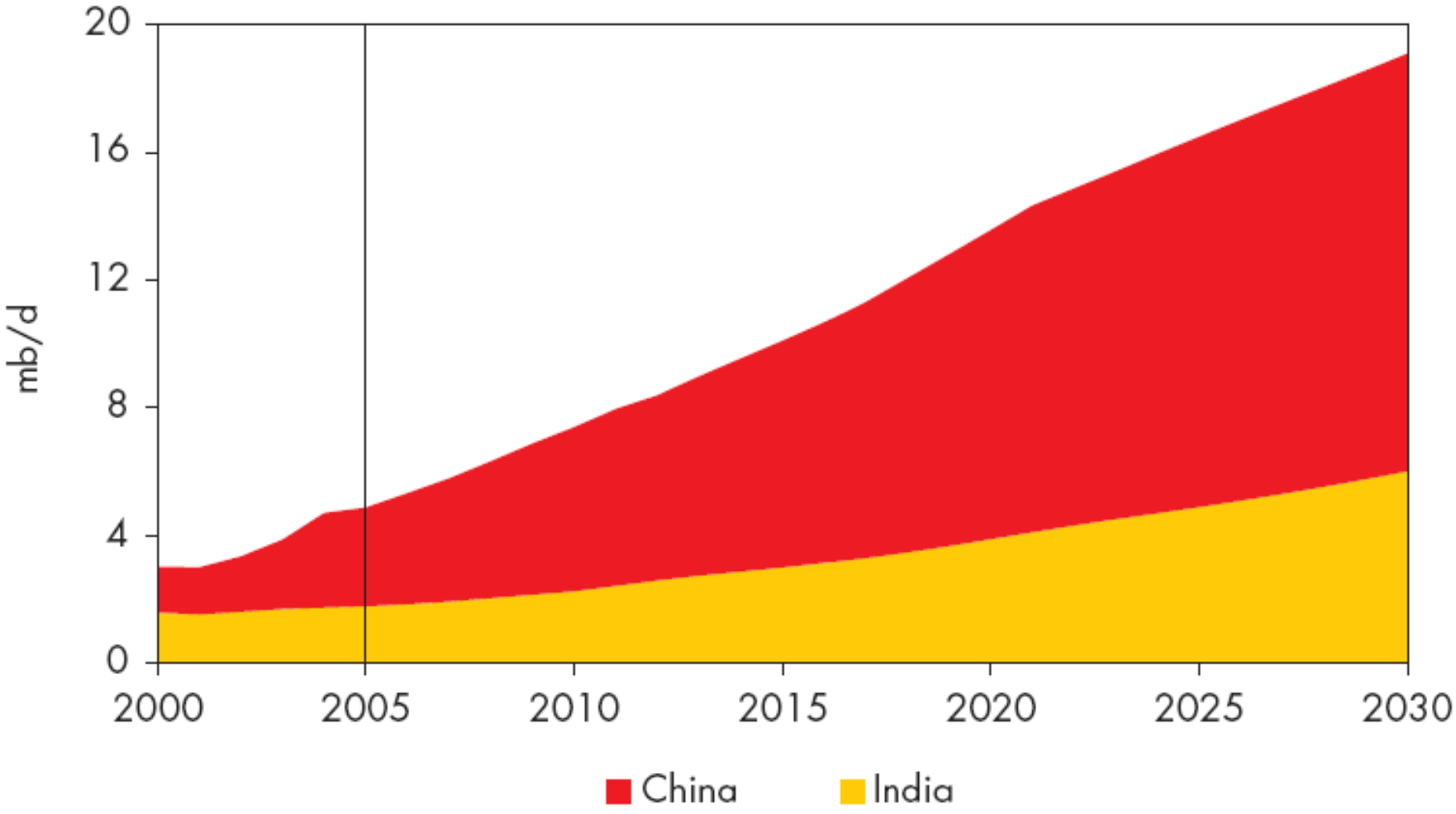
WEO 2007

Projected growth of oil use for road transport in Asia is particularly large



WEO 2007

These oil demands are projected to be met mainly by imports



WEO 2007

Coal use for electric power is projected to grow rapidly

Coal-fired capacity, GWe, 2005 & USEIA projection

	USA	*China*	*India*	*World*
2005	314	299	79	1214
2010	320	478	96	1451
2020	349	756	140	1849
2030	414	1034	173	2295

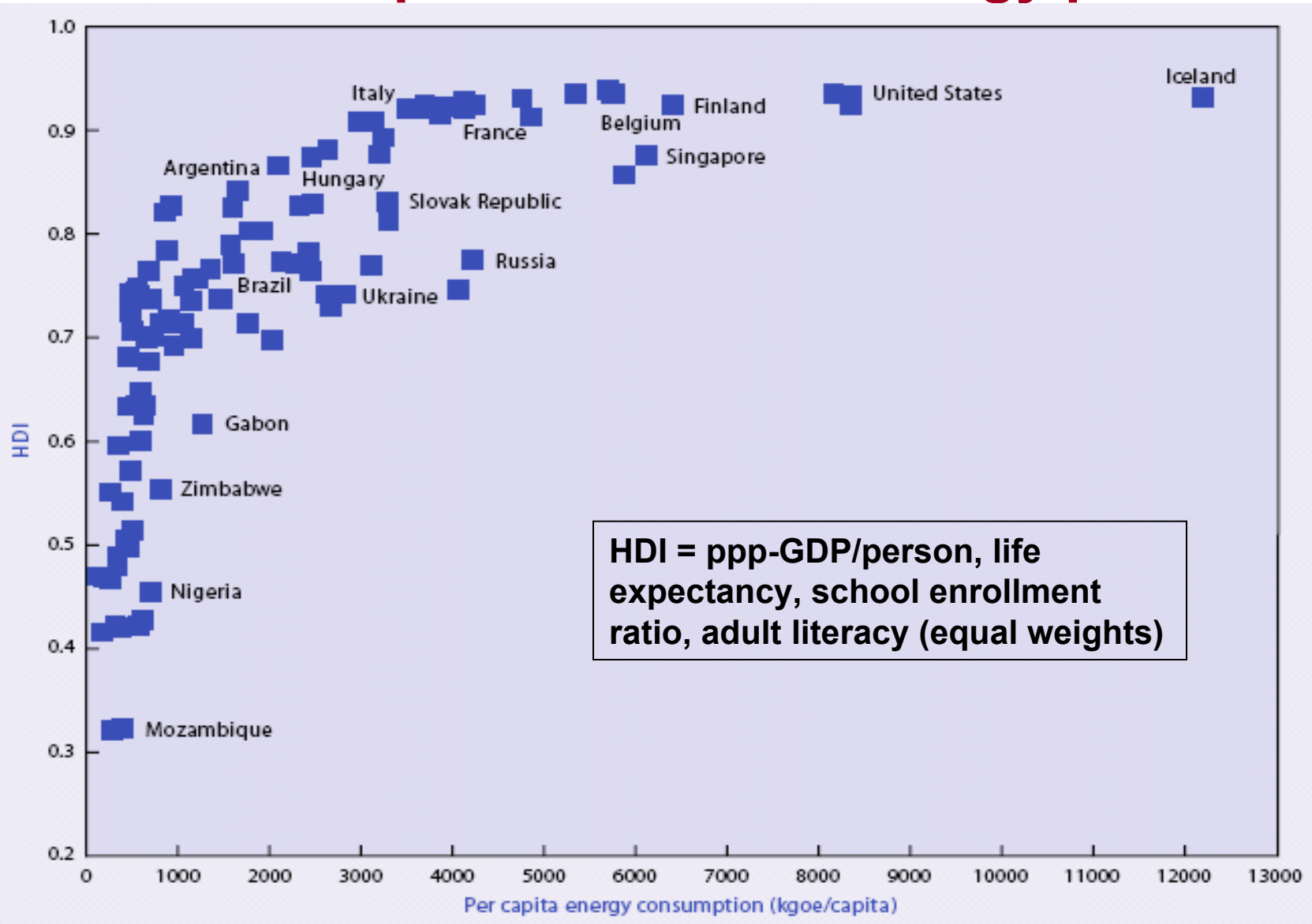
World coal-electric capacity goes up almost 1100 GWe by 2030, and over 800 GWe of the increase is in China and India.

