Fall Term – 2013
Woodrow Wilson School 585b

Living in a Greenhouse: Technology and Policy

Robert Socolow
Phil Hannam, AI

Week Eight: November 8, 2013
1. Wedges
2. Achieving energy efficiency
3. Land use, food, and biocarbon

Your term paper

- *Please, no encyclopedia articles.* Identify a topic that is narrowly defined, then ask and answer interesting questions.
- It is fine that in your first "interim statement" you identified a broad area where you intend to find your topic. But do enough work before submitting your second interim statement (*before midnight next Tuesday*) so that Phil and I can understand where you actually wish to head.
- If you are having trouble choosing a specific topic, tell Phil and me how to help you. E.g.: "I'd like to write about one specific country, but it could be A or B. I like A because…; I like B because…"

What makes a good paper? [from L1]

Each short paper should be sharply focused on a single issue. The term paper can be more ambitious.

All papers should be interesting, **focused**, imaginative, partially quantitative, and coherent. They should be well written, well argued, and well presented.

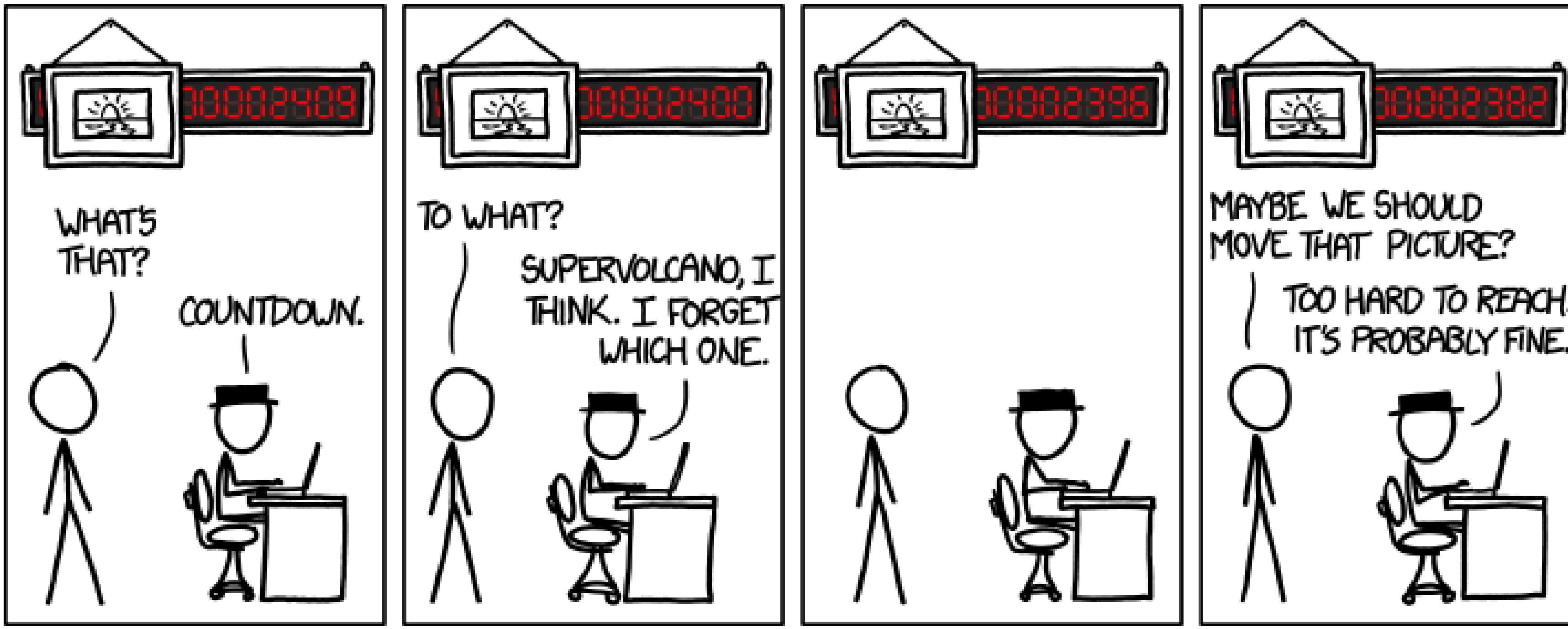
An unusual requirement is that each paper should display some quantitative reasoning. For example, this can be a sample calculation that verifies a statement that you have read. You should show an interest in numbers.

It is fine to build on some comparative advantage; for example, you could choose a topic related to something you have done before or involving a country or town that you know.

You are encouraged to discuss all papers with Phil and me electronically, but only well ahead of the deadlines. Experience suggests that we will lead you to people in the Princeton community who may be helpful.

No matter what your topic, you will encounter sales pitches, masquerading as impartial analysis. Learning to deal with biased information is one of the aims of this course.

Significant Figures



Source: Peter Gleick, *Significant Figures,* Feb 8 2013: "Thanks to xkcd.org and Randall Munroe, licensed under a Creative Commons Attribution – NonCommercial 2.5 License."

“Wedges”

I am particularly well known for “Stabilization Wedges: Solving the Climate Problem for the Next 50 years with Current Technologies.” *Science*, Vol. 305, pp. 968-972, August 13, 2004.

I wrote this paper with Prof. Steve Pacala, (Ecology and Evolutionary Biology, Princeton).

The paper helped people conceptualize and understand quantitatively what dealing with climate change looks like. In the last few years, the excitement that the problem is soluble has been dampened by the realization that solutions are disruptive.

Why was "wedges" welcomed?

The stabilization triangle:

- Did not concede doubling is inevitable.
- Shortened the time frame to within business horizons.

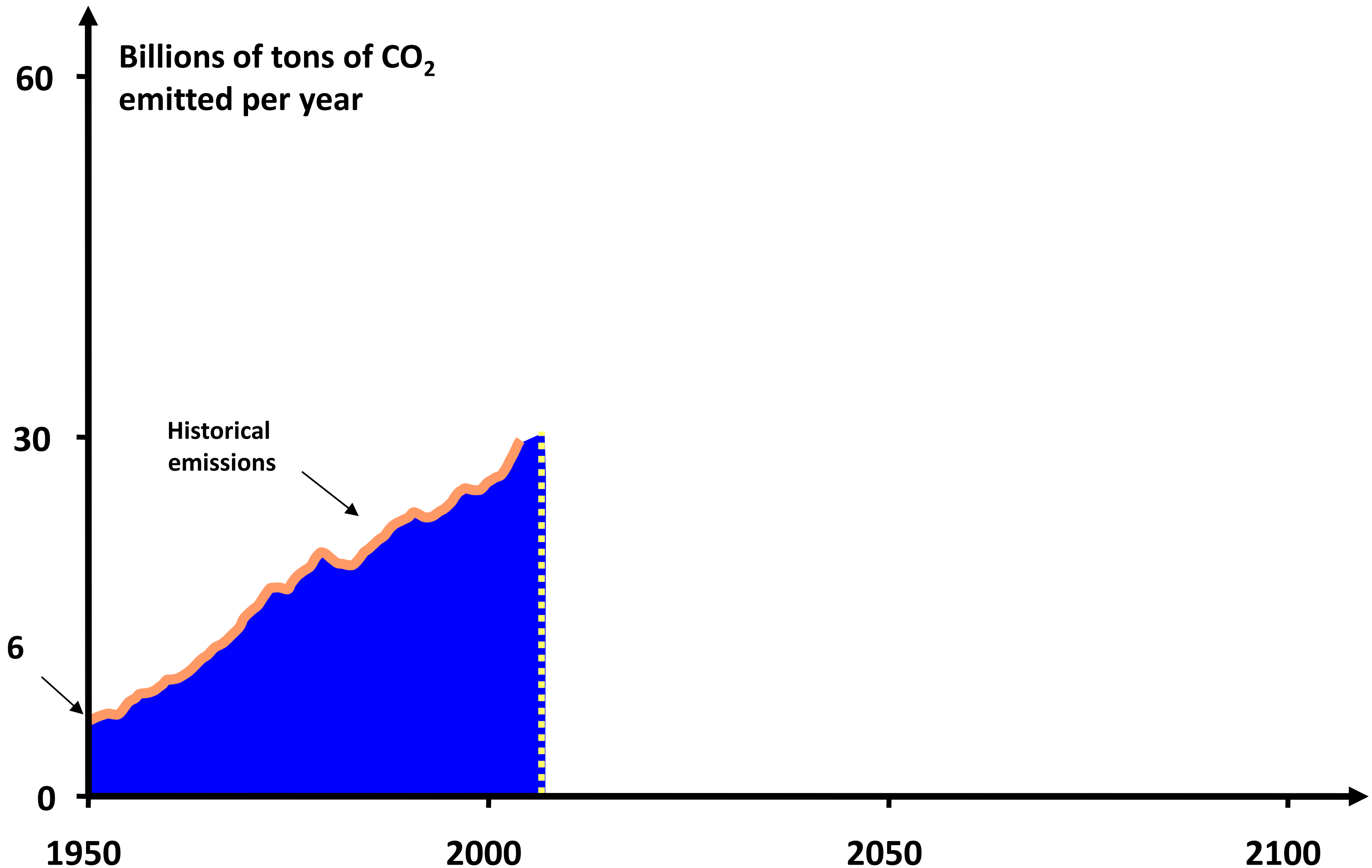
The wedge:

- Decomposed a heroic challenge (the stabilization triangle) into a limited set of monumental tasks.
- Established a unit of action that permits quantitative discussion of cost, pace, risk, and trade-offs.

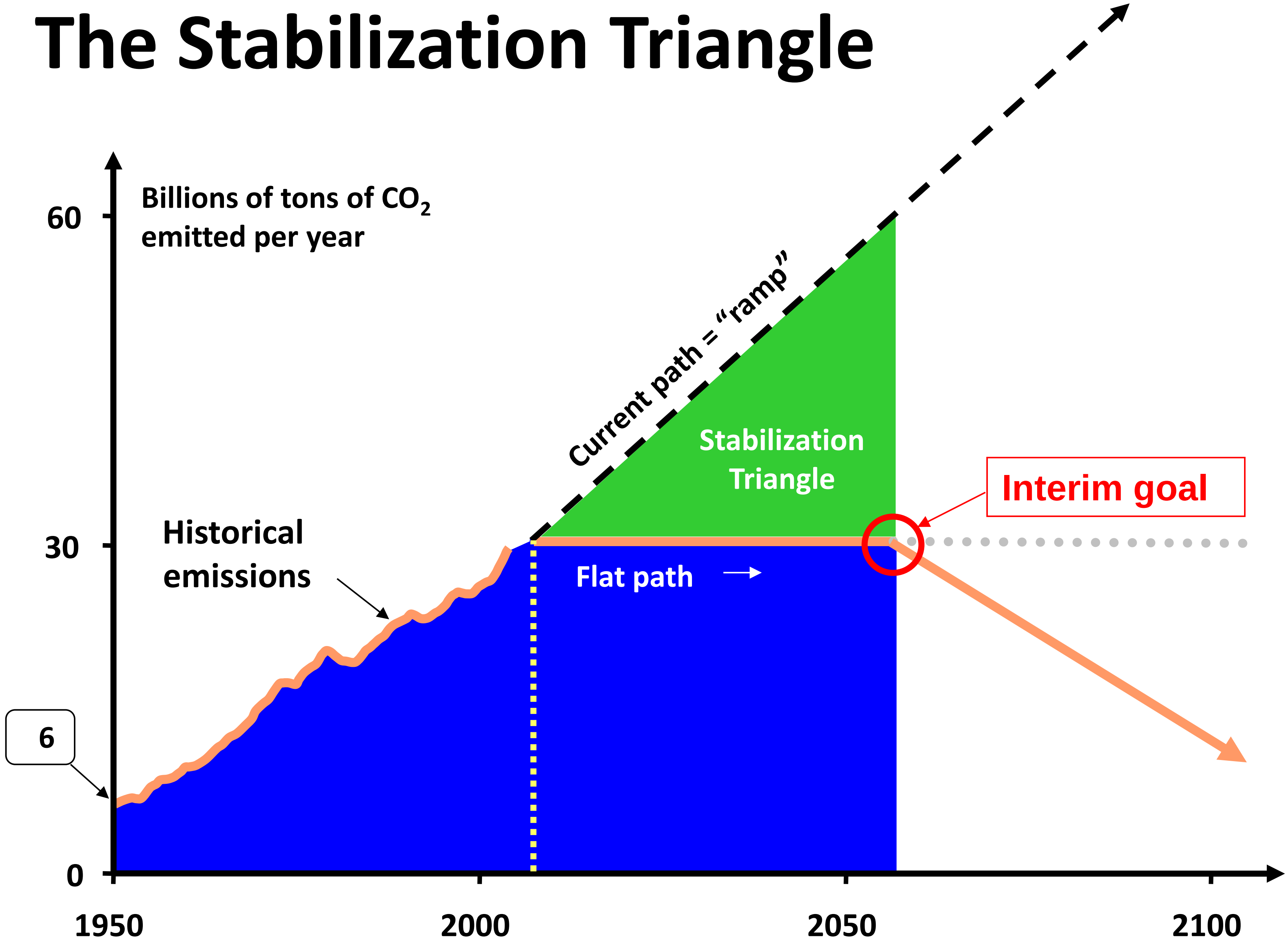
Einstein’s advice

“Make everything as simple as possible, but no simpler.”

Historical Emissions

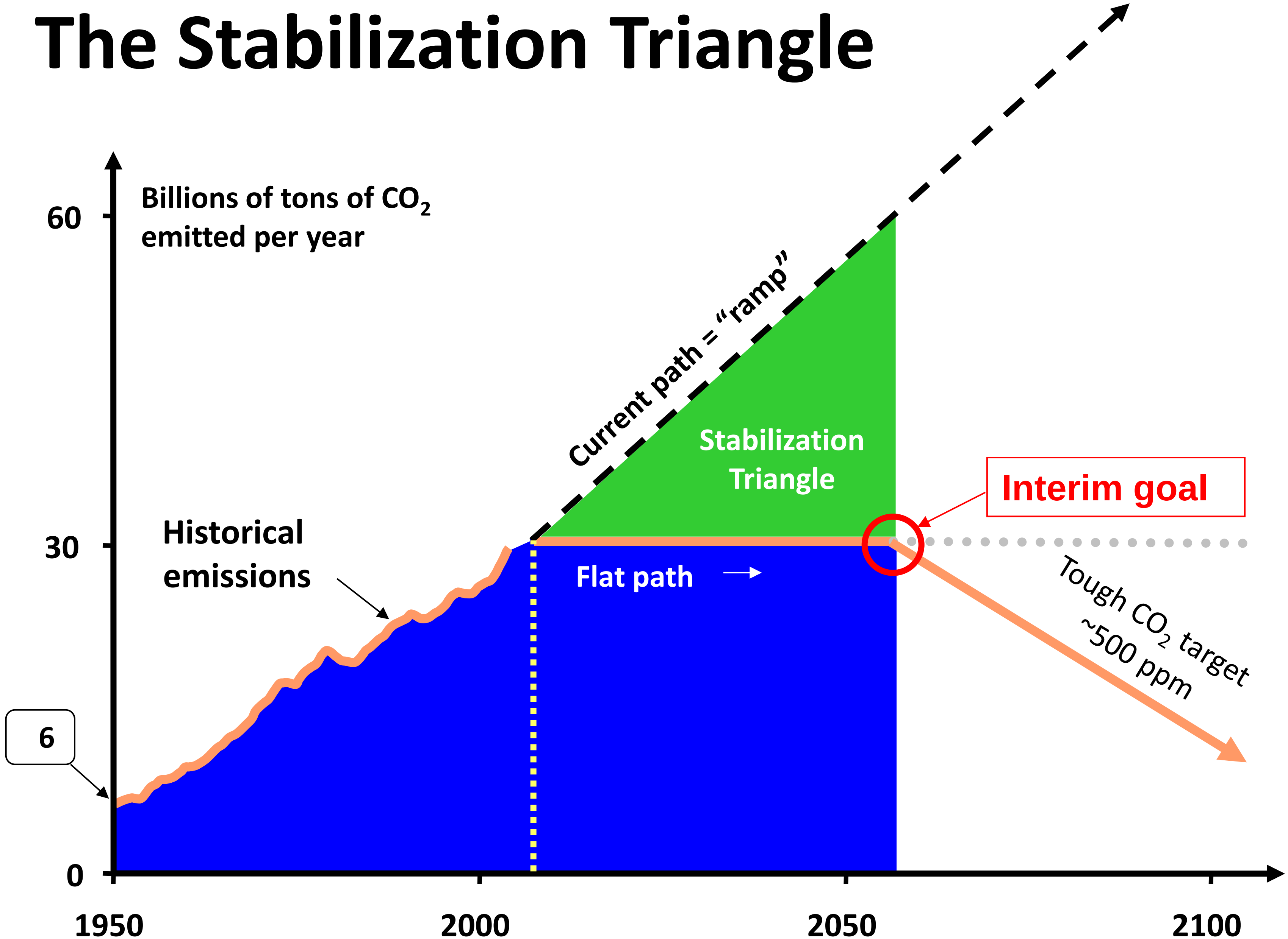


The Stabilization Triangle



Today and for the interim goal, global per-capita emissions are ≈ 4 to 5 tCO_2/yr.