Source: US EIA, International Energy Outlook 2008

The three biggest challenges for the future

- Supplying reliable, affordable, clean energy to meet the basic needs of the world's poorest two billion people, replacing dirty biomass fuels.
- Reducing urban & regional air pollution and the political & economic dangers of overdependence on oil despite growing global demand from the transportation system
- Providing the affordable energy needed to create & sustain prosperity everywhere without wrecking the global climate with carbon dioxide emitted by fossil-fuel burning

The challenge of energy for basic needs: Human development index vs. energy/person

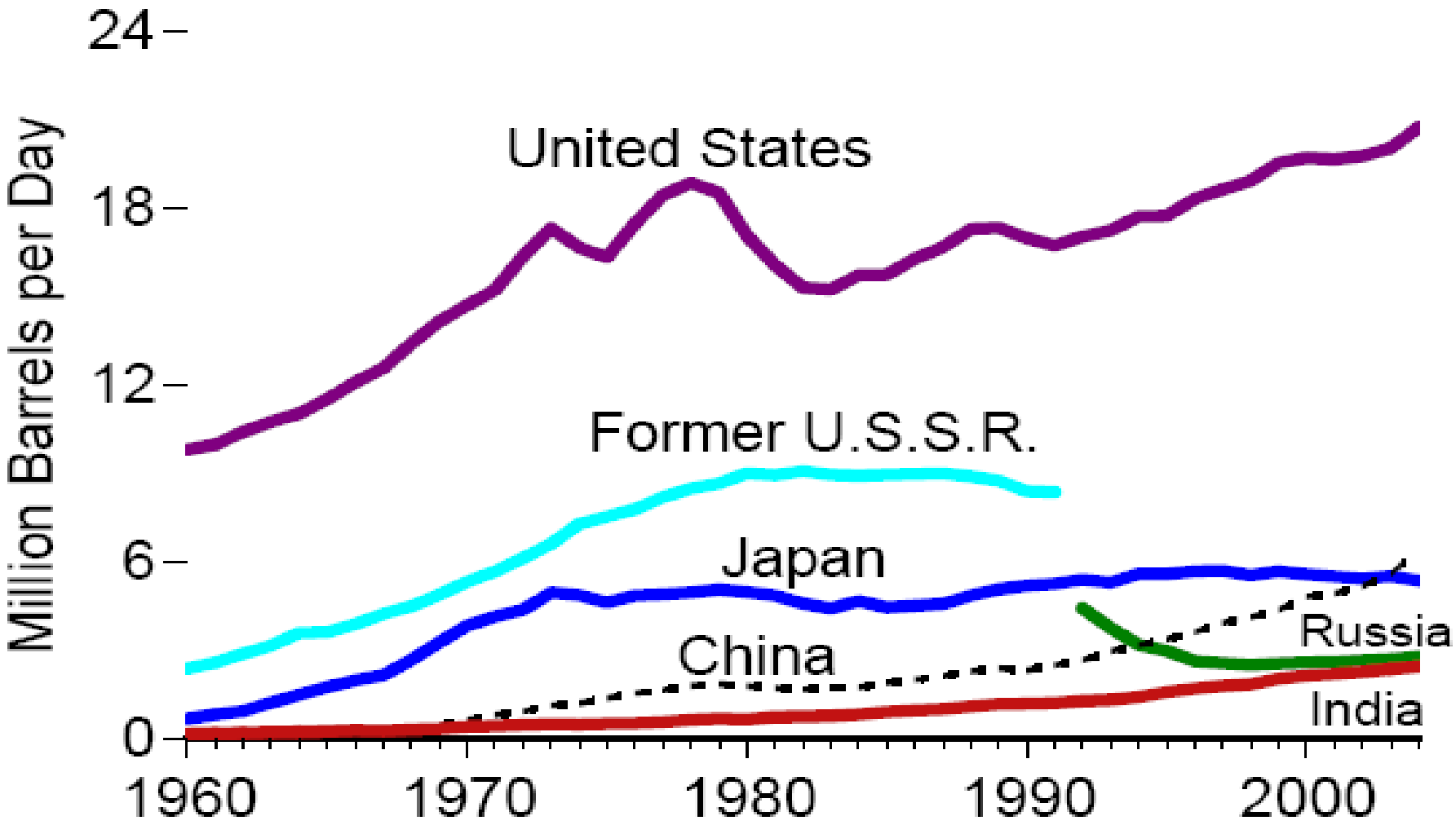


World Energy Assessment 2004

The oil challenge: supply & security

- USA in 2006 used 21 million barrels per day of oil, importing 66% of it.
- Forecasts show US oil use rising to 28 Mb/d by 2030, with <u>all</u> of the increase coming from imports.
- World used 82 Mb/d in 2006, 63% of it traded internationally.
- Consumption forecasted to rise from 82 Mb/d in 2006 to 120 Mb/d in 2030.
- China's imports by 2030 expected to pass 12 Mb/d.
- It remains true that most of the world's known & suspected oil resources are in the Middle East.

USA is biggest oil user, but Asia is growing



The Asia-Pacific region accounted for 30% of world oil consumption in 2005

The oil challenge: environment

- Most oil is used in transport vehicles, and these are the largest sources of NO_x and hydrocarbon air pollution.
- The number of cars in the world is soaring, producing increased congestion and even more pollution.
- Combustion of petroleum fuels accounts for about 40% of CO_2 emissions from energy – same as coal – and this is expected to continue.

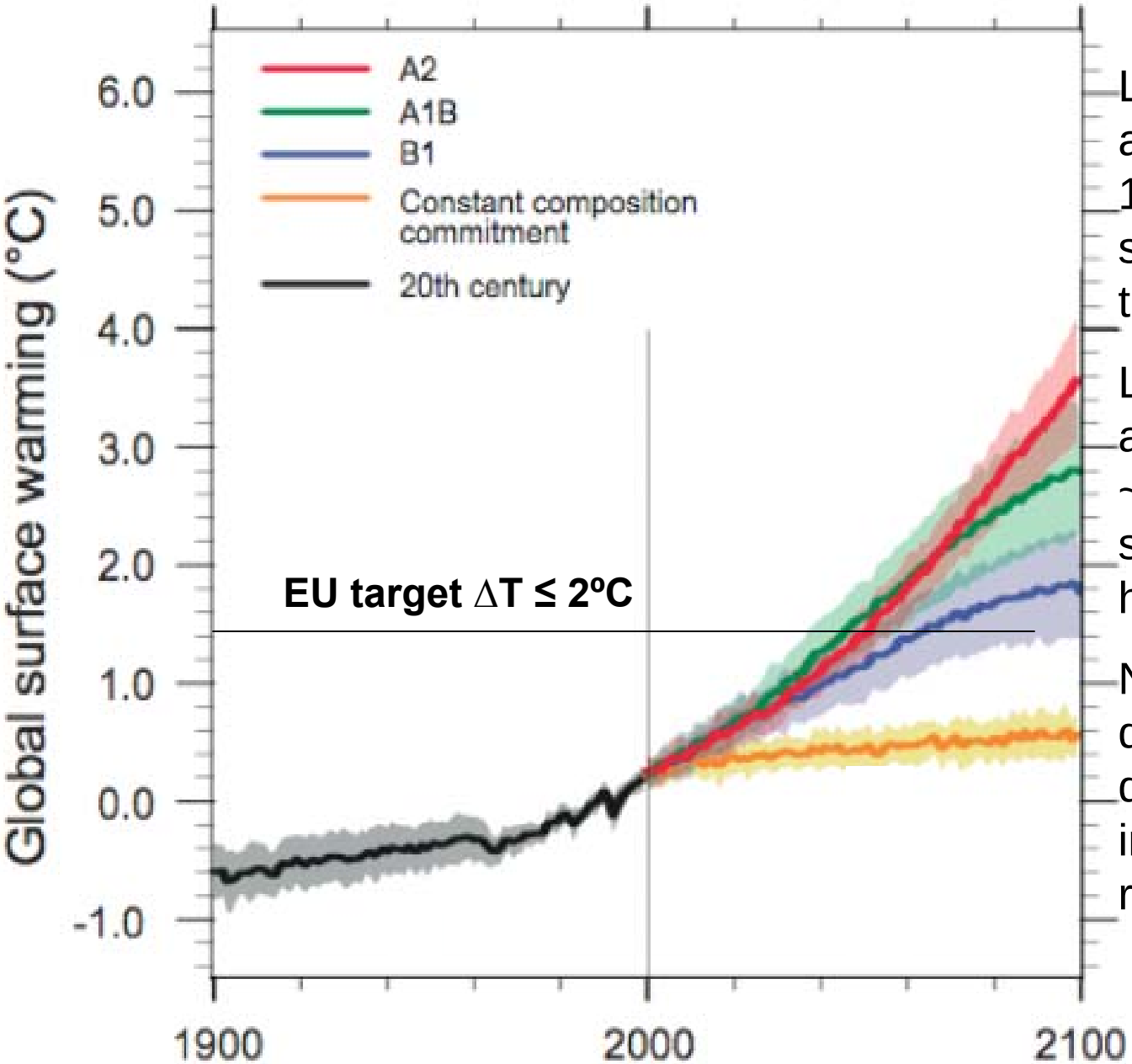
The hardest challenge of all is climate

- Climatic disruption & its impacts are growing more rapidly than predicted just a few years ago.
- Harm from these impacts is already significant, and much more is coming.
- It's too late to avoid "dangerous anthropogenic interference" in Earth's climate. Question is: Can we avoid catastrophic interference?
- Best chance for this requires stabilizing human influences on the atmosphere below 450 ppm CO_2-equivalent.
- Not exceeding 450 ppm CO_2-e requires emissions to be falling in industrial countries by 2015, elsewhere by 2025.
- Doing this will require much better technologies and much stronger policies all over the world.

Climate-change impacts already happening

- monsoon changes → agriculture impacts
- extreme precipitation → more floods
- ΔT + reduced precipitation in some regions & more loss to storm runoff in others → increased drought & soil drying
- ΔT & soil drying → increased wildfires
- ΔT → more heat stress and worse air pollution
- ΔT → pest population explosions → big timber losses (Alaska, CO, CA...)
- tropical ocean ΔT is affecting corals (bleaching)
- increased integrated power of tropical storms is <u>probably</u> linked to ocean ΔT

Bigger disruption is coming: IPCC 2007 scenarios



Last time T was 2ºC above 1900 level was 130,000 yr BP, with sea level 4-6 m higher than today.

Last time T was 3ºC above 1900 level was ~30 million yr BP, with sea level 20-30 m higher than today.

Note: Shaded bands denote 1 standard deviation from mean in ensembles of model runs

IPCC 2007

Tipping points aren't necessarily far off

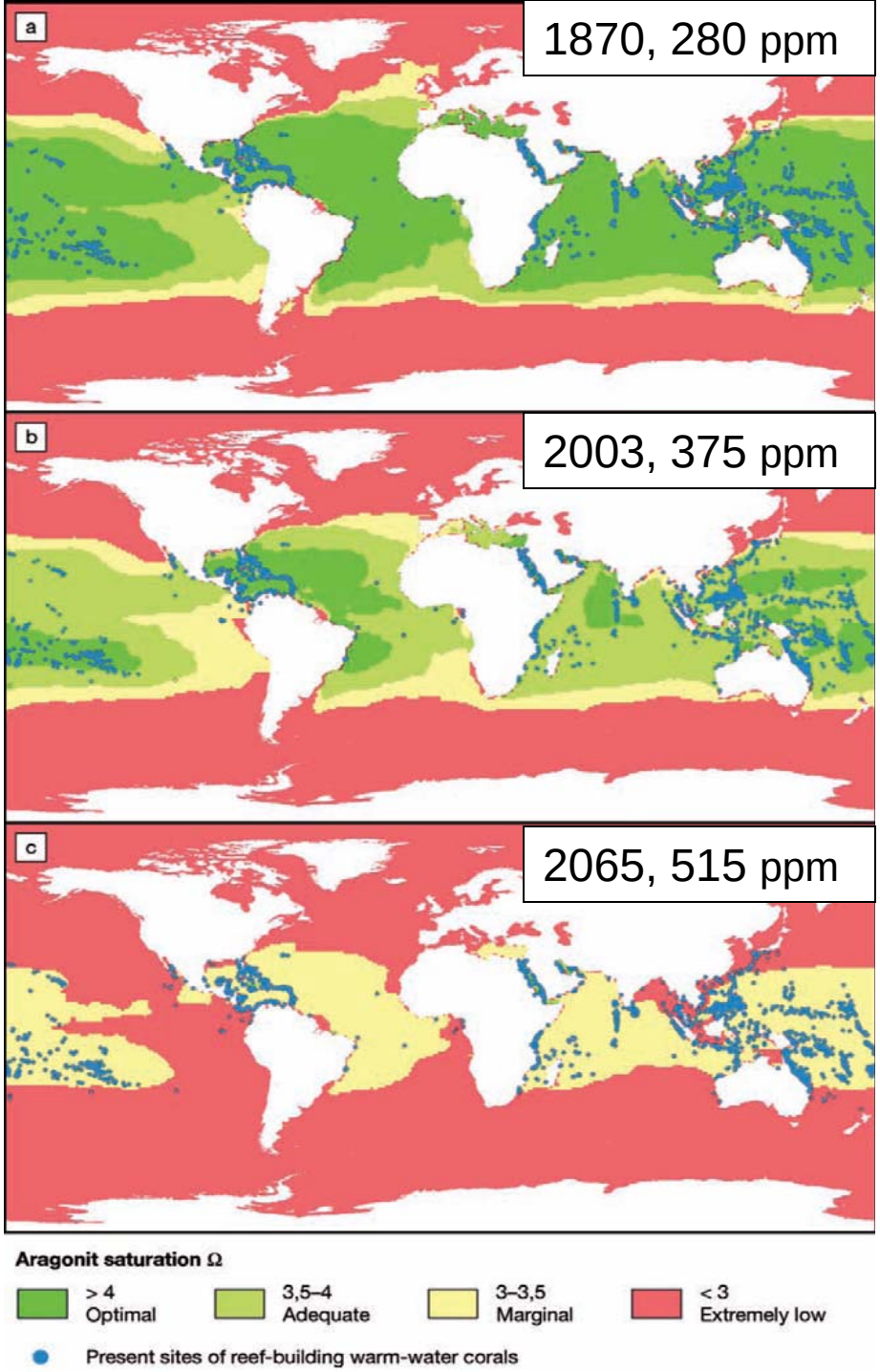
- Arctic sea ice is shrinking much faster than expected; if it disappears and doesn't re-form, climate of N hemisphere would change drastically.
- Tundra & permafrost are warming & thawing, with potential for CO_2 and methane outpouring that would accelerate climate disruption overall.
- Rapid ice-sheet disintegration (1-2 m per century sea-level rise) possible for $\Delta T_{avg} \geq 1.5^{o}C$.
- Ocean acidification by dissolution of part of excess atmospheric CO_2 further stresses corals & other ocean creatures that make $CaCO_3$ shells or skeletons, putting ocean food chains at risk.

Pickling the oceans: a tipping point?

About 1/3 of CO_2 added to atmosphere is quickly taken up by the surface layer of the oceans (top 80 meters).