The Stabilization Triangle



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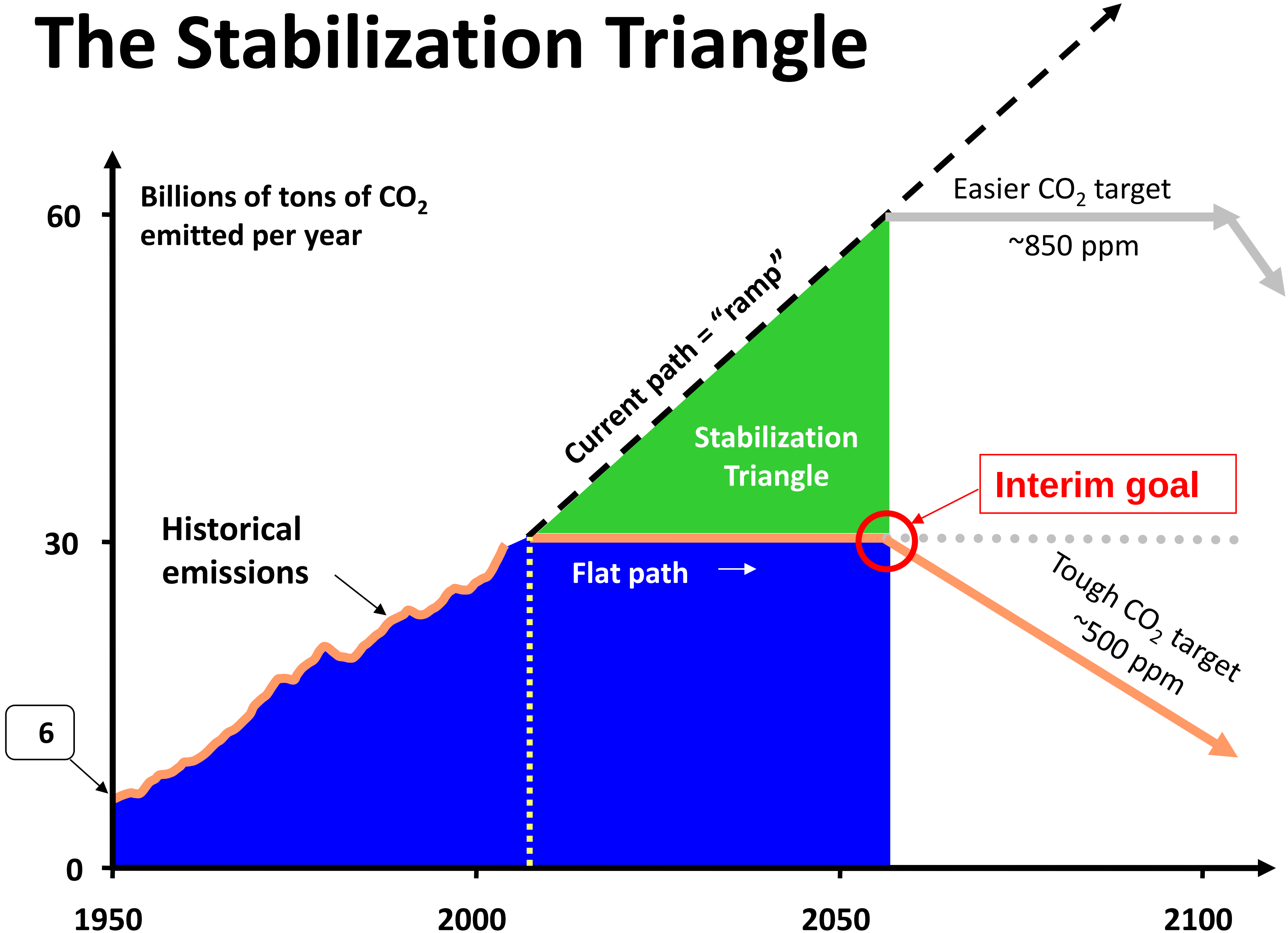
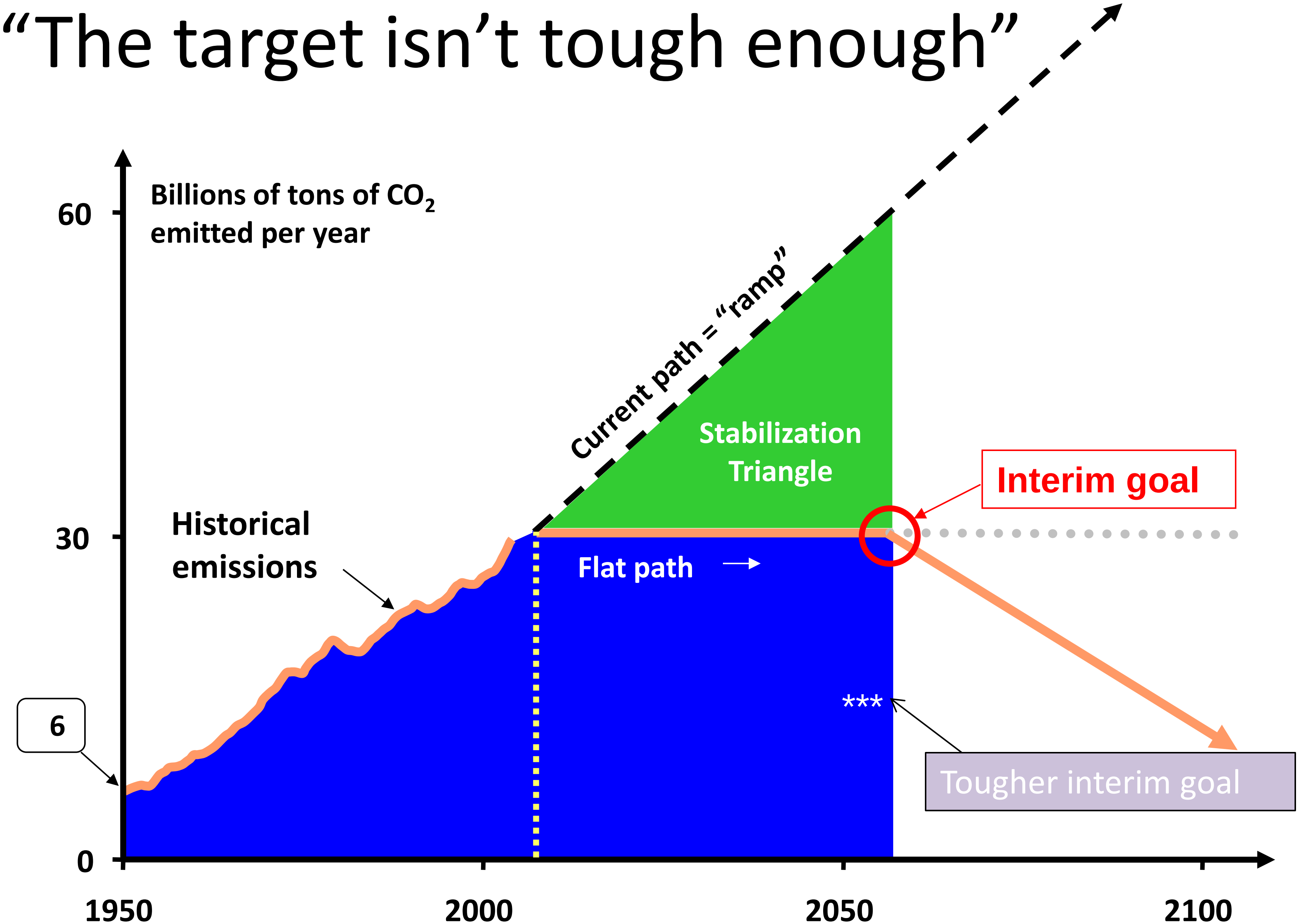
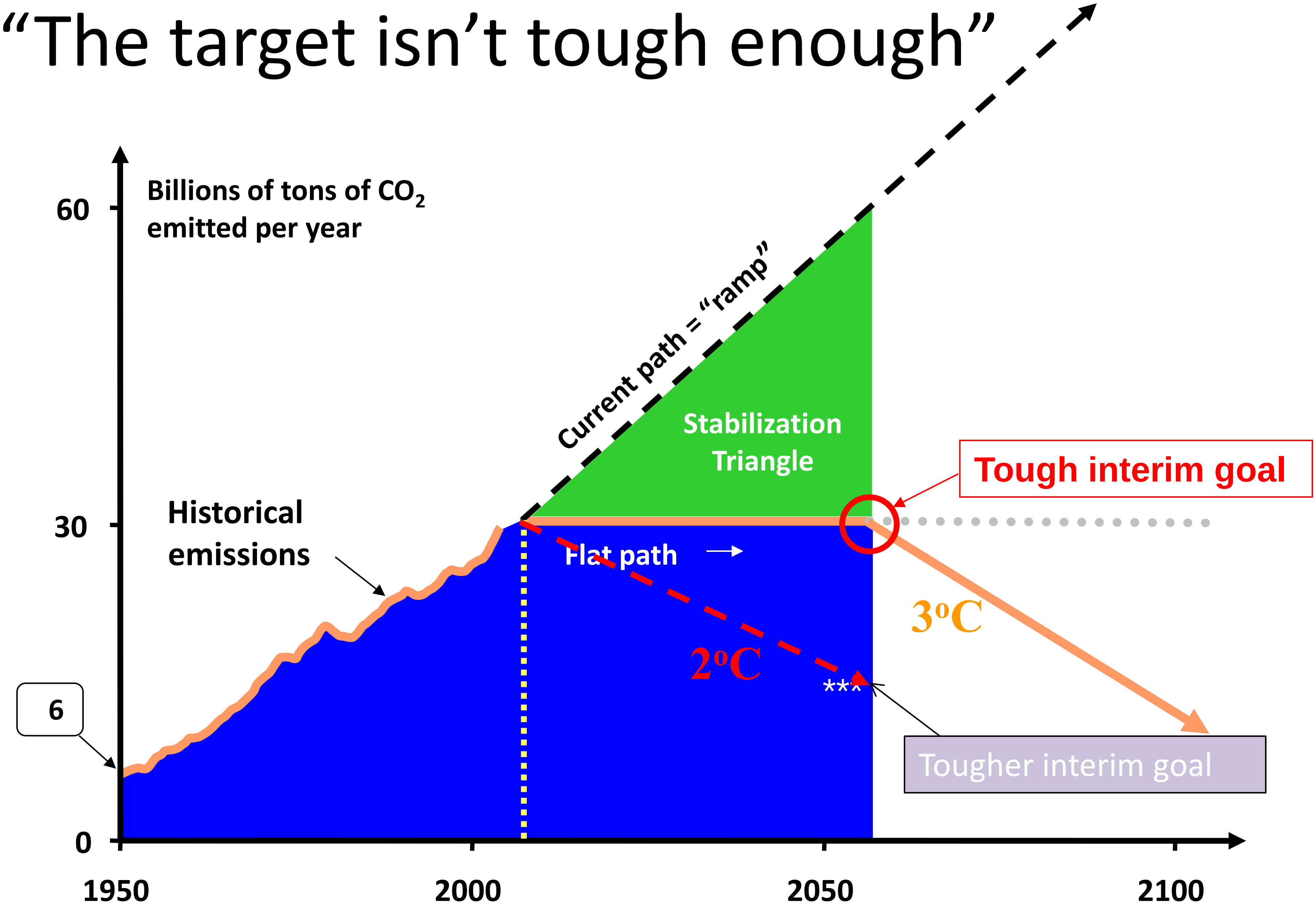
The Stabilization Triangle



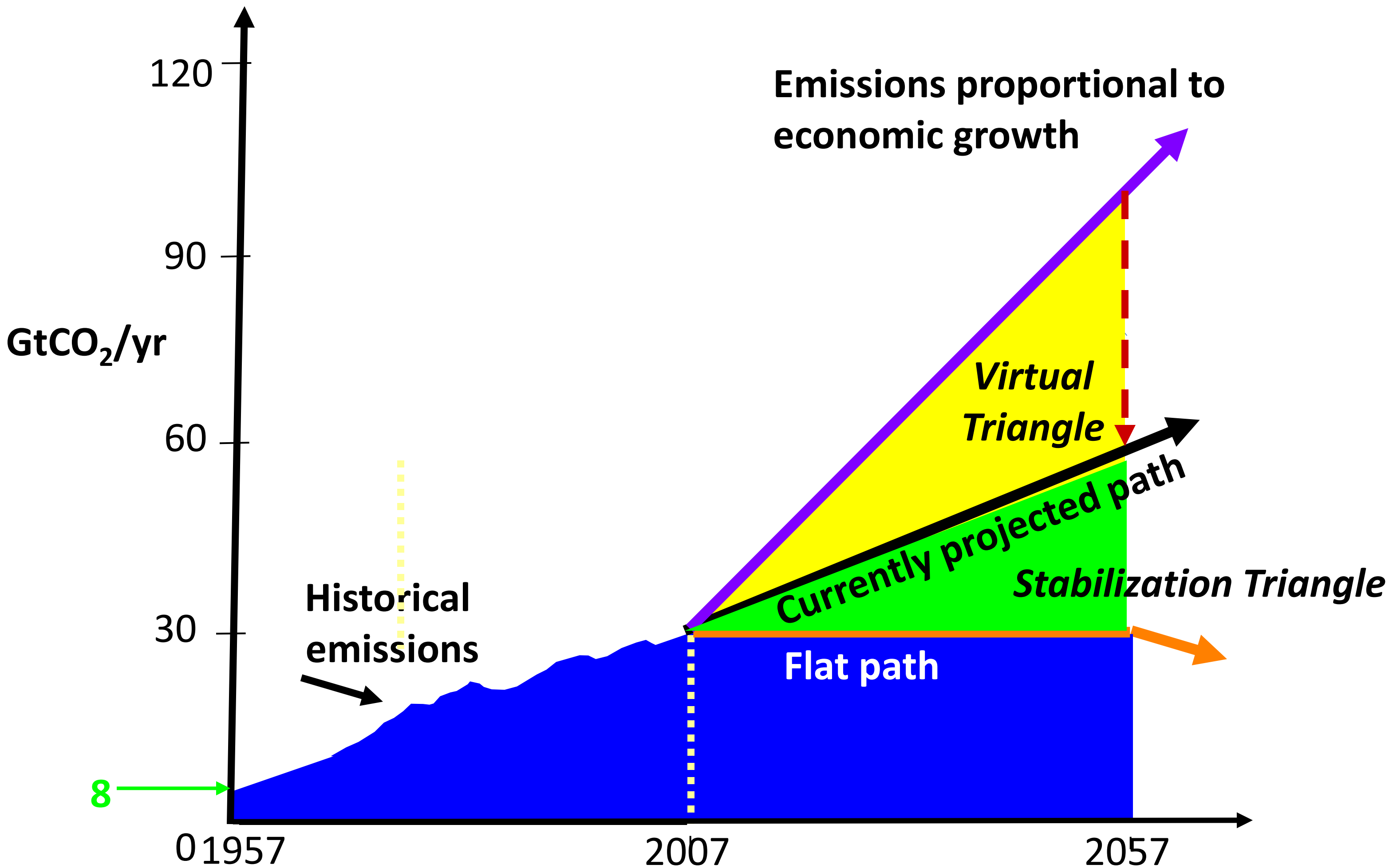
“The target isn’t tough enough”



“The target isn’t tough enough”