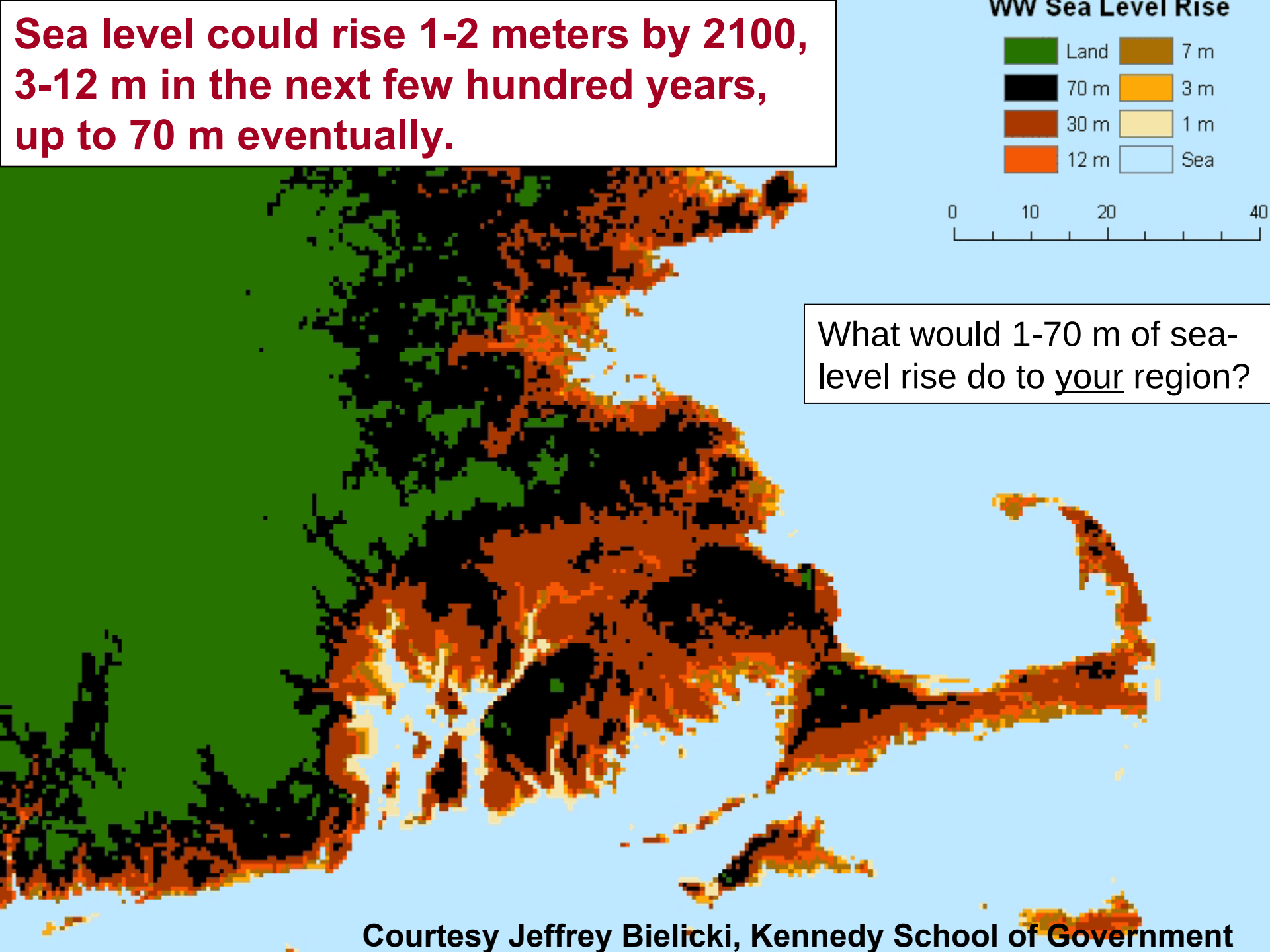
This lowers pH as dissolution of CO_2 forms weak carbonic acid ($H_2O + CO_2 \rightarrow H_2CO_3$).

Increased acidity lowers the availability of $CaCO_3$ to organisms that use it for forming their shells & skeletons, including corals.



Steffen et al., 2004

Sea level could rise 1-2 meters by 2100, 3-12 m in the next few hundred years, up to 70 m eventually.



What would 1-70 m of sea-level rise do to <u>your</u> region?

Courtesy Jeffrey Bielicki, Kennedy School of Government

What to do?

There are only three options:

- Mitigation, meaning measures to reduce the pace & magnitude of the changes in global climate being caused by human activities.

- Adaptation, meaning measures to reduce the adverse impacts on human well-being resulting from the changes in climate that do occur.

- Suffering the adverse impacts that are not avoided by either mitigation or adaptation.

Mitigation possibilities

CERTAINLY

- Reduce emissions of greenhouse gases & soot from the energy sector
- Reduce deforestation; increase reforestation & afforestation
- Modify agricultural practices to reduce emissions of greenhouse gases & build up soil carbon

CONCEIVABLY

- “Geo-engineering” to create cooling effects offsetting greenhouse heating
- “Scrub” greenhouse gases from the atmosphere technologically

Adaptation possibilities include…

- Changing cropping patterns
- Developing heat-, drought-, and salt-resistant crop varieties
- Strengthening public-health & environmental-engineering defenses against tropical diseases
- Building new water projects for flood control & drought management
- Building dikes and storm-surge barriers against sea-level rise
- Avoiding further development on flood plains & near sea level

Some are “win-win”: They’d make sense in any case.

Mitigation & adaptation are both essential

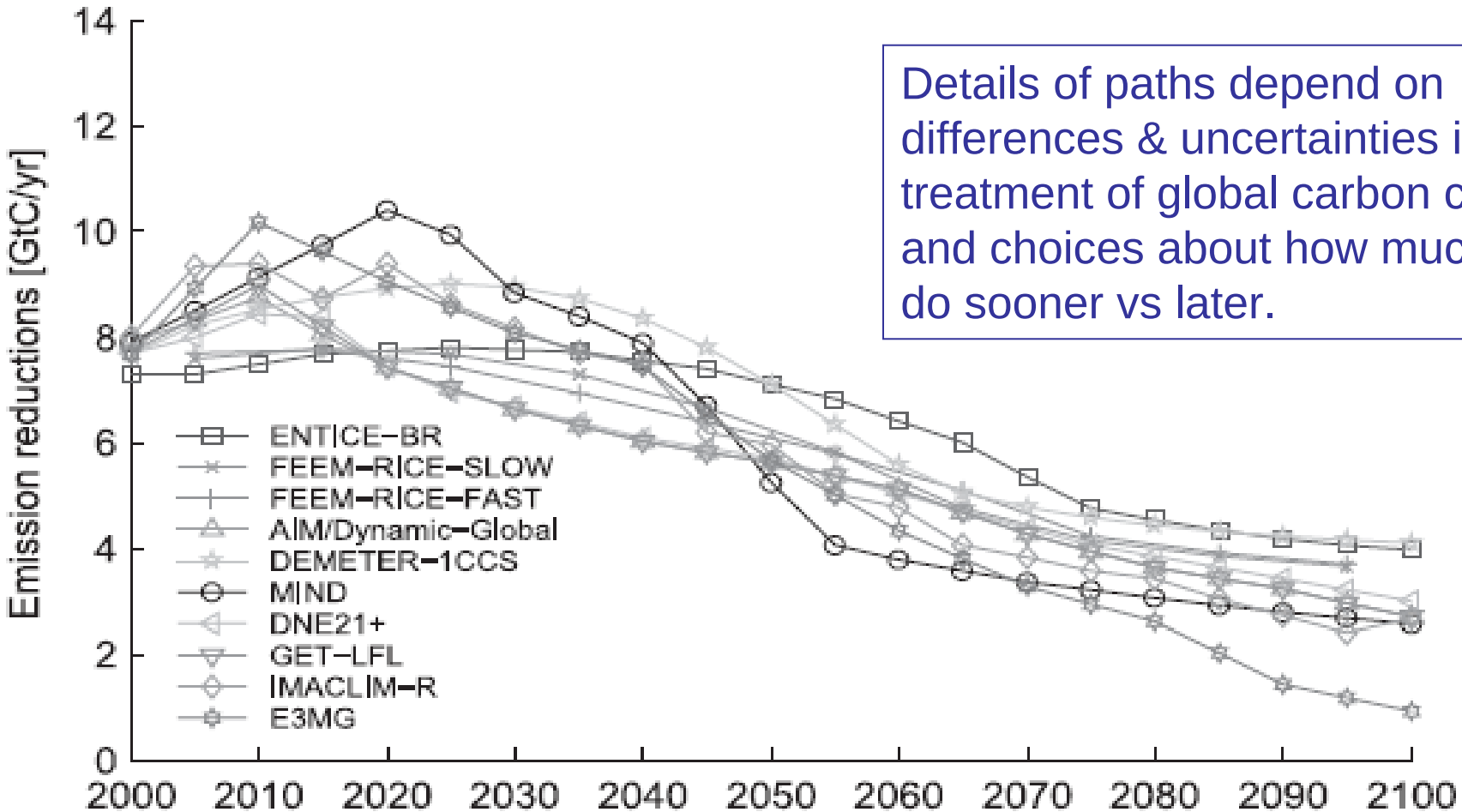
- No feasible amount of mitigation can stop climate change immediately.
- Adaptation efforts are already taking place and must be expanded.
- But adaptation becomes costlier & less effective as the magnitude of climate changes grows.
- The more mitigation can be achieved at affordable cost, the smaller the burdens placed on adaptation and the smaller the suffering.

How much mitigation, how soon?

- Limiting ΔT_{avg} to ≤2ºC is now widely considered the most prudent target that still might be attainable.
  - EU officially embraced this target in 2002
- For 50% chance of ΔT_{avg}≤2ºC, <u>sum</u> of human influences (CO_2, other GHG, and atmospheric particulate matter) must be stabilized at a level equivalent to 450 ppm of CO_2 ("450 ppm CO_2-e").
  - In 2005 we were at 380 ppm CO_2 and 430 ppm CO_2-e from all GHG combined.
  - Effects of particles (warming from some, cooling from others) added up to a net negative 50 ppm CO_2-e, so total human influence in 2005 was 430 – 50 = 380 ppm CO_2-e.

Global CO_2 emissions paths from 2000 that would stabilize concentration at 450 ppm

(50% chance of $\Delta T < 2°C$ if non-CO_2 effects cancel)



Details of paths depend on differences & uncertainties in treatment of global carbon cycle and choices about how much to do sooner vs later.

Grubb et al., The Energy Journal, 2006

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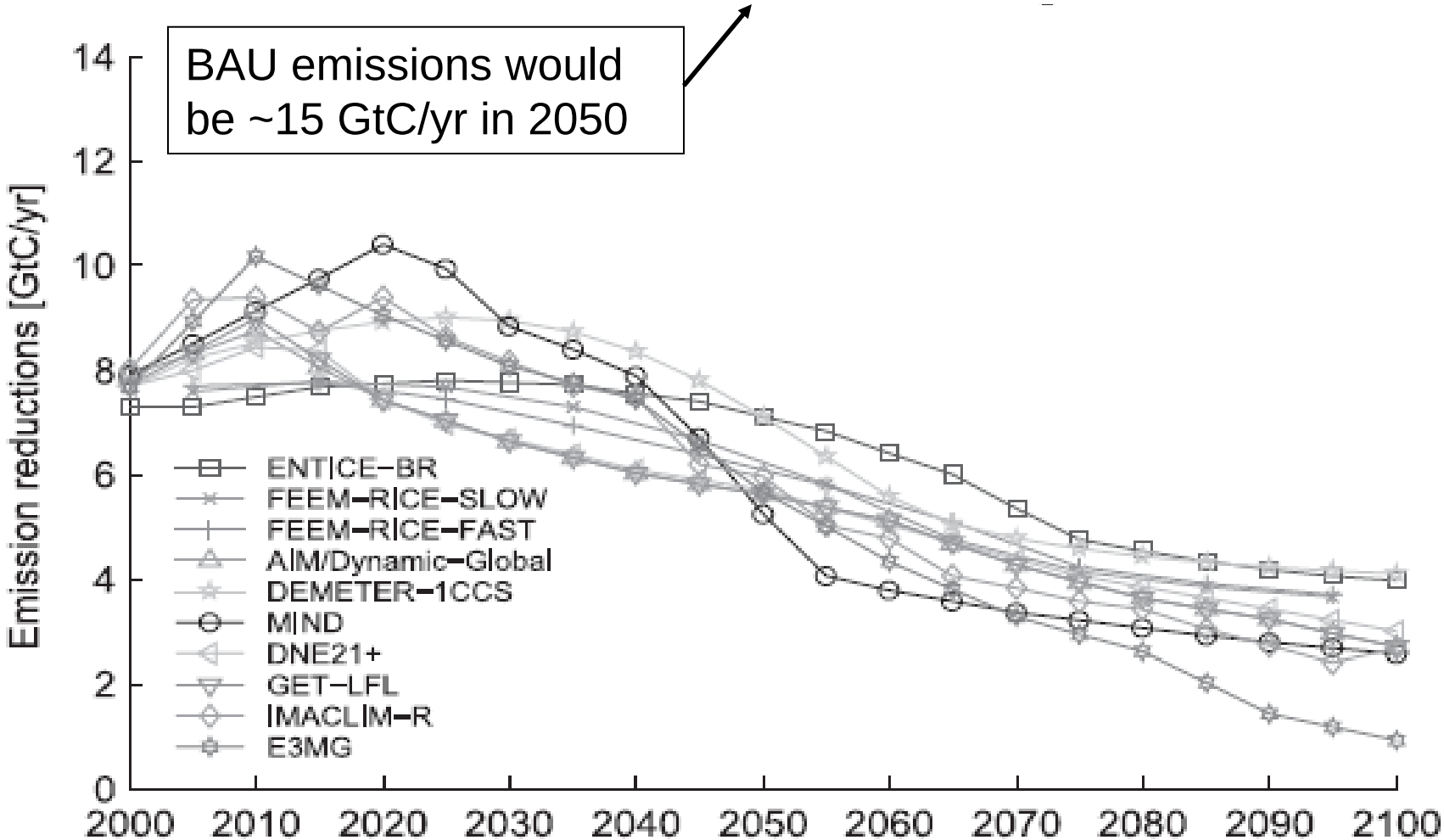

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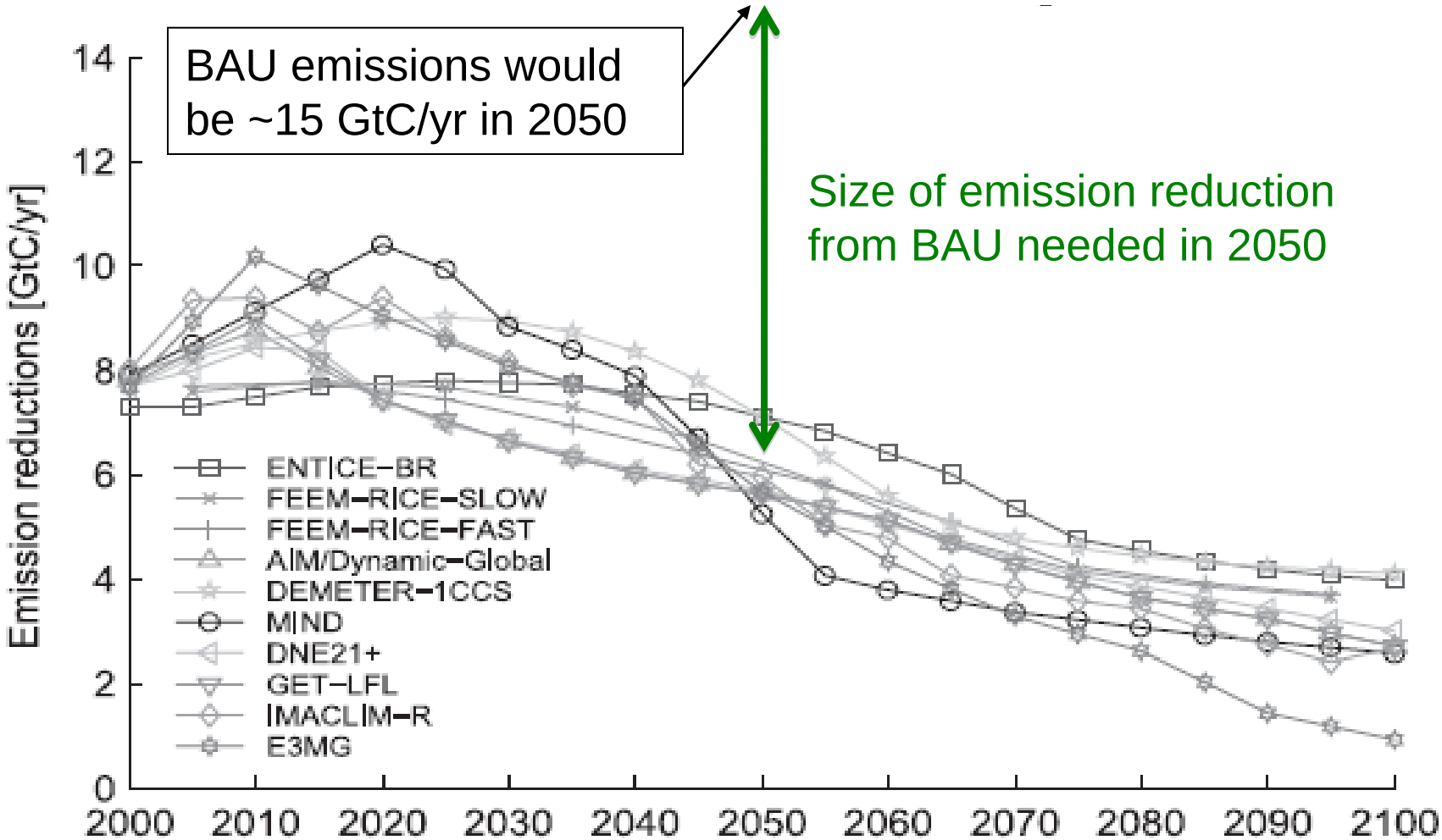