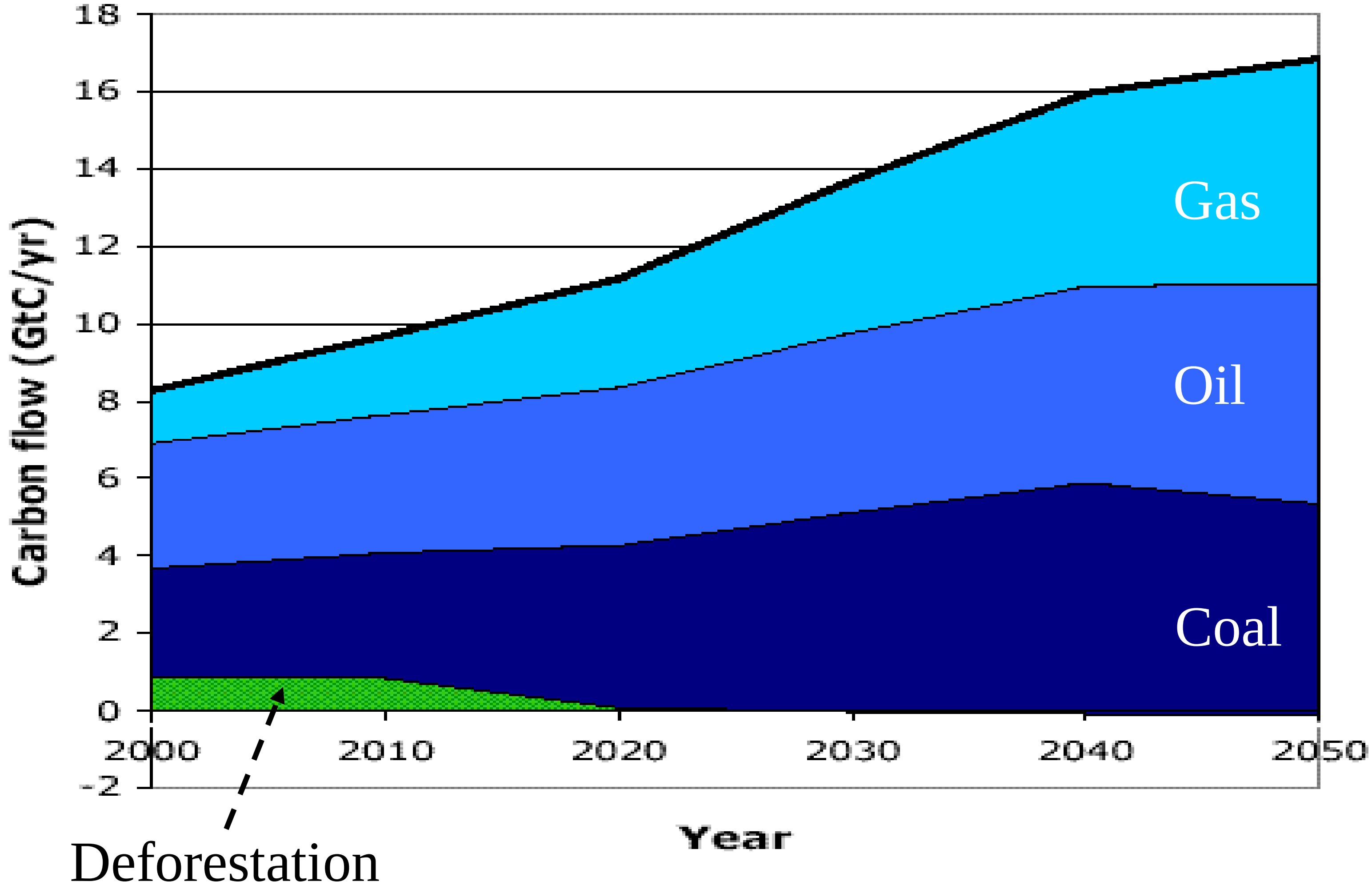


The Virtual Triangle: Large Carbon Savings Are Already in the Baseline

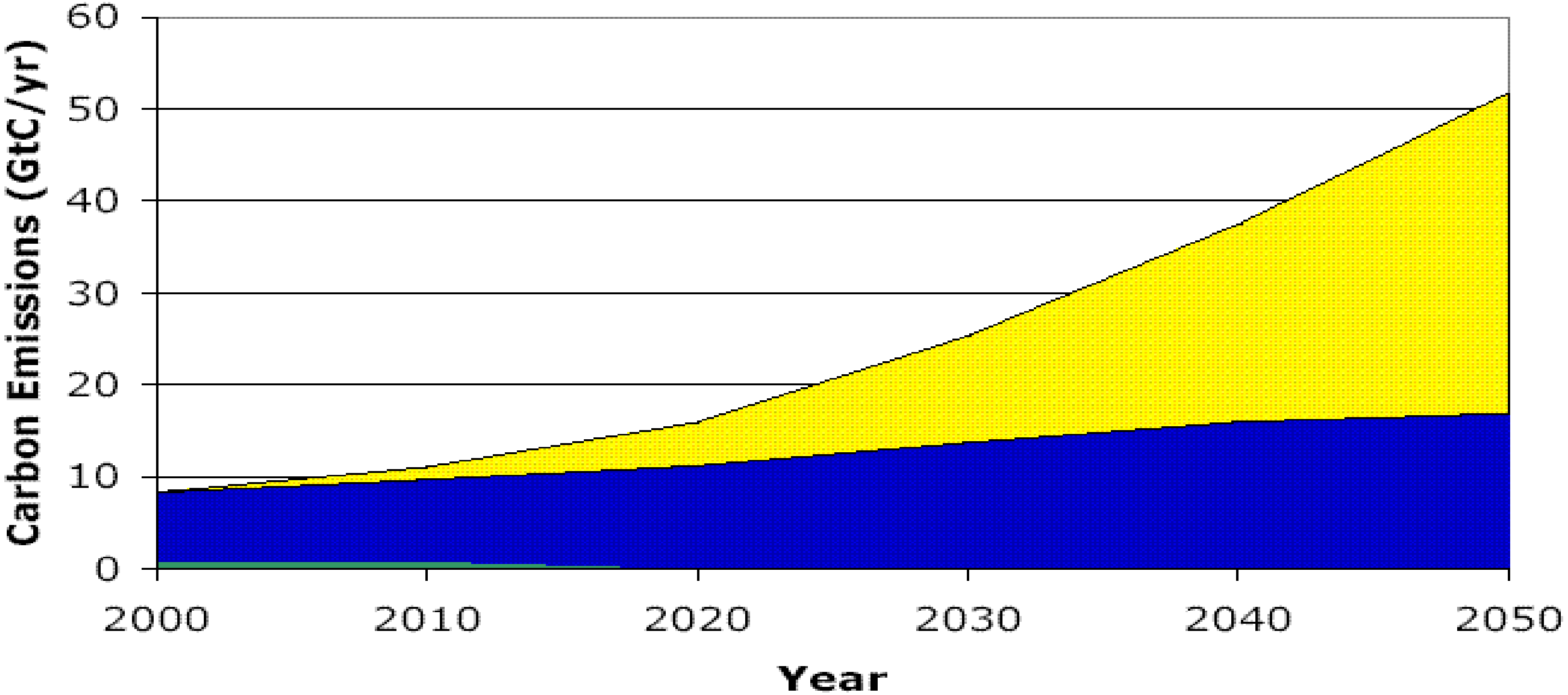


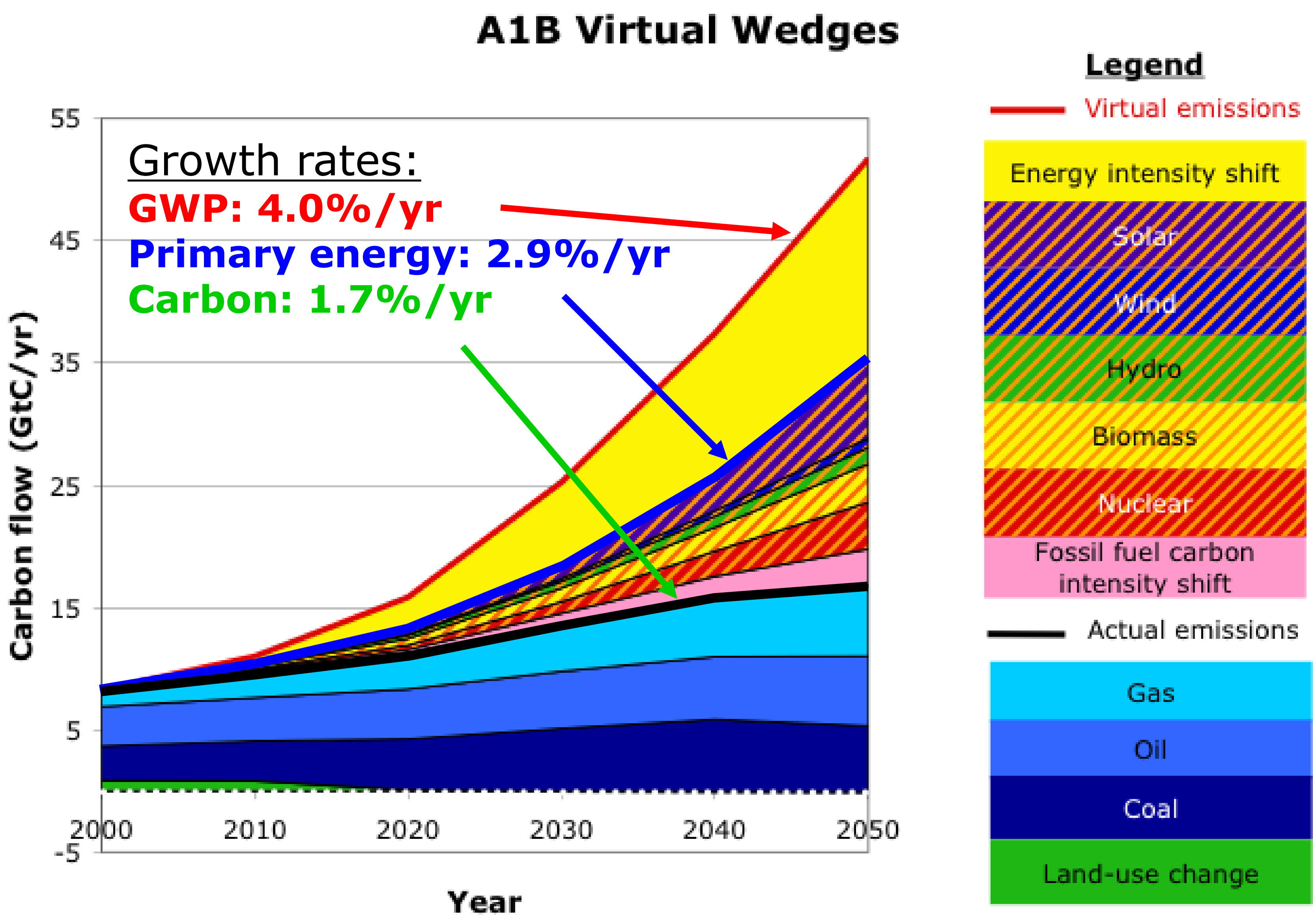
Models differ widely in their estimates of contributions to the virtual triangle from structural shifts (toward services), energy efficiency, and carbon-free energy.

A1B, 2000-2050, by fuel

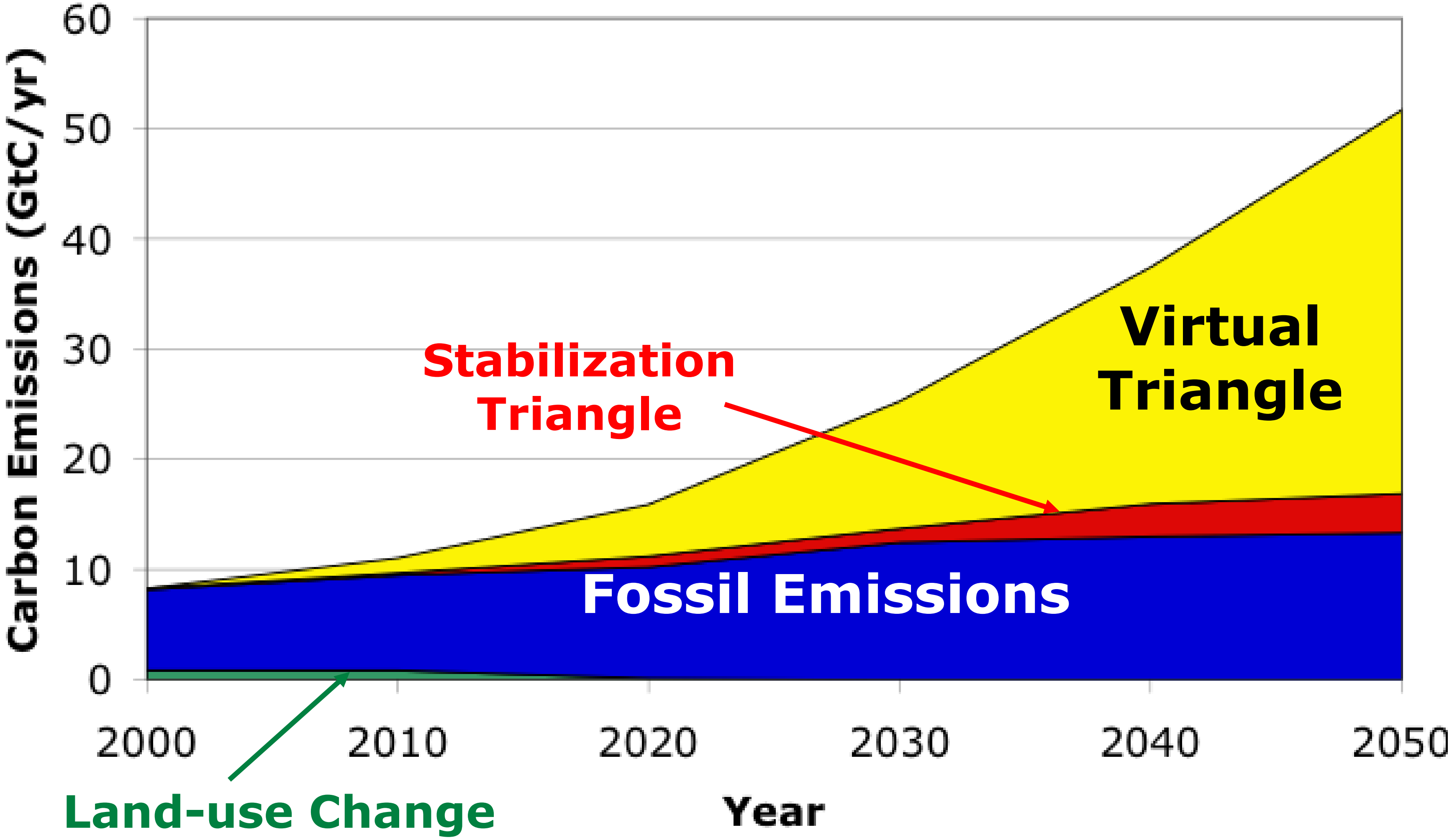


A1B Virtual Triangle

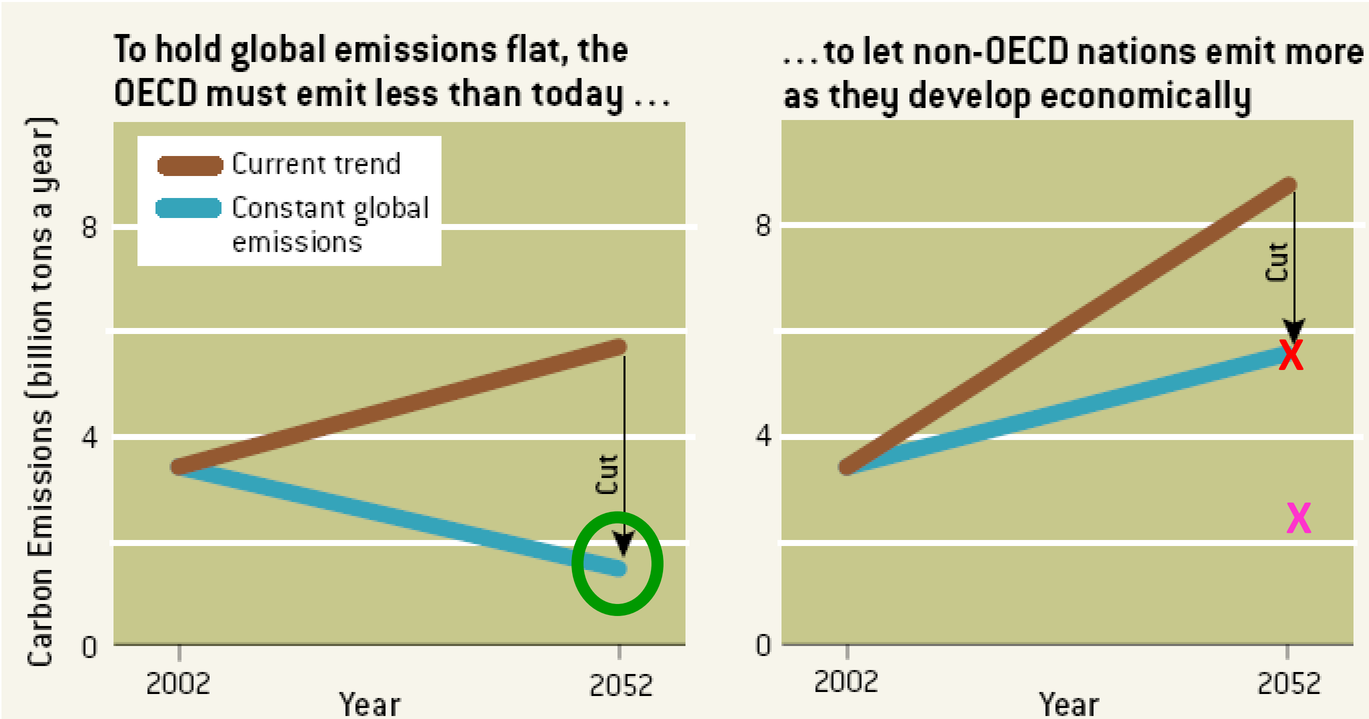



A1B Virtual Wedges
Growth rates:
GWP: 4.0%/yr
Primary energy: 2.9%/yr
Carbon: 1.7%/yr
Carbon flow (GtC/yr)
55
45
35
25
15
5
-5
2000
2010
2020
2030
2040
2050
Year
Legend
Virtual emissions
Energy intensity shift
Solar
Wind
Hydro
Biomass
Nuclear
Fossil fuel carbon intensity shift
Actual emissions
Gas
Oil
Coal
Land-use change

A1B vs. A1B-550 Emissions



“Flat” vs. “down 50%” is mostly about the developing world’s emissions

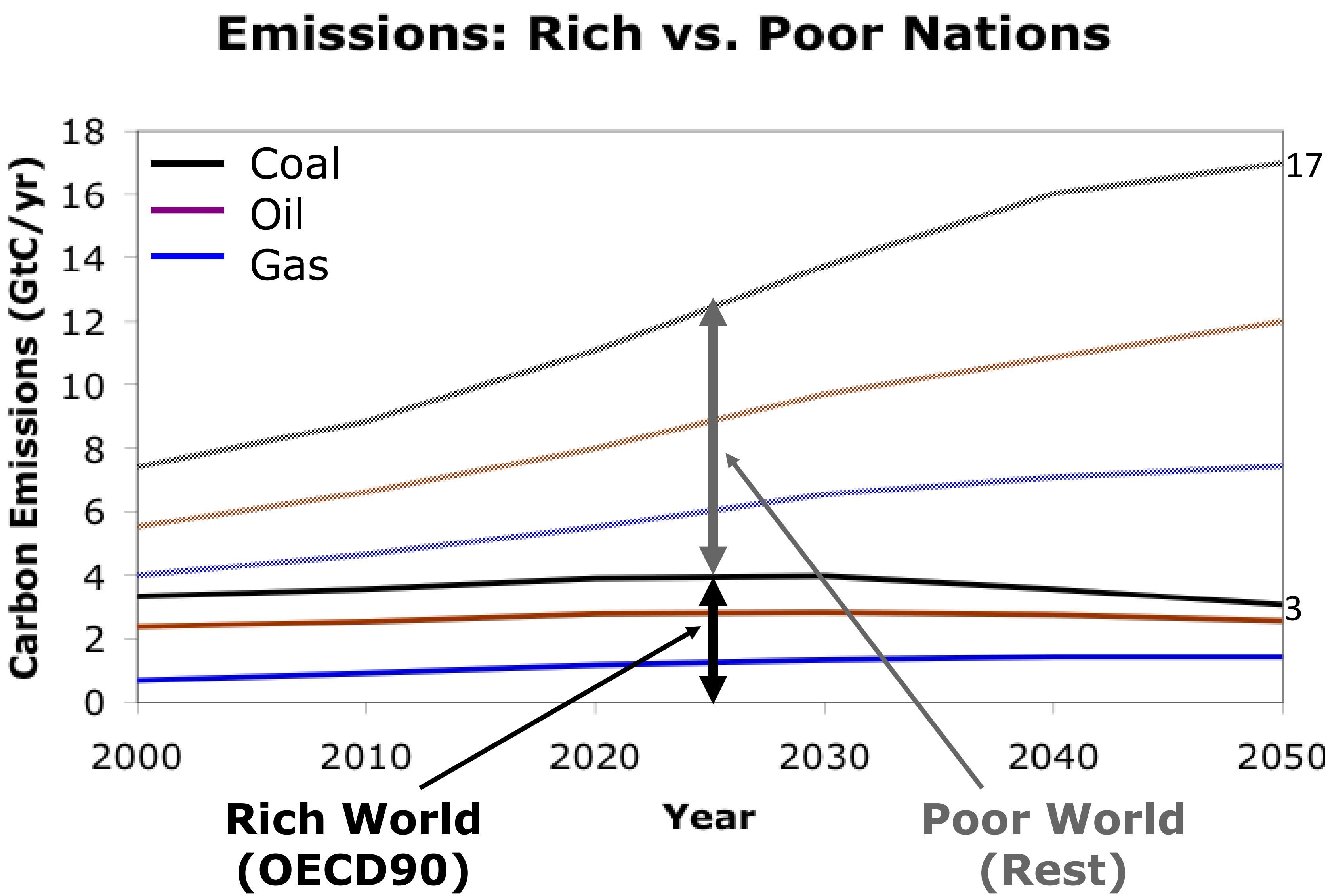


Up 60% **or down 60%**

Up 140% or up 60%, ***or down 40%***

Source of Figure: Socolow and Pacala, “A plan to keep carbon in check,” *Scientific American*, Sept 2006.