Grubb et al., The Energy Journal, 2006

Possible focuses for policy: the option space

- Remove barriers to harvesting the low-hanging fruit (and the fruit lying on the ground)

  options include: consumer education; labeling; remedies for perverse incentives /disincentives

- Provide incentives for reaching higher into the tree

  options include: elimination of subsidies for high-emitting energy sources; provision of subsidies for low-emitting ones; charges on emissions; regulation

- Support and promote energy RD&D to lower the highest-hanging fruit

  options include: gov't funding; tax credits for private RD&D; price guarantees; international cooperation

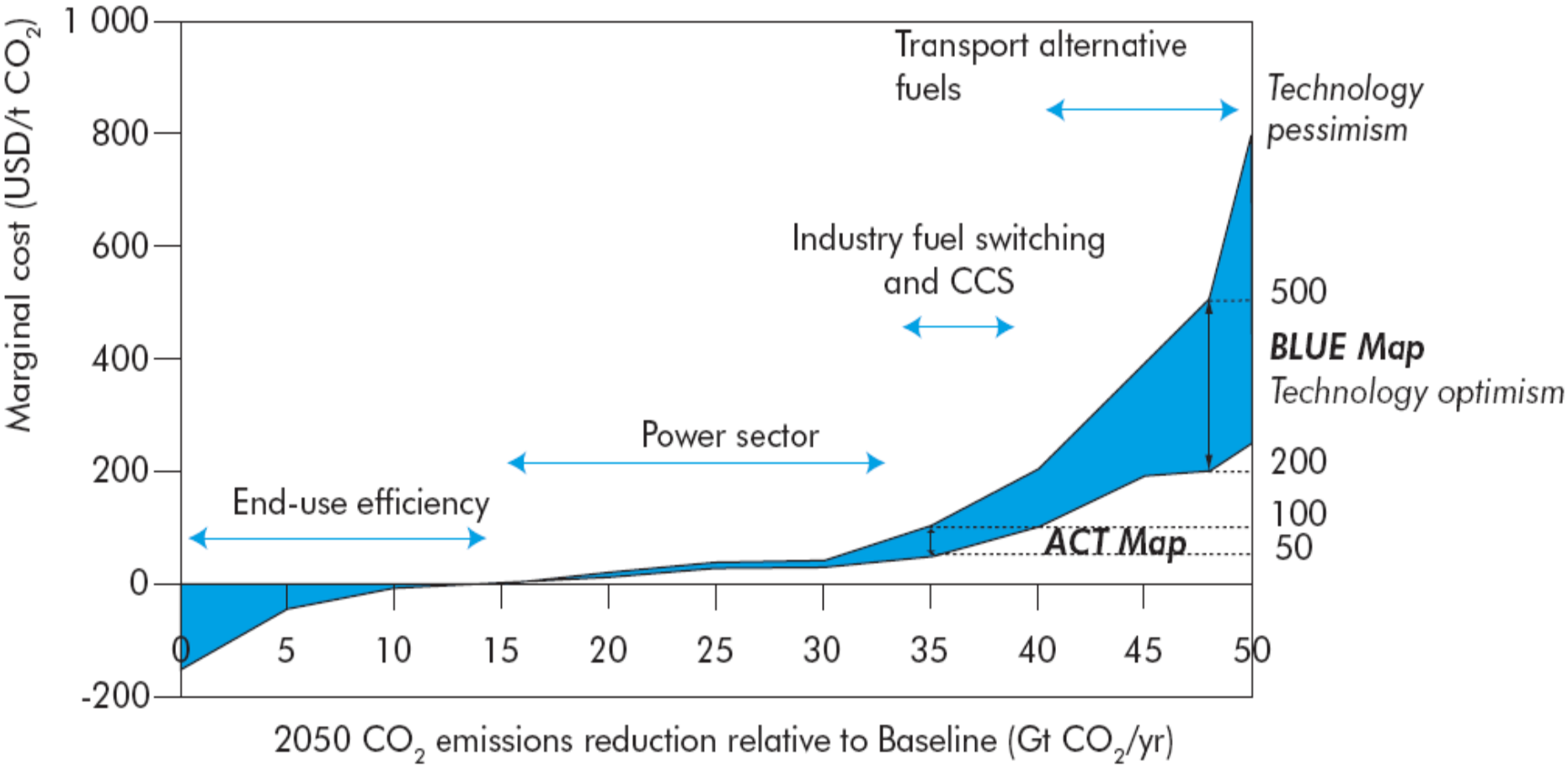
The role of technology: IEA 2008 Scenarios

- "ACT" scenario family (Accelerated Technology)
  - Back to 2005 CO_2 emissions by 2050 (peak 2030)
  - Based on available & almost available technology
  - "Optimistic" peak cost ≈ \$50/tCO_2, average less
  - Incremental cost to 2050 = \$17T (~\$400B/yr = 0.4% of average GWP)
- "BLUE" scenario family
  - 50% of 2005 CO_2 emissions in 2050 (peak 2020)
  - Requires accelerated technology innovation
  - "Optimistic" peak cost ≈ \$100/tCO2, average less
  - Incremental cost to 2050 = \$45T (~\$1.1T/yr) = 1% of average GWP

"Pessimistic" cost estimates are 2x higher.