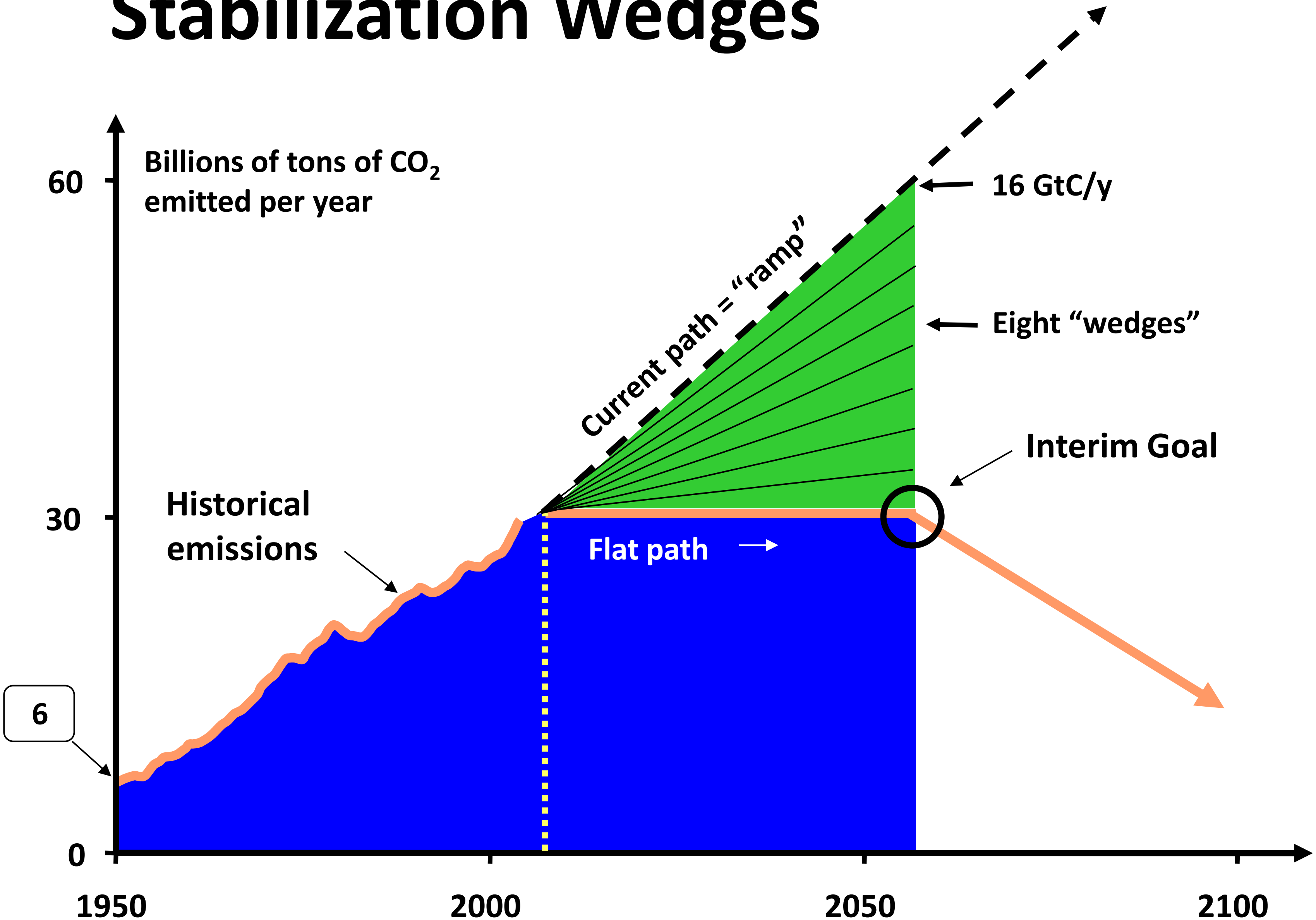
A1B, 2000-2050, by Fuel: Rich *vs.* Poor



The developing world will decide what kind of planet we live on.

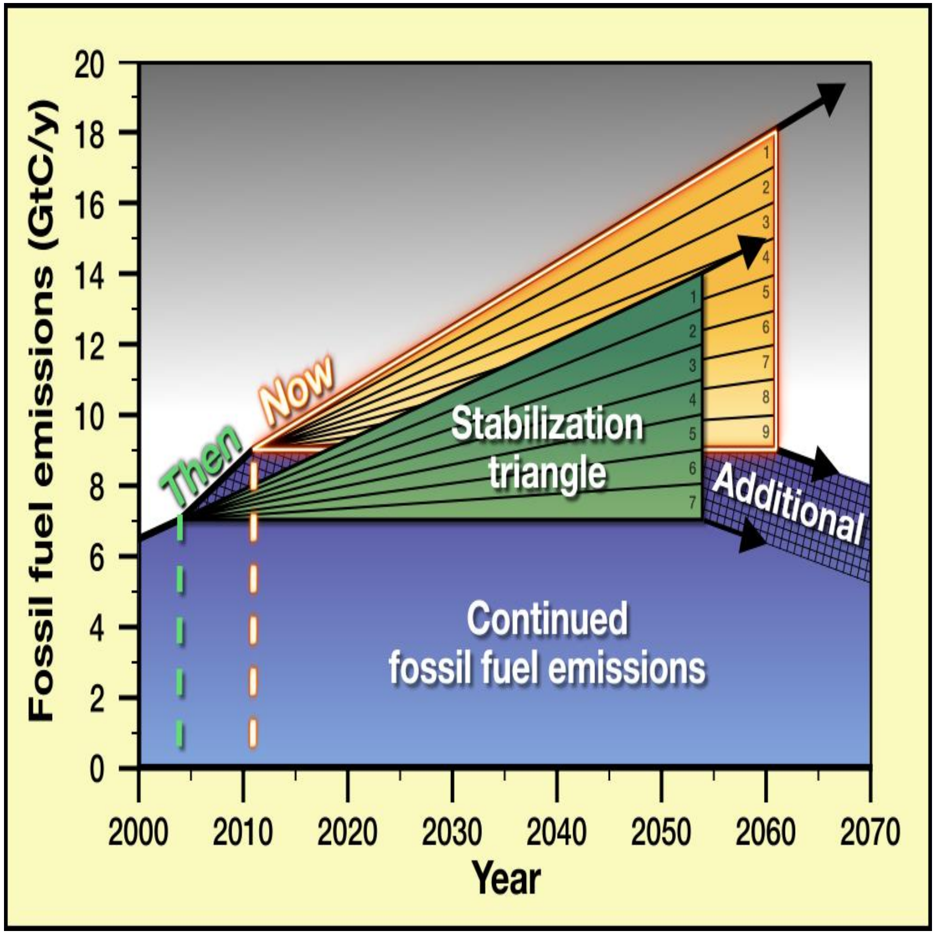
For a while longer, the industrialized countries will lead.

Stabilization Wedges



“Wedges reaffirmed,”

a short essay released on Sept 27, 2011



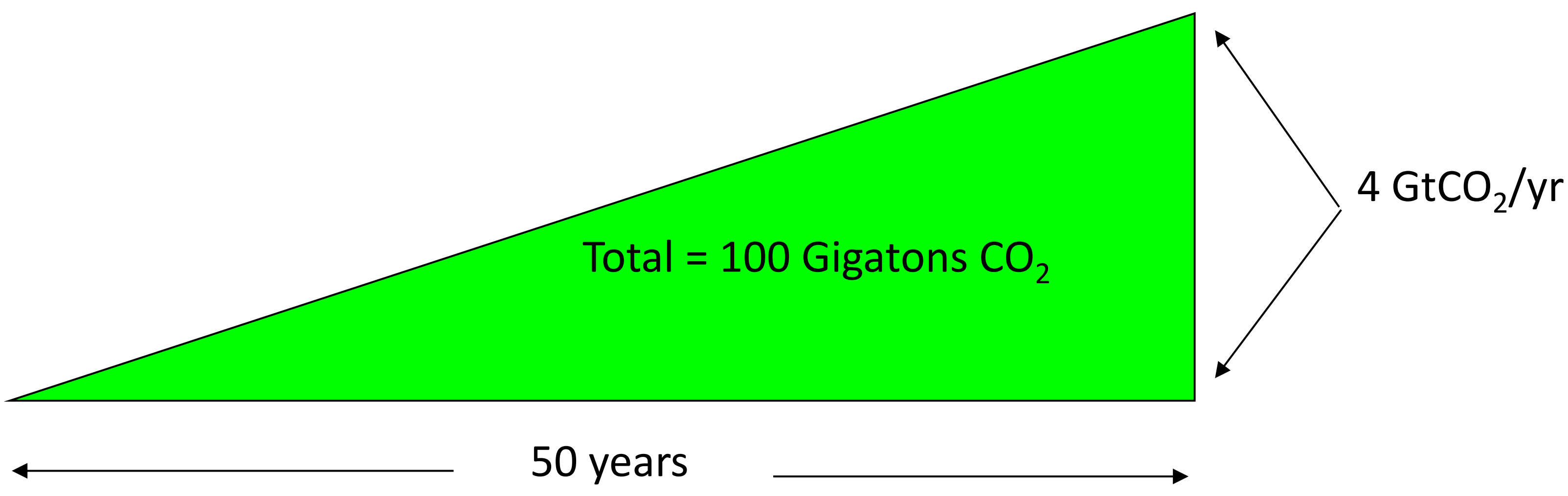
The essay was accompanied by comments from:

Carter Bales
Ralph Cicerone
Freeman Dyson
Christopher Field
Robert Fri
David Hawkins
Rush Holt
Robert May
Phil Sharp
Nicholas Stern

Released at www.thebulletin.org and www.climatecentral.org.
Commenting is continuing at www.dotearth.blogs.nytimes.com.

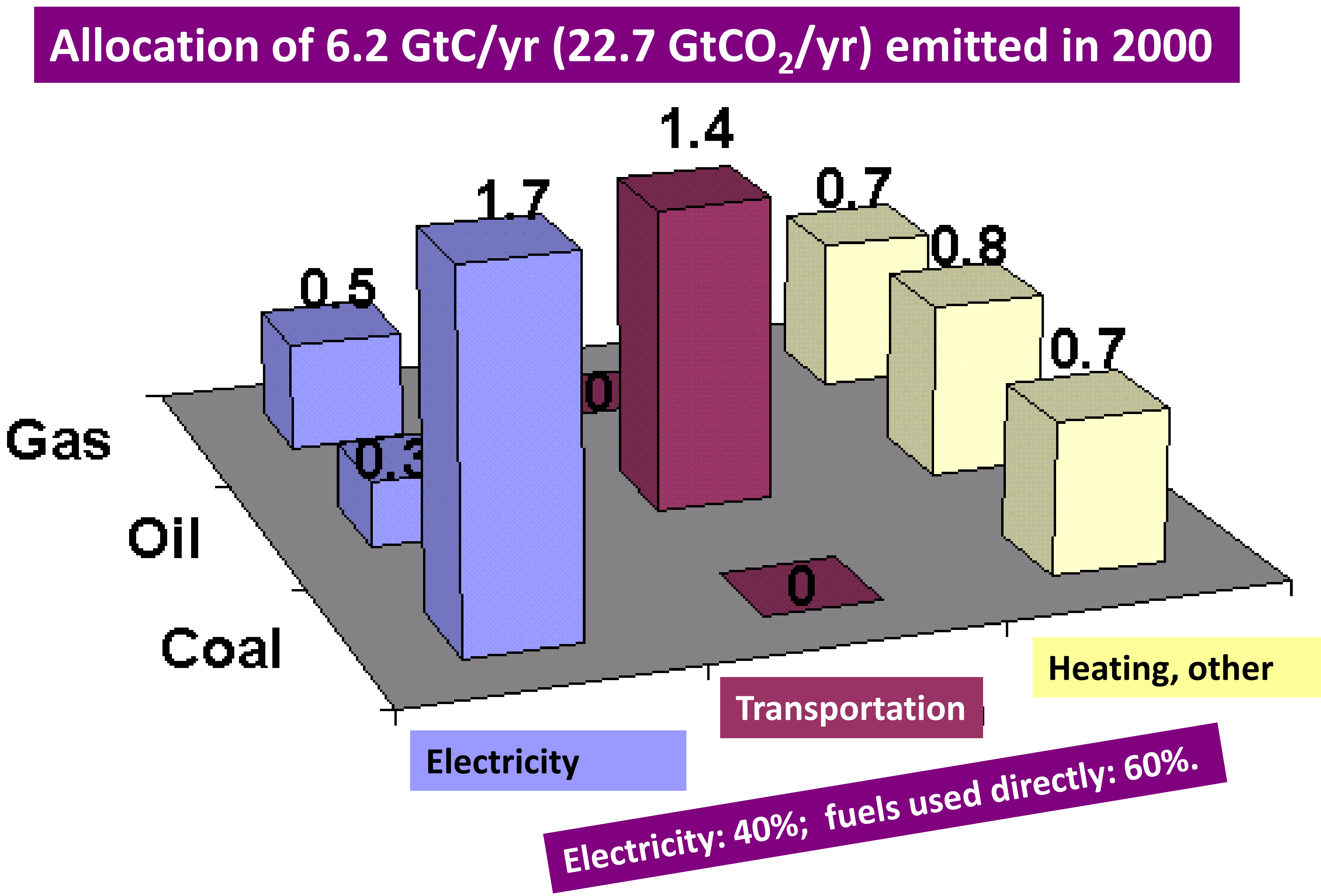
What is a "Wedge"?

A "wedge" is a strategy to reduce carbon emissions that grows in 50 years from zero to 4 $GtCO_2$/yr. The strategy has the potential to be commercialized at very large scale.



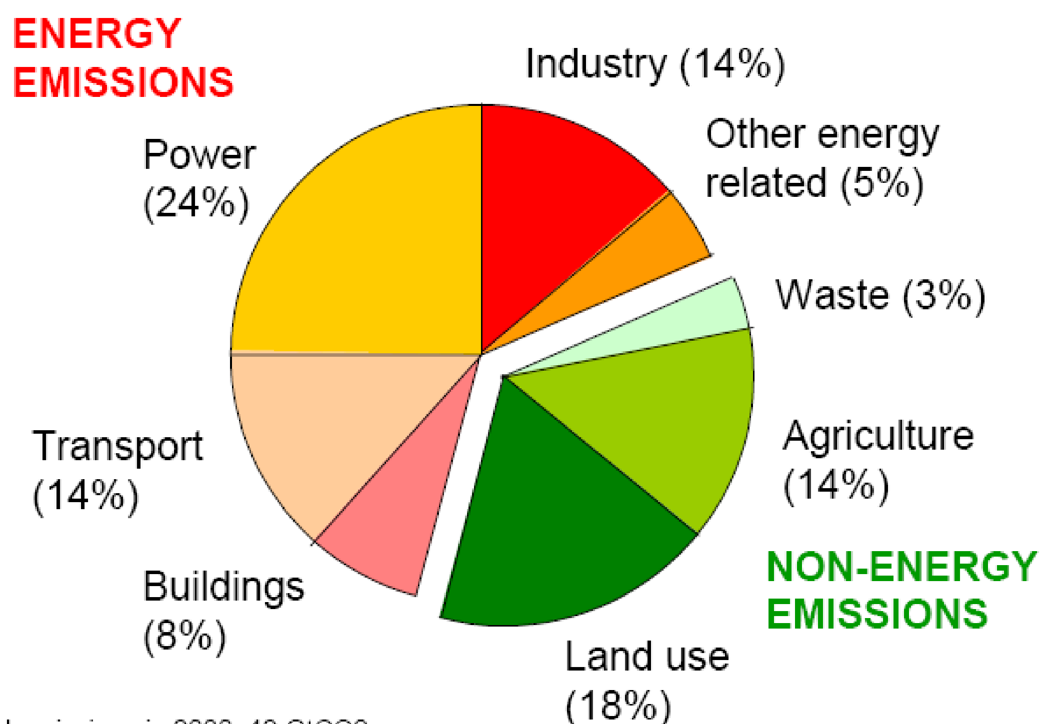
Cumulatively, a wedge redirects the flow of 100 $GtCO_2$ in its first 50 years. This is **six trillion dollars** at \$60/tCO_2. A "solution" to the CO_2 problem should have the potential to provide at least one wedge.