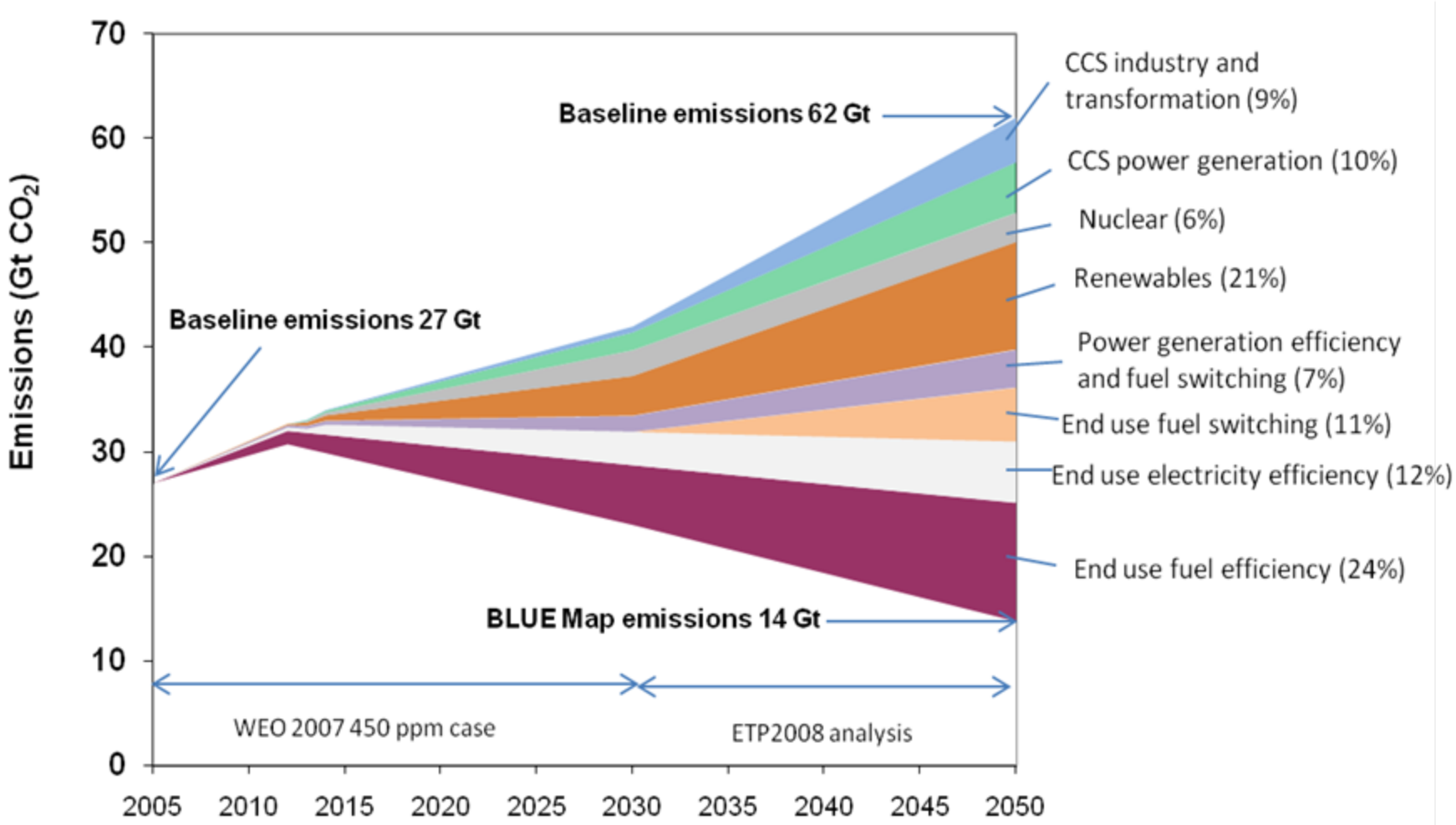
Supply curves for emissions reductions in 2050

(US 2005$/t$CO_2$ below reference scenario (marginal cost)



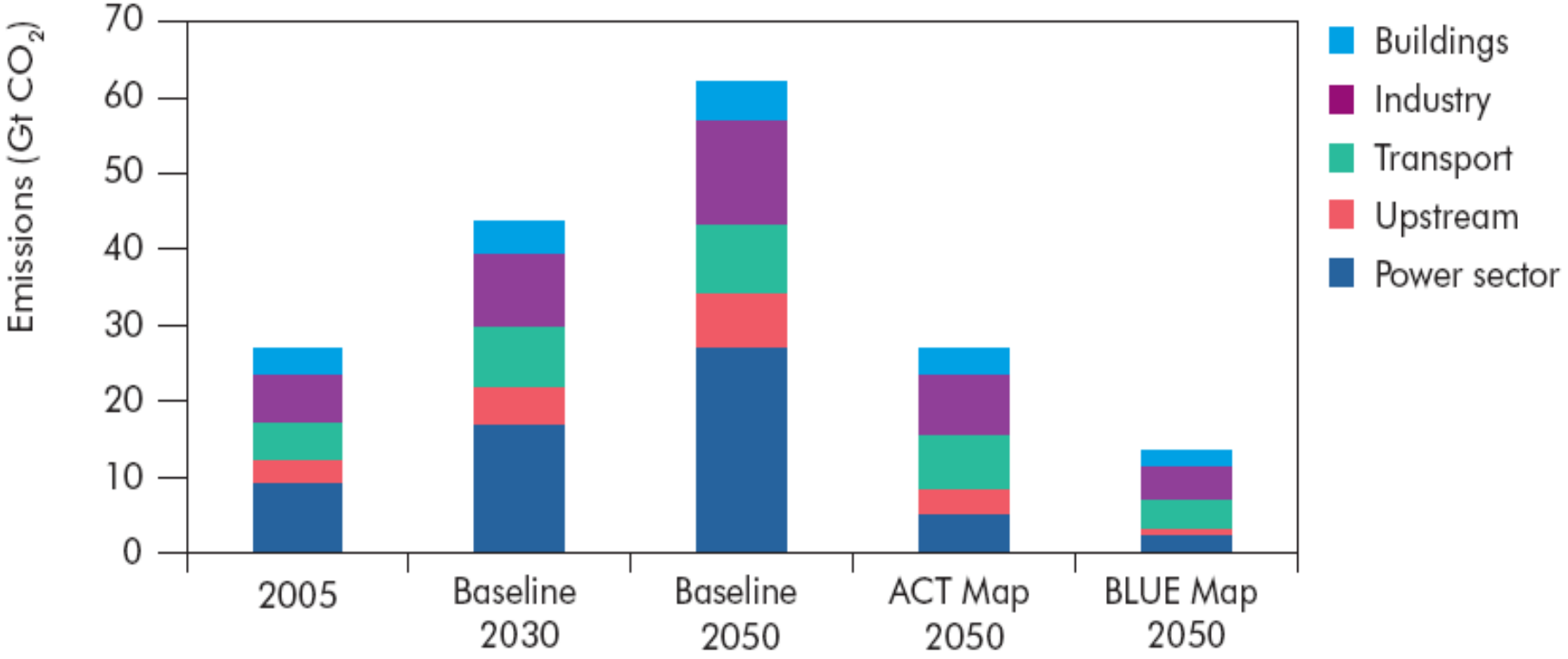
IEA 2008

IEA's 2008 "BLUE" CO_2-emissions scenario



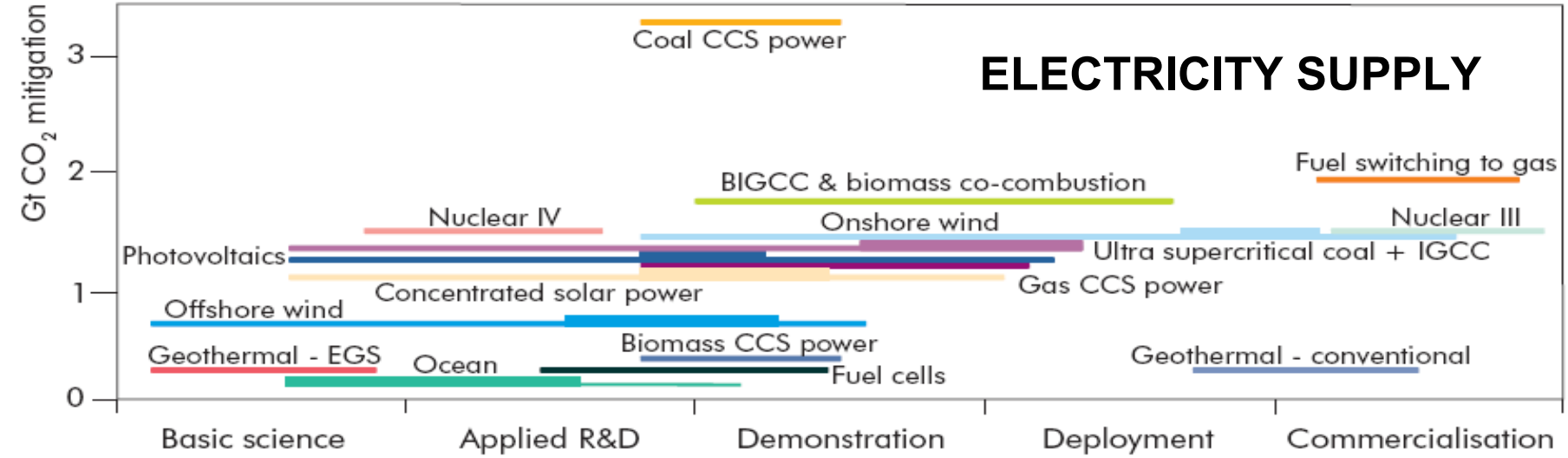
Improved efficiency and decarbonising the power sector could bring emissions back to current levels by 2050. To achieve a 50 % cut we would also have to revolutionise the transport sector.