Global CO_2 Emissions by Sector and Fuel



Global GHG emissions, by source

Figure 1 Greenhouse-gas emissions in 2000, by source

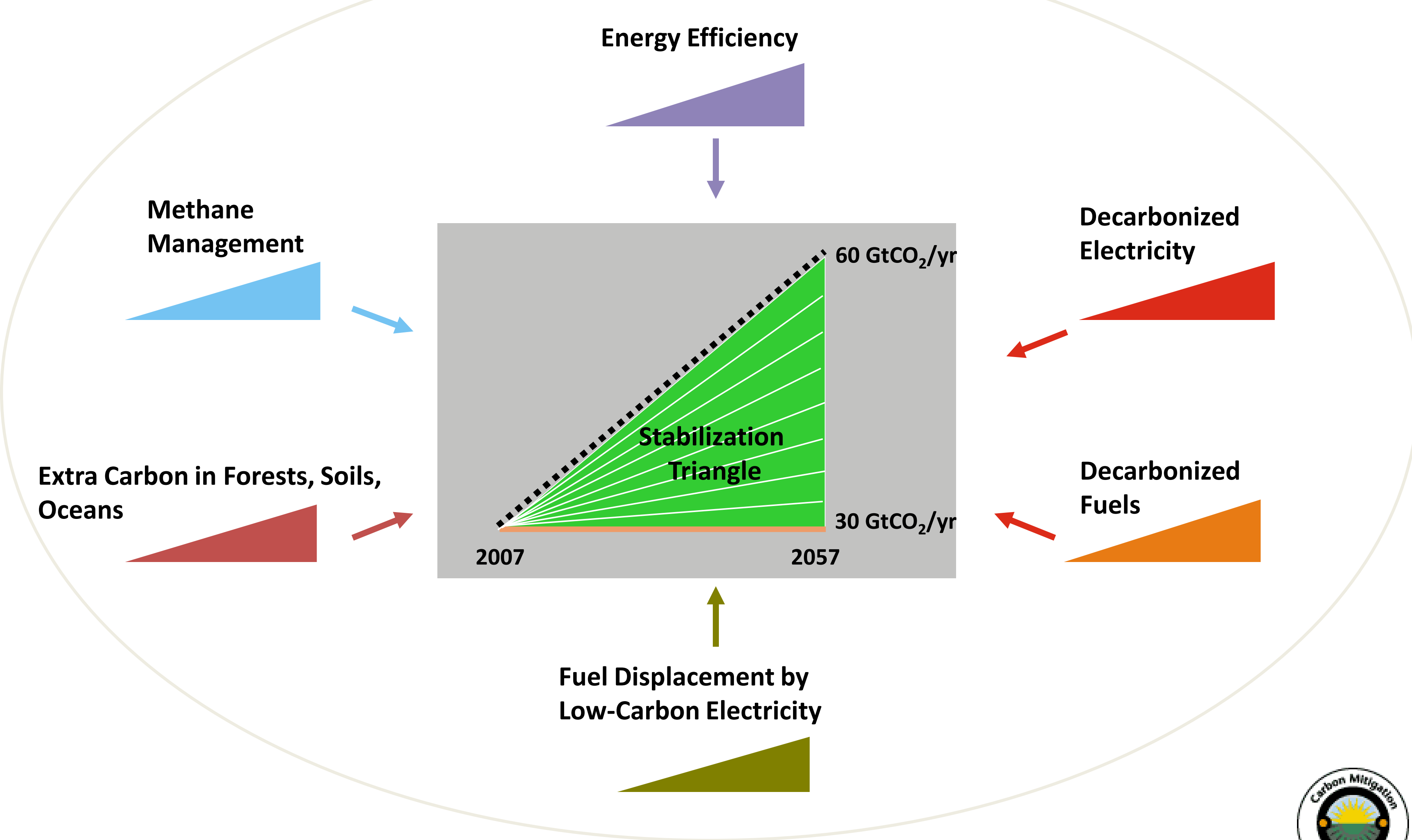


Total emissions in 2000: 42 GtCO2e.

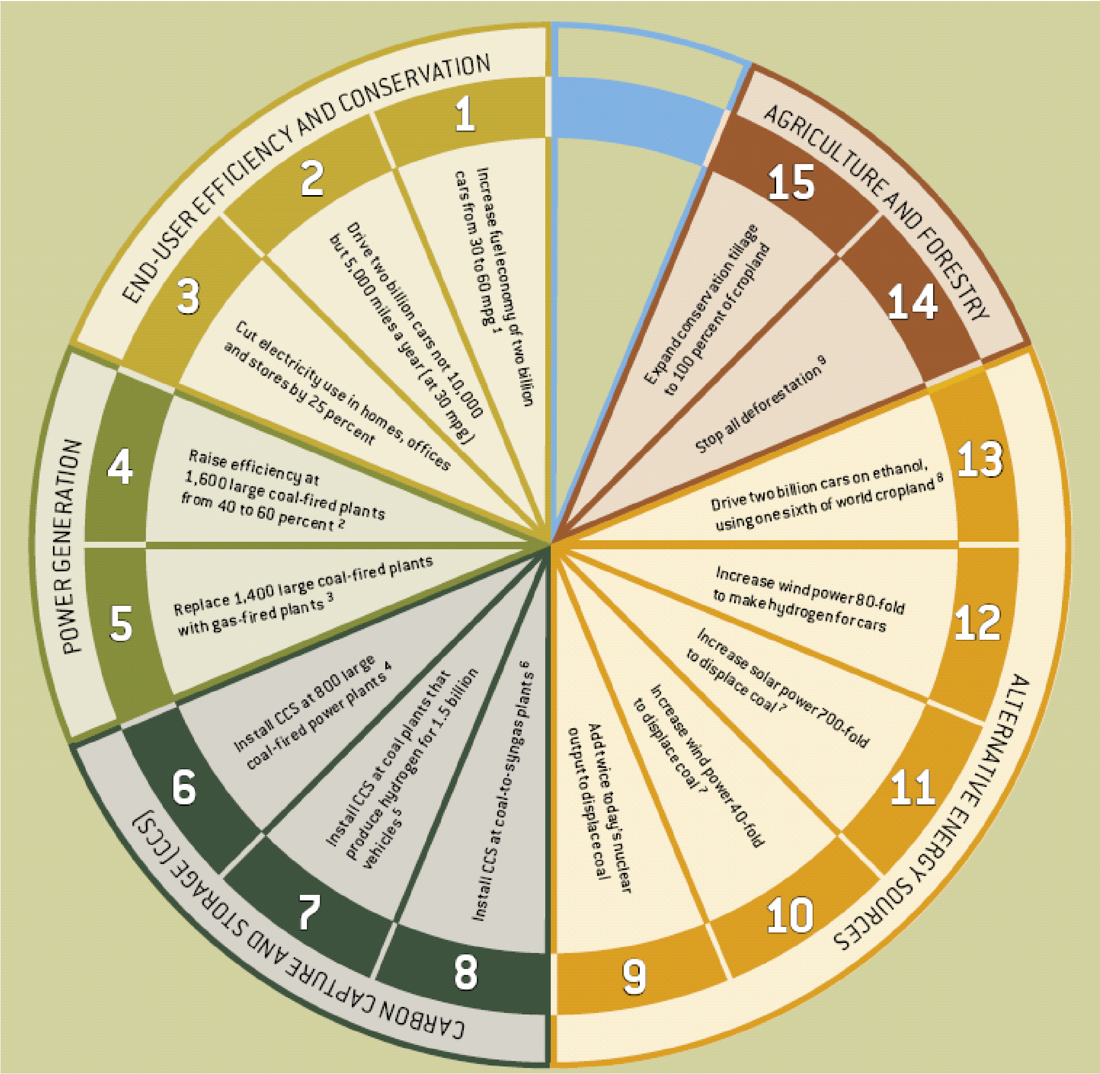
Energy emissions are mostly CO_2 (some non-CO_2 in industry and other energy related).
Non-energy emissions are CO_2 (land use) and non-CO_2 (agriculture and waste).

Source: Prepared by Stern Review, from data drawn from World Resources Institute Climate Analysis Indicators Tool (CAIT) on-line database version 3.0.

Fill the Stabilization Triangle with Eight Wedges in six broad categories

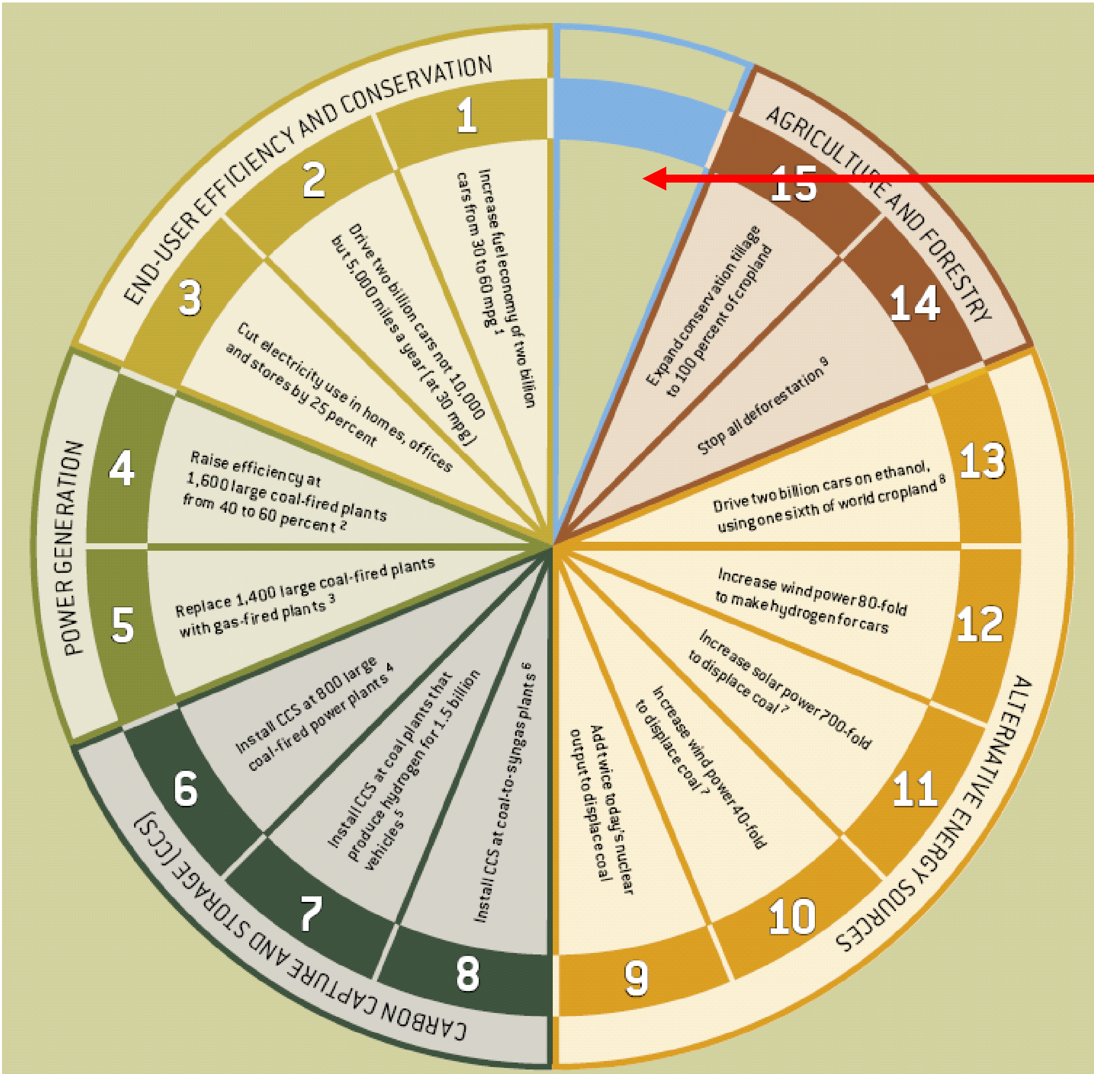


15 Ways to Make a Wedge



Source; Socolow and Pacala, *Scientific American*, September 2006, p.54

15 Ways to Make a Wedge



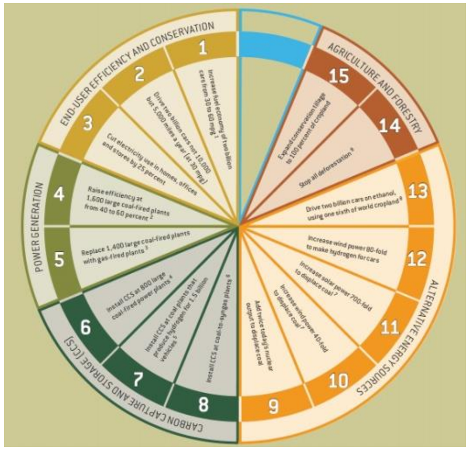
Industrial energy efficiency
"Upstream" investment
Concentrated solar power
Methane mitigation
Population

Not commercial, so not included:

Fusion
Capture of CO_2 from air

Source; Socolow and Pacala, *Scientific American*, September 2006, p.54

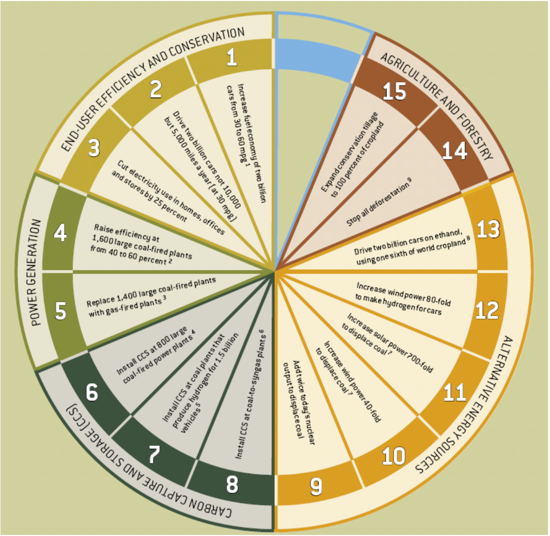
Dartboard notes



Notes:
1 World fleet size in 2056 could well be two billion cars. Assume they average 10,000 miles a year.
2 “Large” is one-gigawatt (GW) capacity. Plants run 90 percent of the time.
3 Here and below, assume coal plants run 90 percent of the time at 50 percent efficiency. Present coal power output is equivalent to 800 such plants.
4 Assume 90 percent of CO_2 is captured.
5 Assume a car (10,000 miles a year, 60 miles per gallon equivalent) requires 170 kilograms of hydrogen a year.
6 Assume 30 million barrels of synfuels a day, about a third of today’s total oil production. Assume half of carbon originally in the coal is captured.
7 Assume wind and solar produce, on average, 30 percent of peak power. Thus replace 2,100 GW of 90-percent-time coal power with 2,100 GW (peak) wind or solar plus 1,400 GW of load-following coal power, for net displacement of 700 GW.
8 Assume 60-mpg cars, 10,000 miles a year, biomass yield of 15 tons a hectare, and negligible fossil-fuel inputs. World cropland is 1,500 million hectares.
9 Carbon emissions from deforestation are currently about two billion tons a year. Assume that by 2056 the rate falls by half in the business-as-usual projection and to zero in the flat path.

Source; Socolow and Pacala, *Scientific American*, September 2006, p.54

How many wedges of one kind?



Source; Socolow and Pacala, *Scientific American*, September 2006, p.54

Generic questions:

Is the overall cost for the second use of a wedge larger or smaller than the cost of its first use? (Is the second "wind" wedge less costly than the first?)

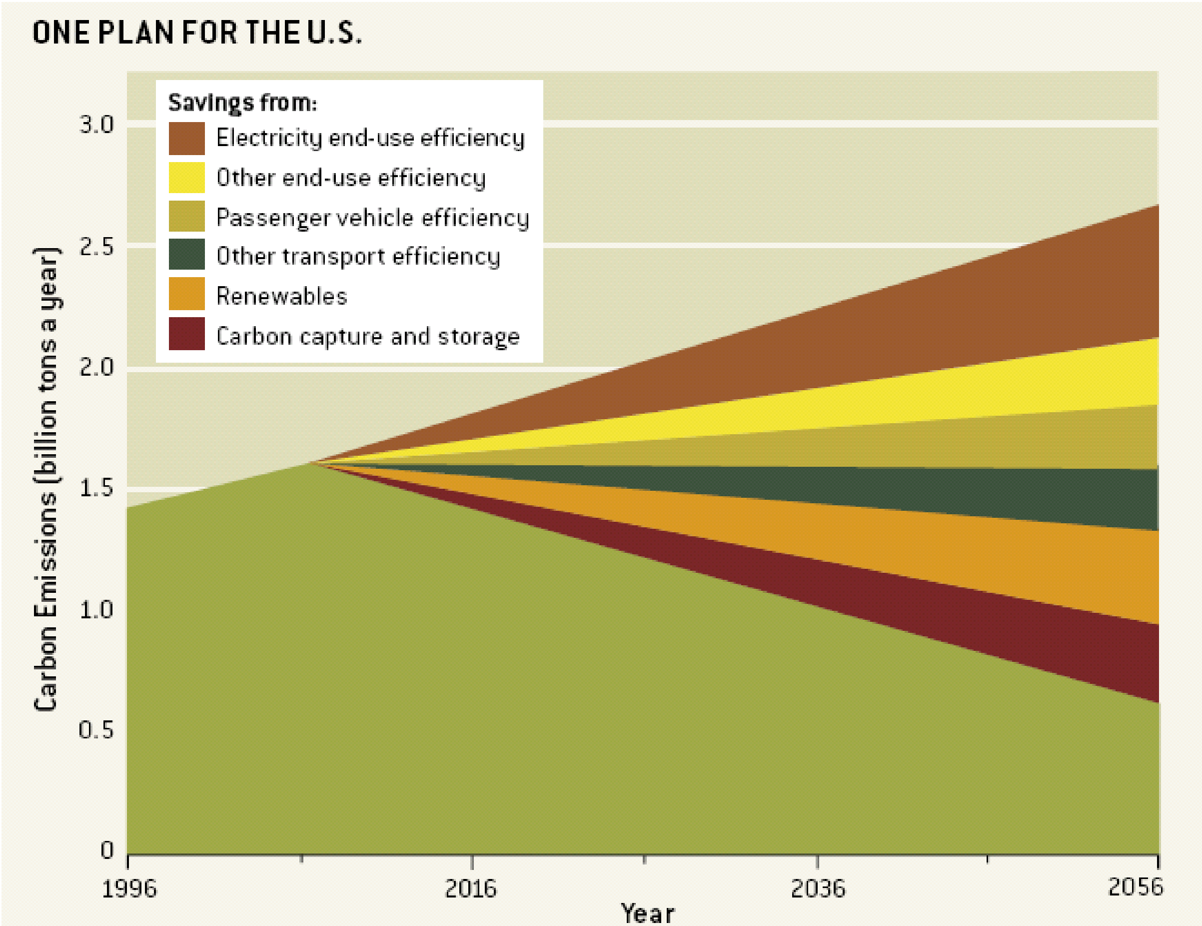
How many times can the same wedge be used before creating insurmountable problems?