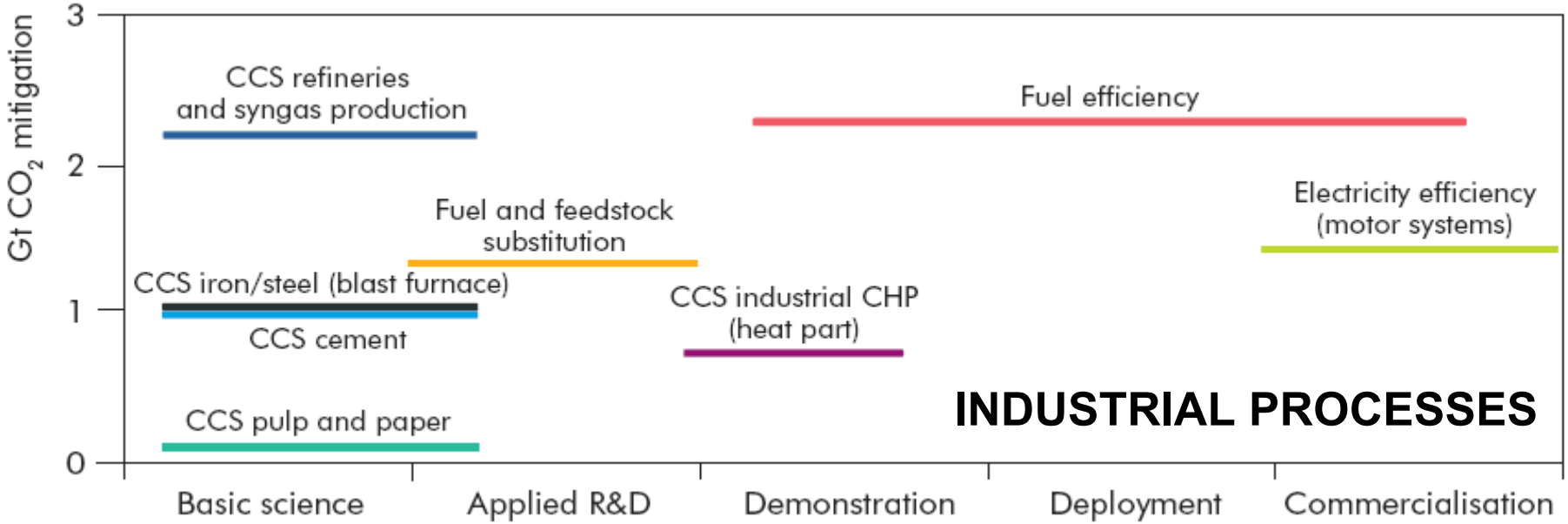
Distribution of emissions in IEA scenarios



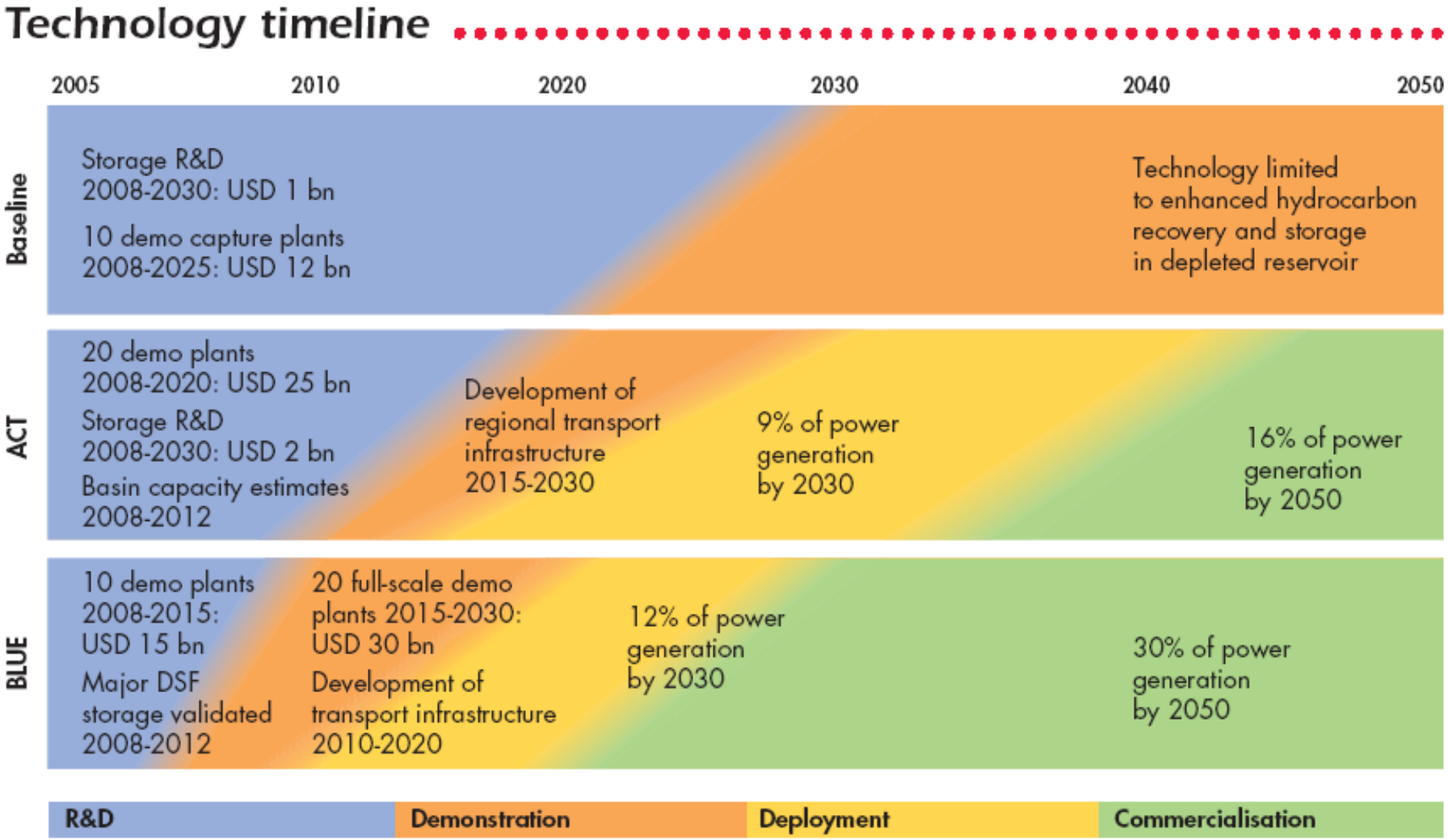
IEA 2008

State of development and CO_2 mitigation potential in 2030 for high-priority technologies (IEA 2008)





Global CCS Technology Roadmap



In this roadmap, commercialisation assumes an incentive of USD 50/t CO_2 saved.

IEA 2008

Key conclusions

- The fast path to deployment of advanced coal technologies is only possible with the help of international cooperation.
- Cooperation between the USA and China is the most important part of this.
- The current state of this cooperation is that it is quite extensive “on paper” (MOUs), but not enough is happening “on the ground”.
- The Harvard-MOST-CAS collaboration can make a big contribution by helping define the specific activities that now should be added.

Thank you!