“The Wedge Model is the iPod of climate change: You fill it with your favorite things.”

David Hawkins, NRDC, 2007.

Therefore, prepare to negotiate with others, who have different favorite things.

U.S. Wedges

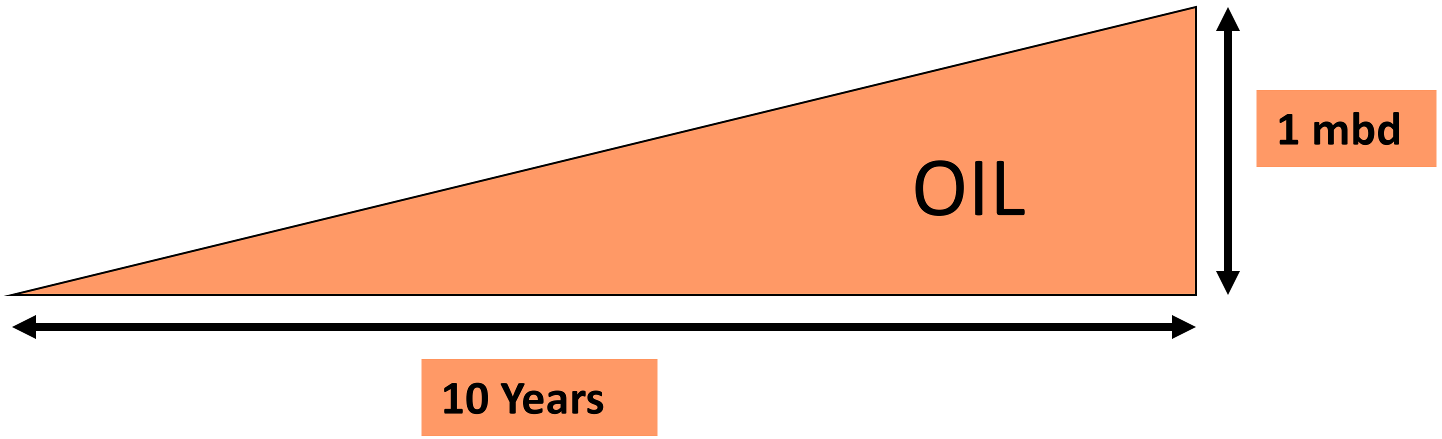


▲ U.S. share of emissions reductions could, in this Natural Resources Defense Council scenario, be achieved by efficiency gains, renewable energy and clean coal.

Source: Lashof and Hawkins, NRDC, *in* Socolow and Pacala, *Scientific American*, September 2006, p. 57

The Analogous Oil Wedge

1 oil wedge is a strategy or campaign that results in the reduction of pressure on oil markets (by either supply augmentation or demand reduction) by 1 million barrels per day after 10 years.



This is a much smaller wedge than the carbon stabilization wedge:

Much smaller vertical dimension: **26x(1 mbd) = 4 $GtCO_2$/yr**.

Smaller slope: **5.2* (1 mbd/10 yr) = (4 $GtCO_2$/yr)/50 yr**

At $55/bbl, area of oil wedge is $100 billion (30 times smaller).

Inventor of the oil wedge: Robert Hirsch

Mitigation is Not Risk-Free

Therefore, the lowest conceivable greenhouse targets, achievable only by casting caution to the winds, are not optimal.

“Solutions” can bring serious problems of their own.

Every “solution” has a dark side.

Conservation	Regimentation
Renewables	Competing uses of land
“Clean coal”	Mining: worker and land impacts
Nuclear power	Nuclear war
Geoengineering	Technological hegemony

Risk management: In choosing targets, we must take into account both the risks of disruption from climate change and the risks of disruption from mitigation.

Iterative risk management: the basis for a renewed commitment

In another decade we'll know a lot more about the earth, both because of new climate science and because of what the earth tells us about itself.

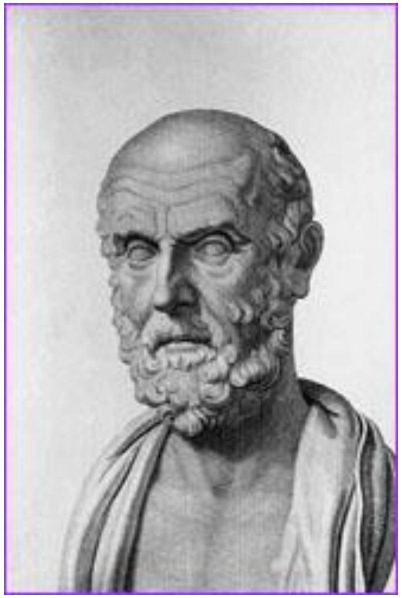
We’ll also know more about the solutions themselves, thanks to both R&D and field experience.

All this argues for making decisions *iteratively*.

Iterative risk management

“I will apply, for the benefit of the sick, all measures that are required, avoiding those twin traps of overtreatment and therapeutic nihilism.”

Hippocrates



* Modern version of the Hippocratic oath, Louis Lasagna, 1964, http://www.pbs.org/wgbh/nova/doctors/oath_modern.html

After the Break we will hunt
for wedges of energy efficiency
and land-use change.

BREAK

Required readings for Week 9:

Low-carbon fossil-fuel-based energy via CO_2 capture & storage

Required Readings

IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H. C. de Coninck, M. Loos, and L. A. Meyer (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 442 pp. *[Read Summary for Policymakers]*

Socolow, R. H. (2005). Can we bury global warming? *Scientific American*, *293*(1), 49-55.

America's Climate Choices (2009). Chapter 7: Fossil-Fuel Energy [Particularly "Electric Power Generation with Fossil Fuels" and "Geological Storage of CO2"]

MIT (2007). The Future of Coal. *[Chapter 3: Coal-based electricity generation].*

Liu, H., & Gallagher, K. S. (2010). Catalyzing strategic transformation to a low-carbon economy: A CCS roadmap for China. *Energy Policy*, *38*(1), 59-74.

Recommended readings for Week 9:
Low-carbon fossil-fuel-based energy via CO_2 capture & storage

Recommended Readings

IEA Clean Coal Centre [Stephen Mills]. (2012) "Coal-fired CCS demonstration plants, 2012".

Haszeldine, R. S. (2009). Carbon capture and storage: how green can black be? *Science*, *325*(5948), 1647-1652.

Herzog, H. (2009). "Carbon Dioxide Capture and Storage". Chapter 13, in Helm, D., & Hepburn, C. (Eds.). (2009). *The economics and politics of climate change*. Oxford University Press.

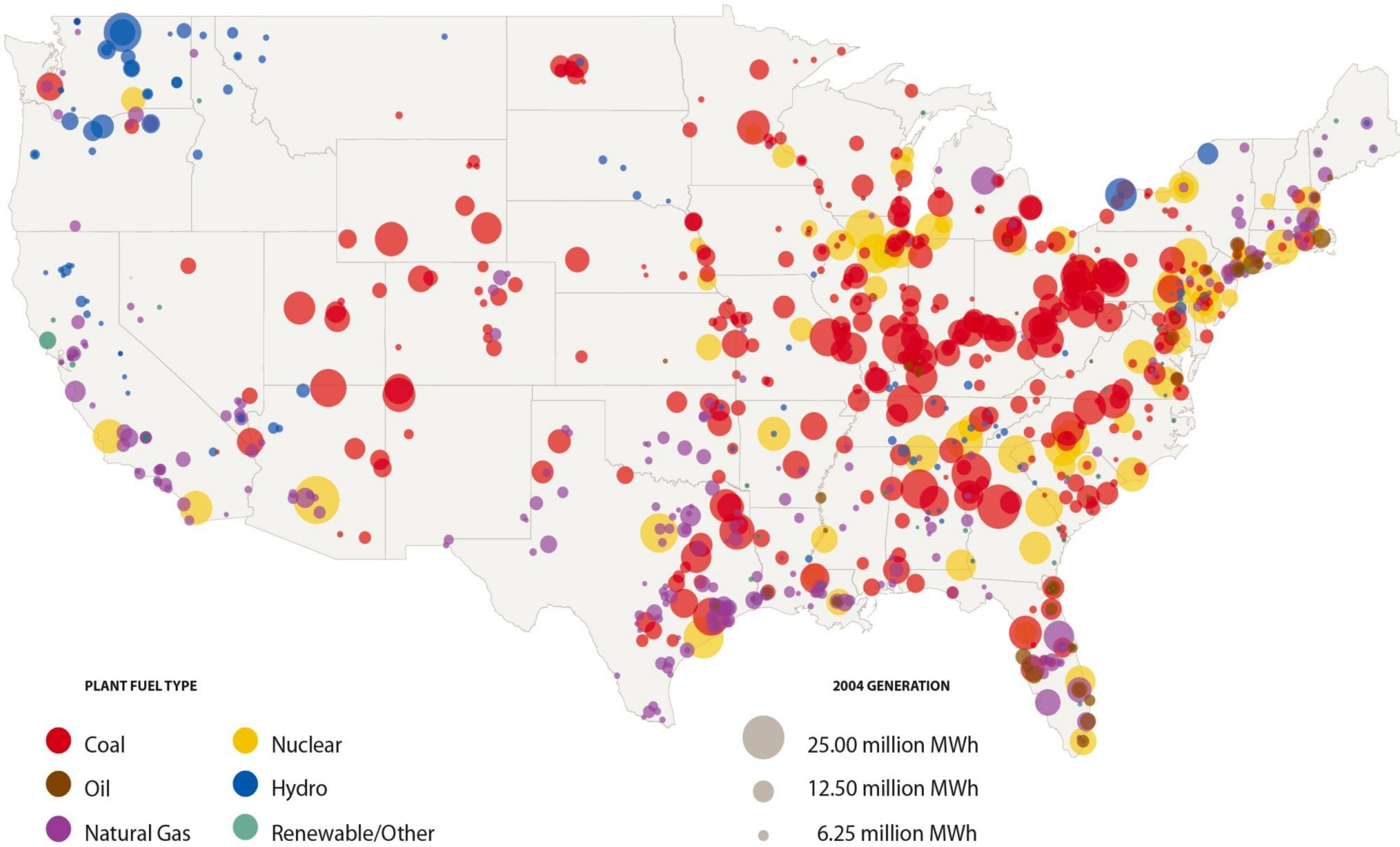
Garg, A., & Shukla, P. R. (2009). Coal and energy security for India: Role of carbon dioxide capture and storage (CCS). *Energy*, *34*(8), 1032-1041.

Environmental Protection Agency, 2010, *Report of the Interagency Task Force on Carbon Capture and Storage*. Read pages 7-27; 50-51; 68-76; and 123-28.

Szulczewski, M. L., MacMinn, C. W., Herzog, H. J., & Juanes, R. (2012). Lifetime of carbon capture and storage as a climate-change mitigation technology. *PNAS*, *109*(14), 5185-5189.

Efficiency wedges

Legacy: U.S. Power Plants



Source: *Benchmarking Air Emissions*, April 2006. The report was co-sponsored by CERES, NRDC and PSEG.

Efficient Use of Electricity

***Three images*:**

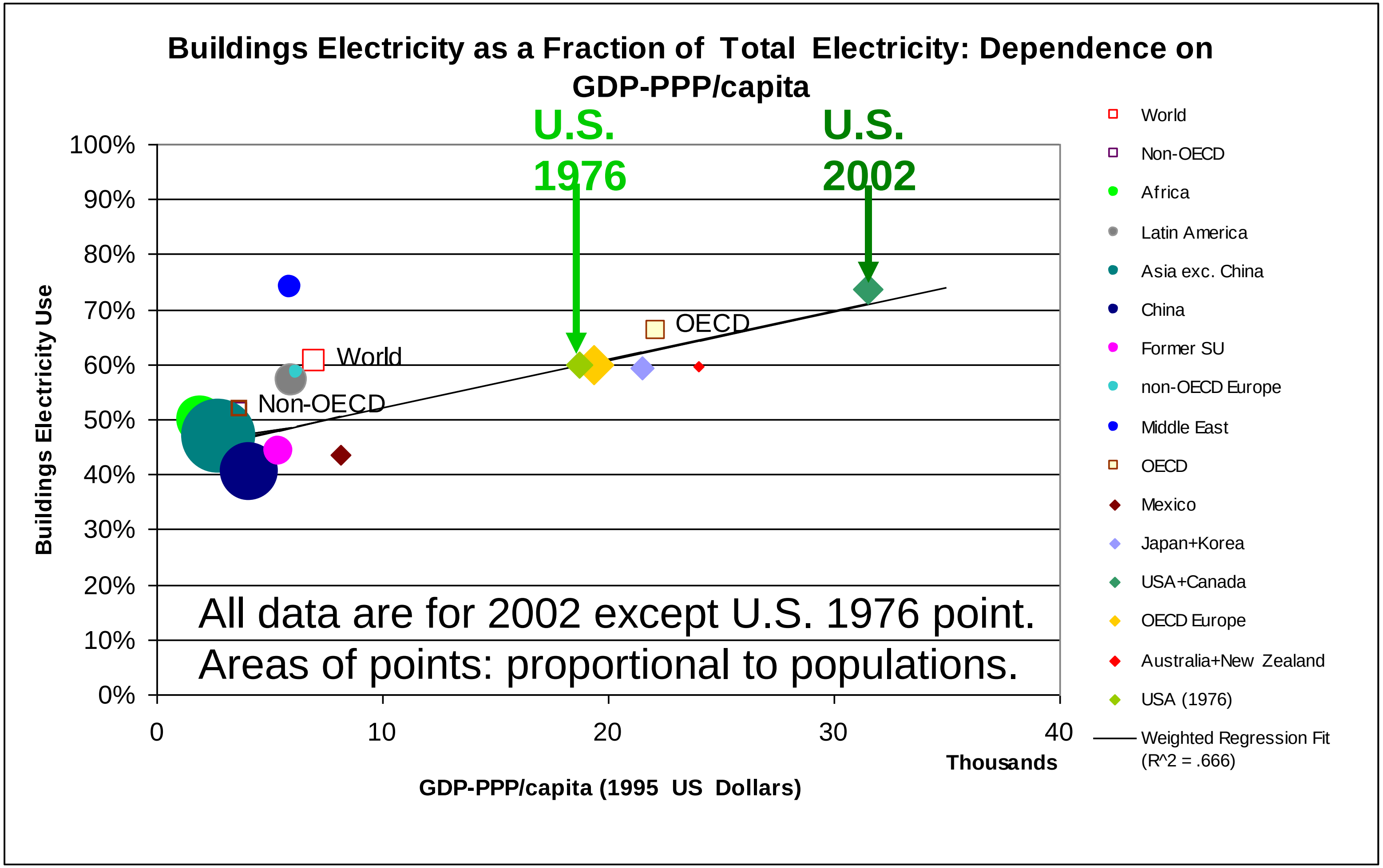
Power electronics for variable-speed-drive motors.

Integration of electricity and thermal energy ("cogeneration").

Can also integrate electricity and fuels/chemicals.

Efficient lighting.

A larger fraction of electricity goes to buildings in rich countries



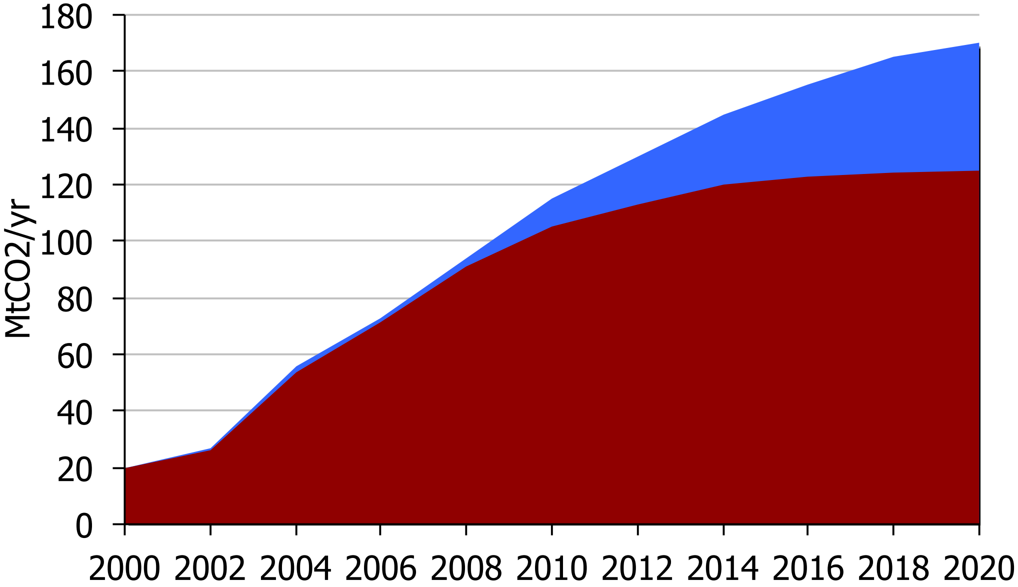
"Buildings Electricity" = 100% of "Commercial and Residential" + 15% of "Industrial" + 10% of "Agricultural."

Data provided by Paul Waide, graphics by Shoibal Chakravarty

China Appliance Standards

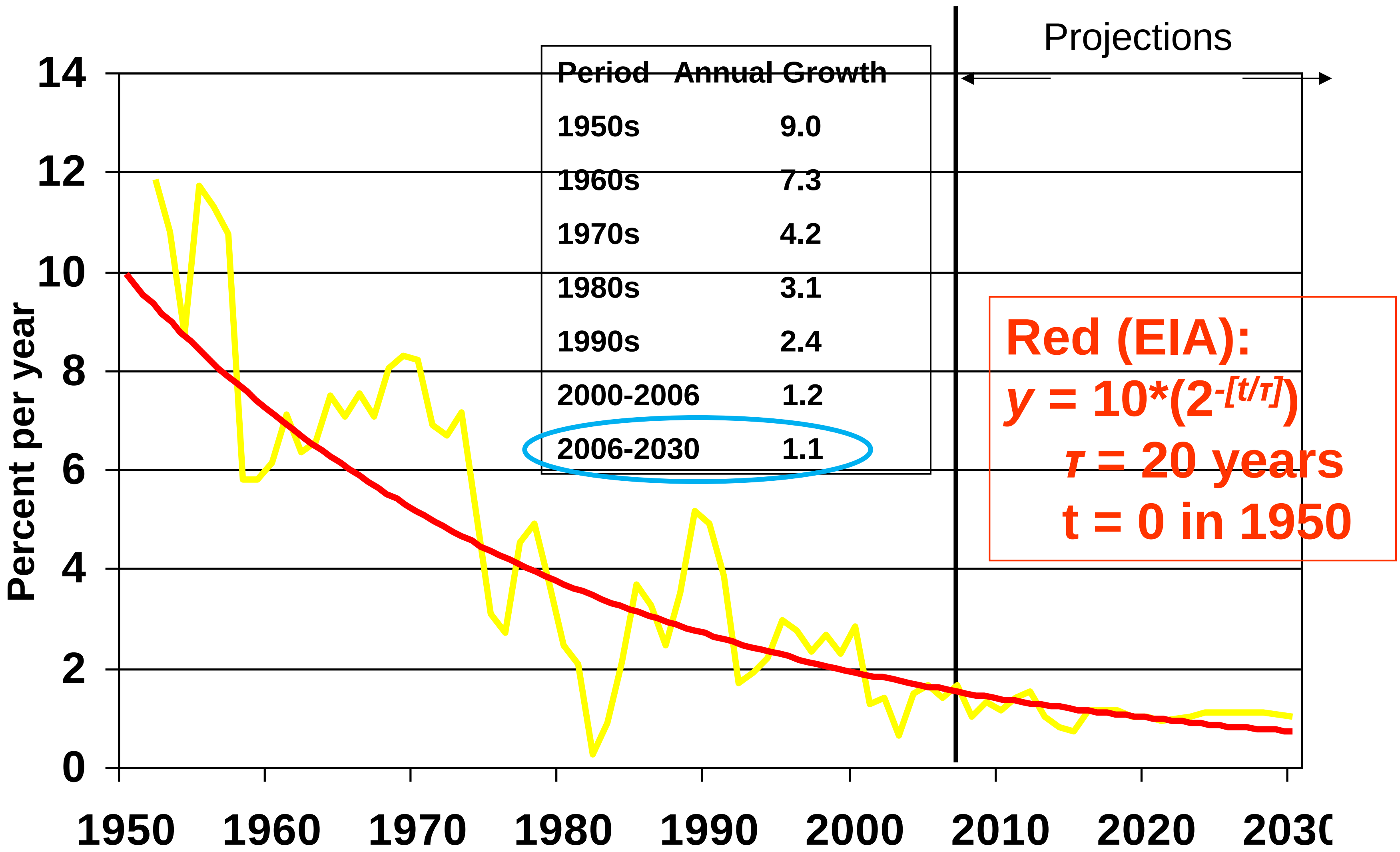
Business as Usual: CO_2 emissions from air conditioners in 2020 are 9x those in 2000.

New Air Conditioner Standard: Down 25% (45 $MtCO_2$/yr) in 2020.



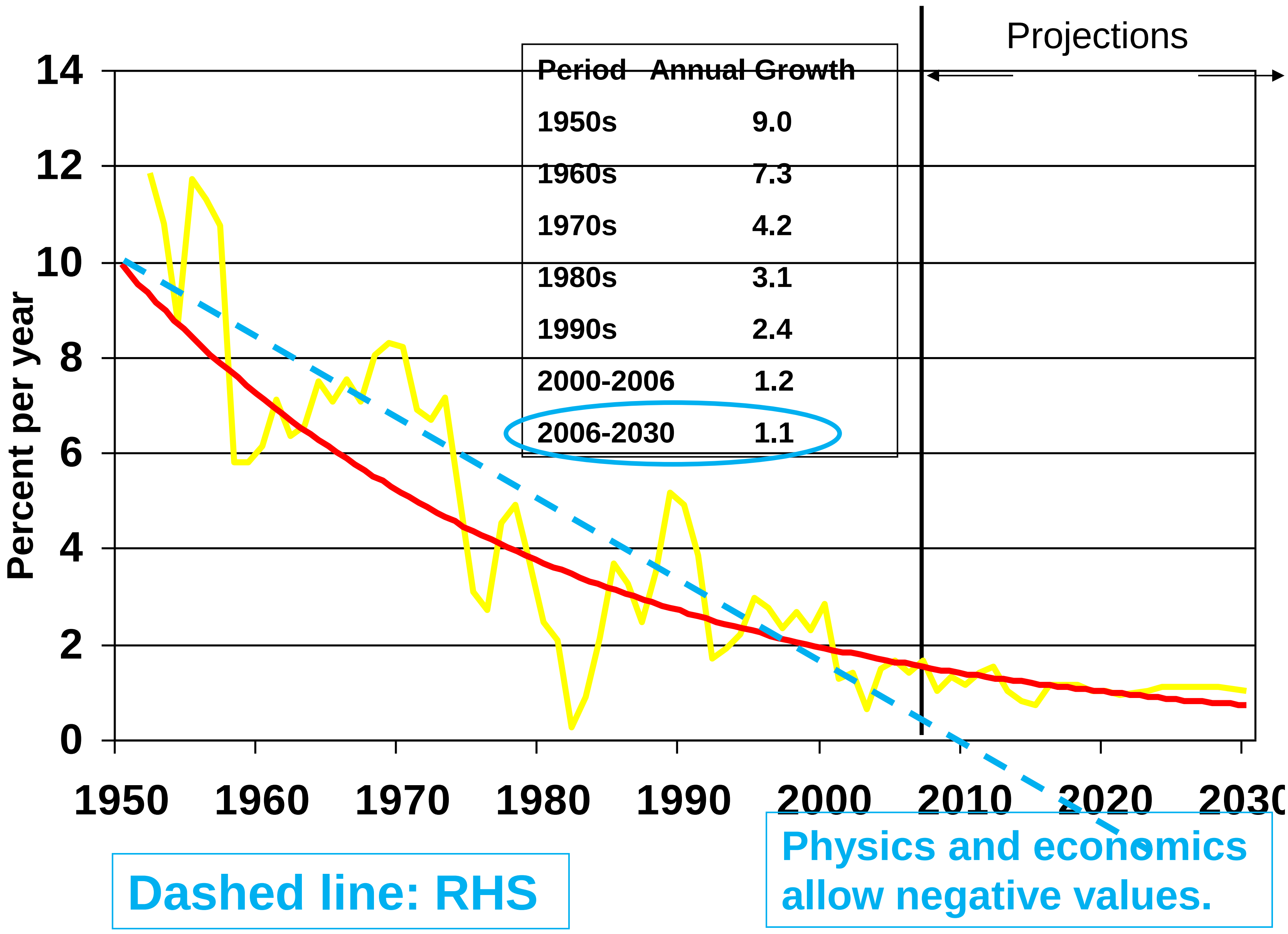
50 million new, efficient air conditioners per year in 2020

Conceive of the far side of a peak

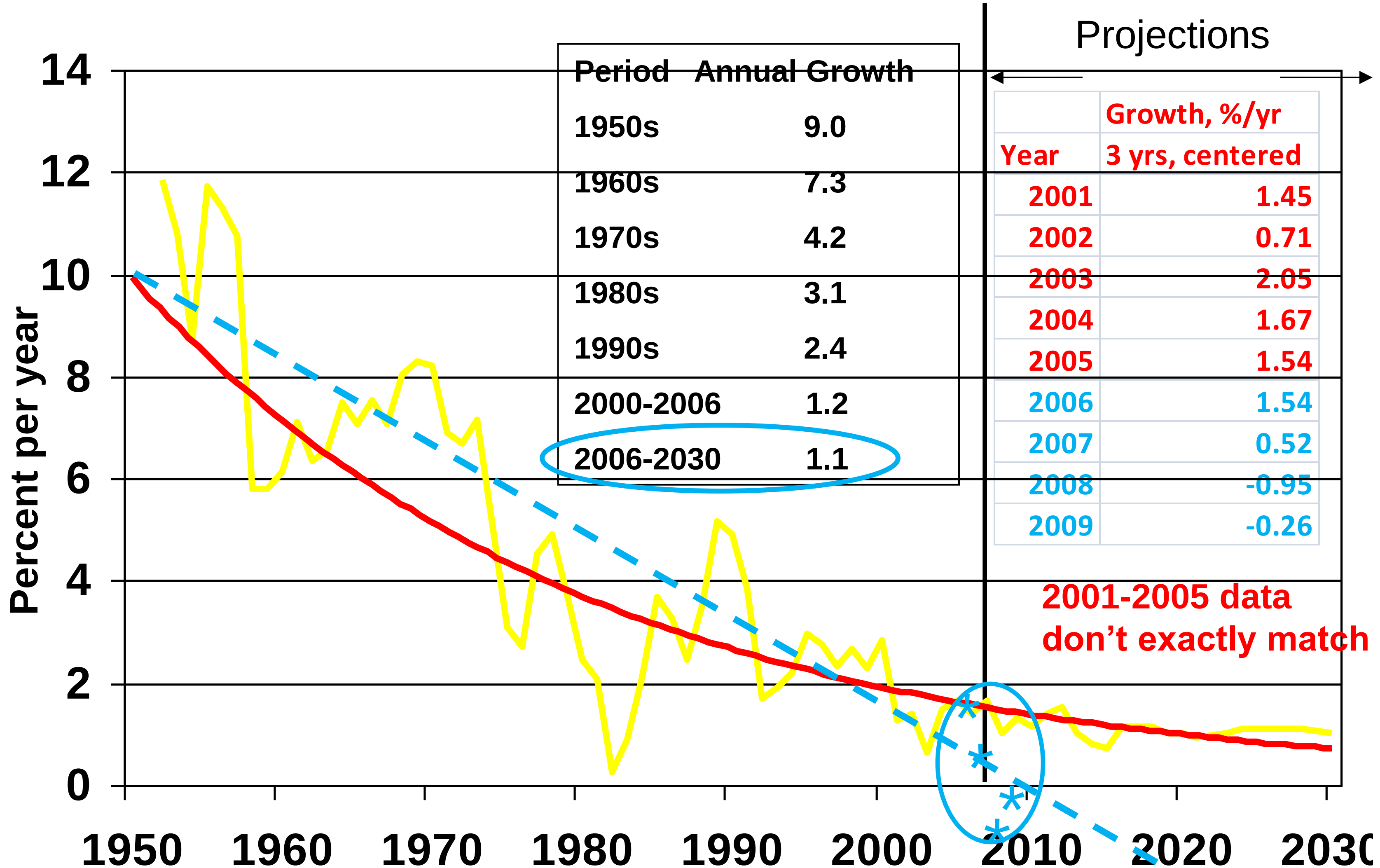


U.S. electricity growth rate (3-year rolling average, percent)

Conceive of the far side of a peak



Conceive of the far side of a peak

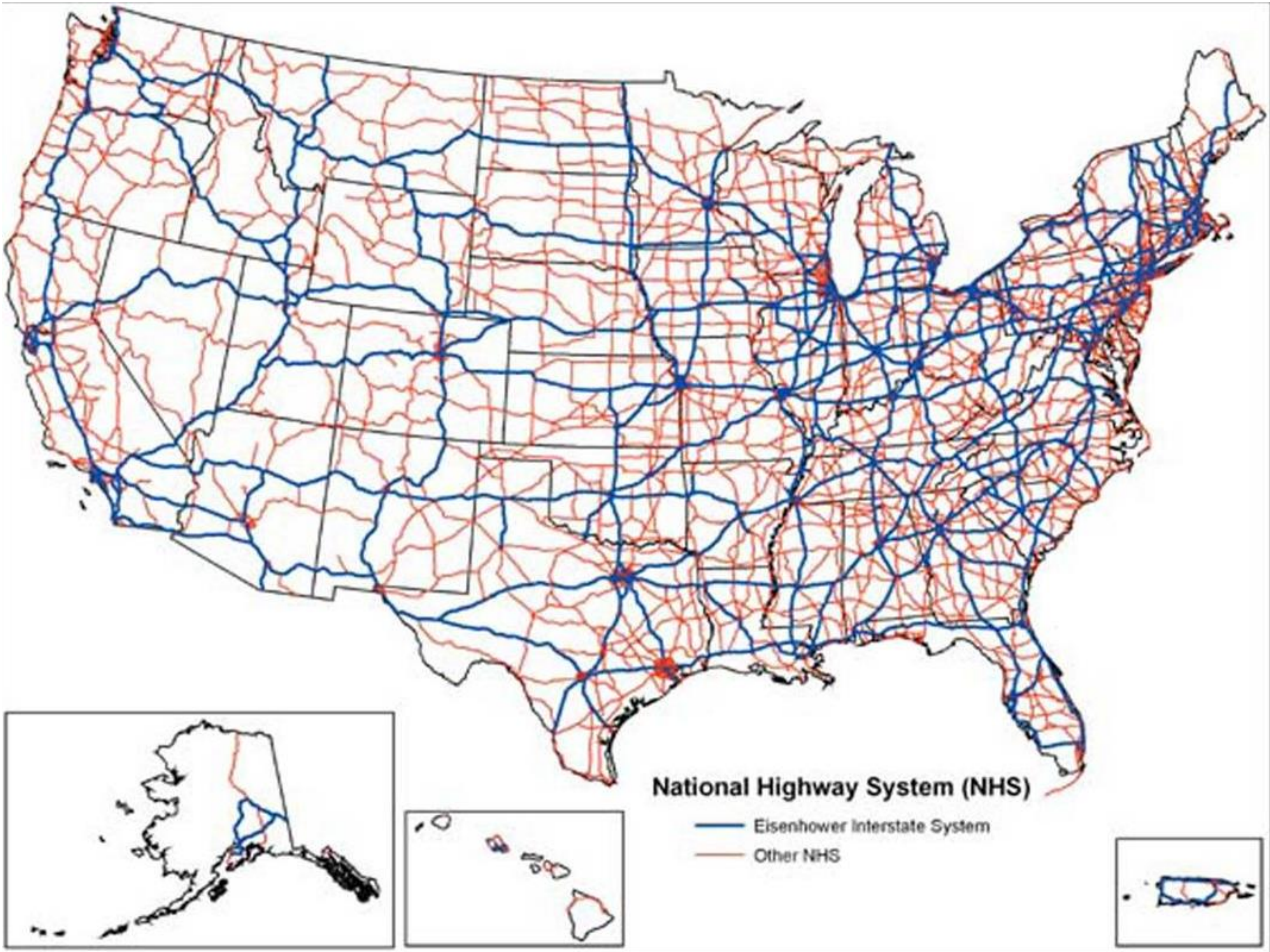


Period	Annual Growth
1950s	9.0
1960s	7.3
1970s	4.2
1980s	3.1
1990s	2.4
2000-2006	1.2
2006-2030	1.1

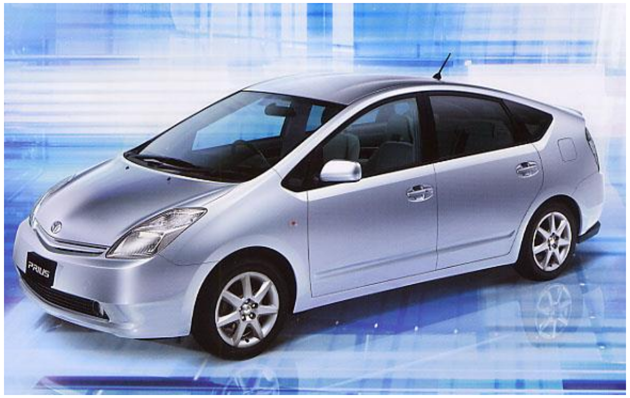
	Growth, %/yr
Year	3 yrs, centered
2001	1.45
2002	0.71
2003	2.05
2004	1.67
2005	1.54
2006	1.54
2007	0.52
2008	-0.95
2009	-0.26

Dashed line: RHS. *New data, EIA*:
http://205.254.135.7/electricity/annual/html/tablees1.cfm

Legacy: U.S. Highway System



Transportation Efficiency Wedges



N liters/100 km ≈ 235/N mpg
So 8 liters/100/km ≈ 30 mpg

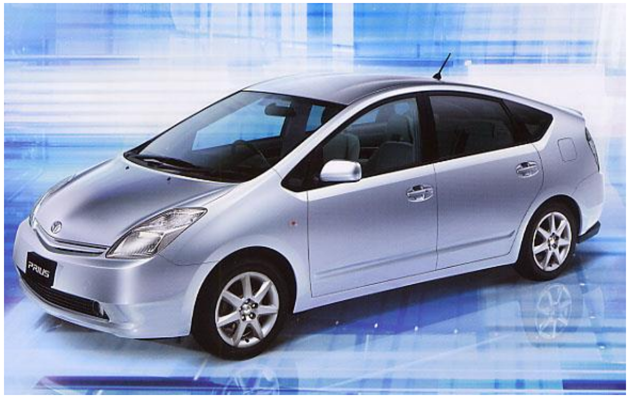
Note: Drive 16,000 km at 8 liters/100km: emit 1 tC (≈ 4 tCO_2)

Efficiency wedge: In 2062, 2 billion cars driven 16,000 km/yr at not 8 but 4 l/100km.

Vehicle-use wedge: IN 2062, 2 billion cars at 8 l/100km, driven not 16,000 but 8,000 km/yr.

2 billion cars at 4 l/100km, driven 8,000 km/yr: 1.5 wedges.

The frontier for motive power



Efficient energy conversion

Combustion, drive train, aerodynamics, rolling resistance

Primary source for traditional fuel (gasoline, diesel, jetfuel)

"Conventional" and "unconventional" crude oil

Synthetic fuel from natural gas, coal, or biomass

Non-traditional "fuel"

Compressed natural gas

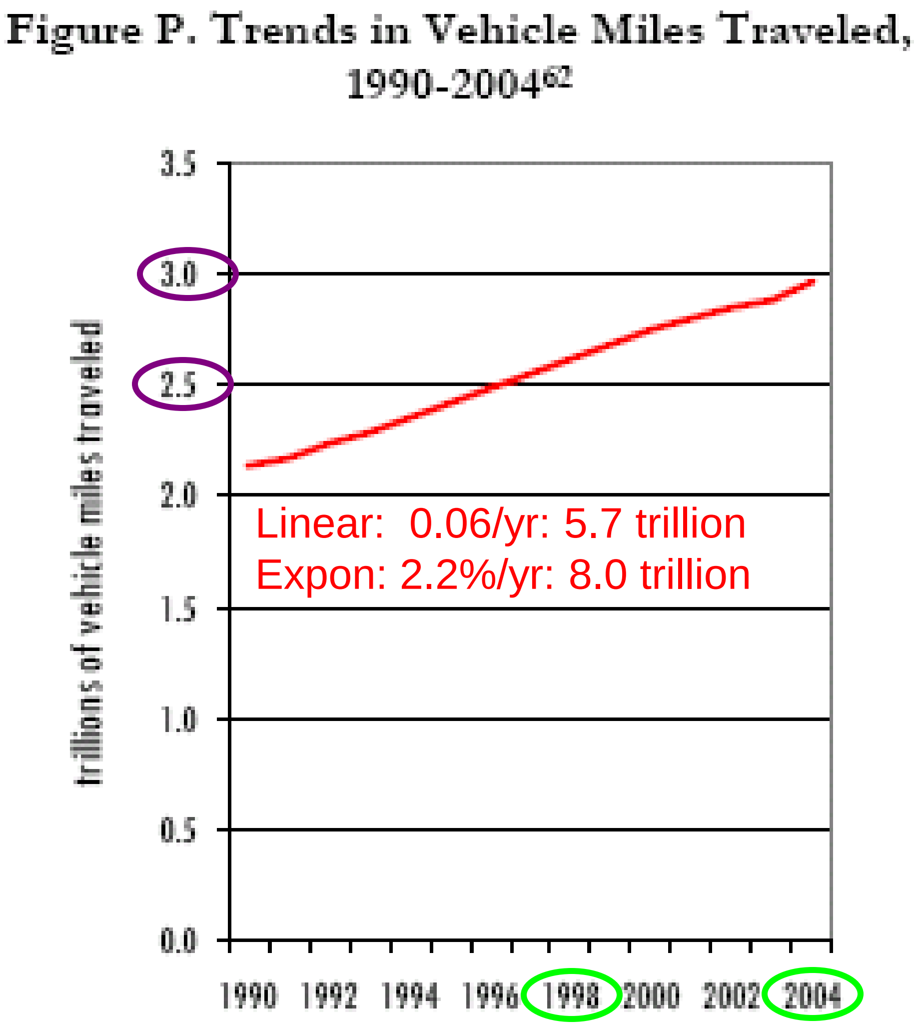
Electrochemical energy (battery or fuel cell)

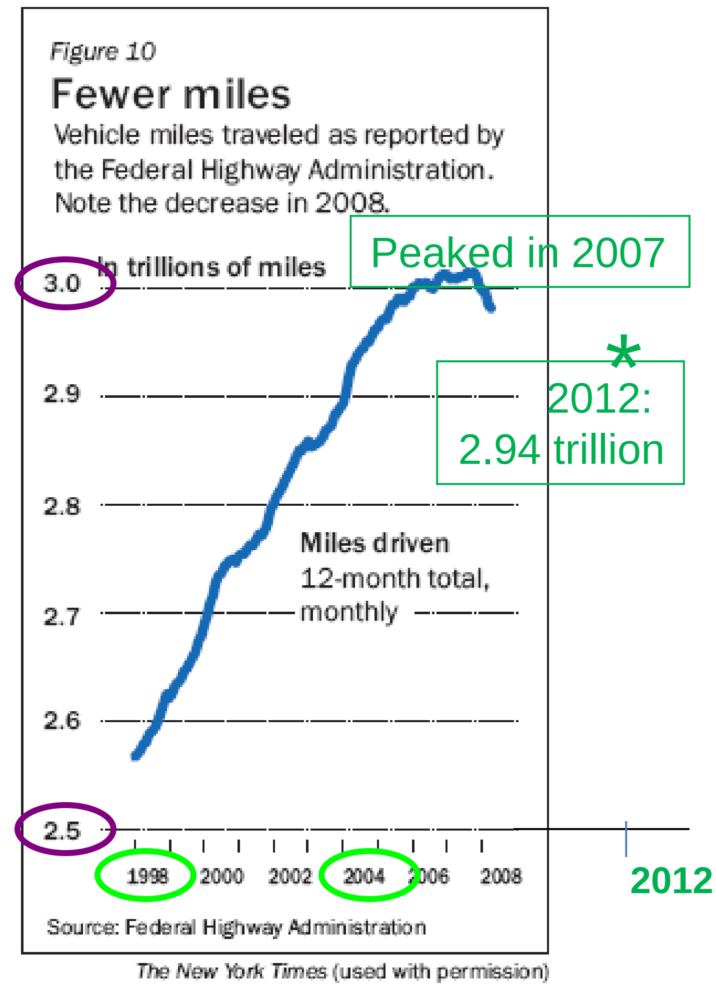
System efficiency

Most cars have only one person in them most of the time.

Many trips can be replaced by information technology.

U.S. vehicle-miles traveled, two views





Sources: *Left*: U.S. PIRG Education Fund, 2007. *The Carbon Boom: State and National Trends in Carbon Dioxide Emissions Since 1990, April 2007* (44 pp.), p. 27. *Right*: American Physical Society, 2008. *Energy Future: Think Efficiency.*

Has energy demand peaked in industrialized countries?

If any industrialized country makes energy efficiency a priority, at least two of its peaks can be in its past:

- oil consumption
- electric power consumption

Efficiency comes in little packages

“The climate problem was created by millions of bad decisions over decades, but climate stability can be restored by millions of sensible choices—buying a more efficient lamp or car, adding insulation or caulk to your home, repealing subsidies for waste and rewarding desired outcomes (for example, by paying architects and engineers for savings, not expenditures).”

Amory Lovins, “More profit with less carbon,” *Scientific American*, September 2005, p. 82.

Ways to drive efficiency investments

Measure, measure, measure: “Trust, but verify”
Focus attention on performance: construction detail, secondary decisions (interior design), operation and maintenance.

Set tough performance standards
Examples: appliance efficiency, interior temperature, light levels

Use price (spot-market, time-of-day) to flatten loads
Stimulate load management and storage technology, behavioral change.

Address poverty via lifeline rates (e.g., for the first 300 kWh/month)
Subsidize retrofit of highly inefficient older buildings of the urban core.

Explanations for limited success: Consumers

Mistrust of information
Biased information
Inaccurate information
Short time-horizons
Limit to the number of things to worry about

Explanations for limited success: Industry and government

Distraction from key mission
Out of comfort zone
Annual budgets (governments, especially)
Principle-agent problems and split incentives (landlord-tenant)
Limit to the number of things to worry about

Explanations for limited success: Systems

Take-back effects (better insulation yields a warmer house with same energy use)

Rebound effects (higher fuel economy means more driving)

Budget effects (better insulation means money to buy a new appliance)

The technology-behavior axis.

1. Slot-in technology, no changes observable to the consumer (more efficient aircraft engine, extra wall insulation).
2. Technological change, with benefits and costs to consumer (low-flow shower-head, compact fluorescent bulb)
3. Social and technical change (video-conference instead of business trip, on-line shopping)
4. Predominantly societal change (revival of cities reverses suburbanization, higher prices on energy)
5. Change in individual preferences (smaller families, reduced meat consumption, increased use of public transportation, warmer temperatures indoors in summer are acceptable)

Land-use wedges

1. Emissions from land-use change

2. Carbon management via biocarbon

3. Food-energy couplings, present and future

Agriculture and Climate Change
Impacts, contributions and implications for feeding 9 billion people

David Kanter
Guest contribution
WWS 585b – November 28, 2012

A few slides are here.

Kanter's full set is on Blackboard 2013 in "L8 Supplement."

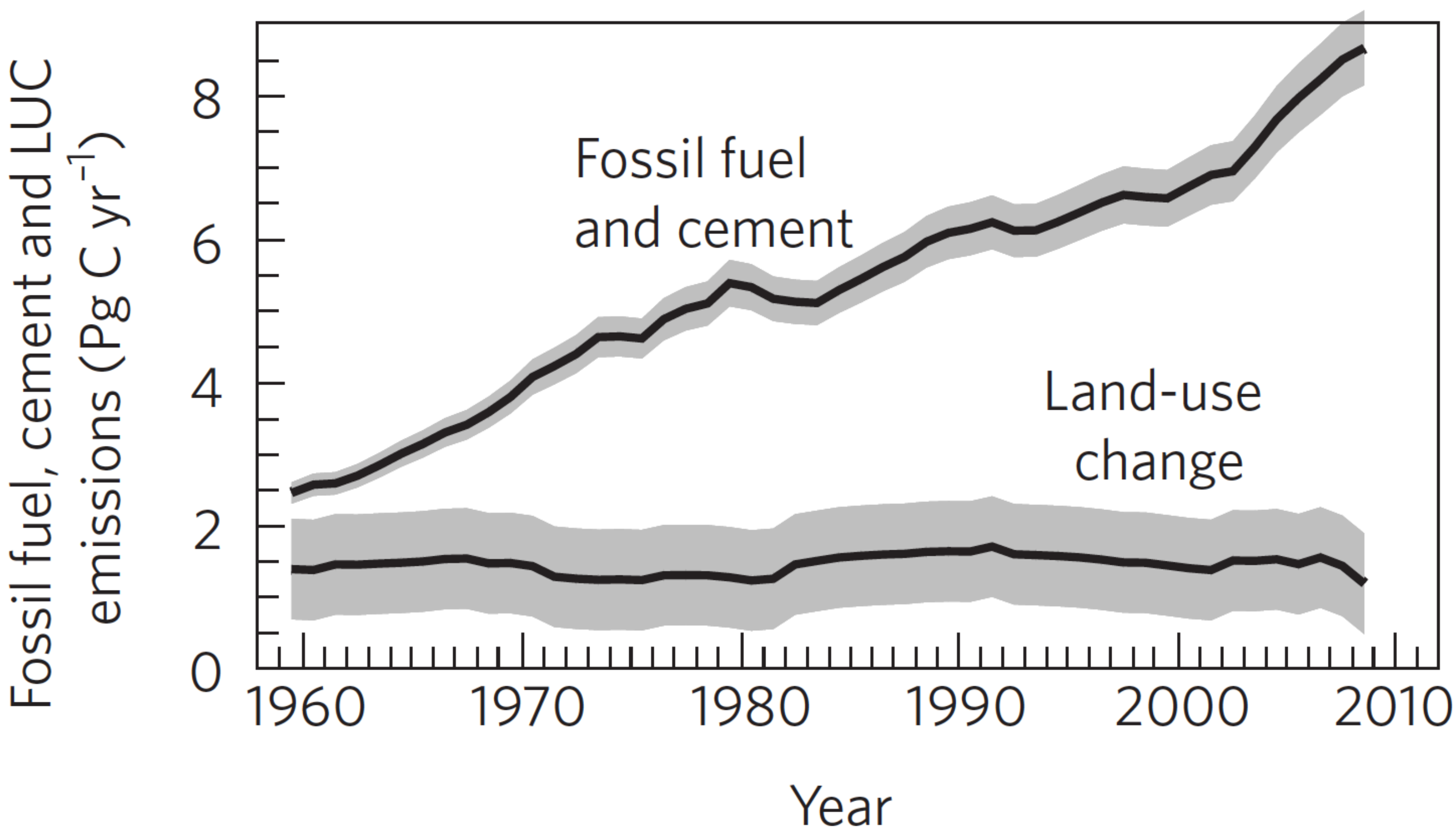
Bioenergy as a climate change mitigation technology

Felix Creutzig
Guest contribution
WWS 585b – November 28, 2012

A few slides are here.

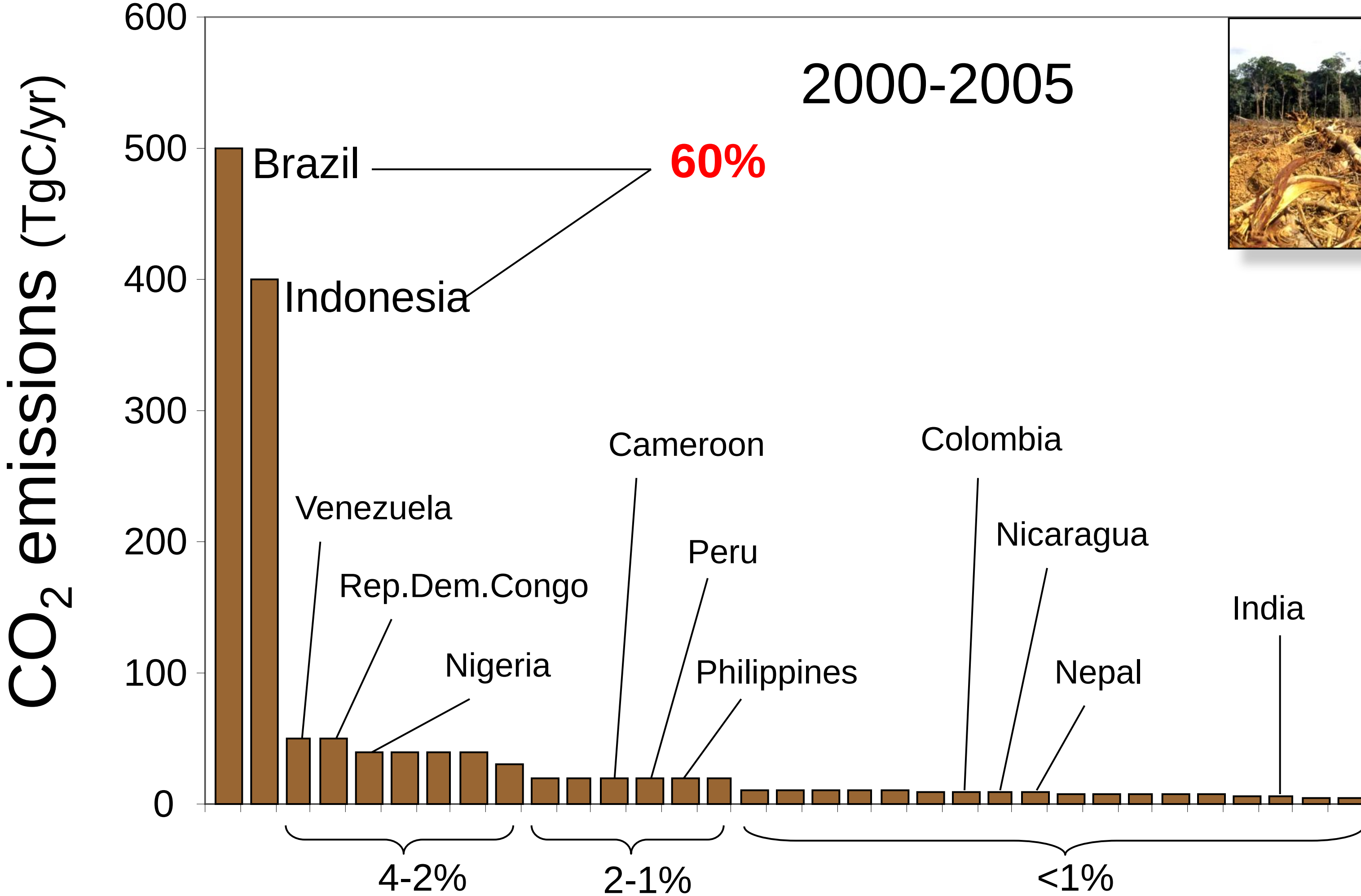
Creutzig's full set is on Blackboard 2013 in "L8 Supplement."

Land use change emissions have remained relatively constant over time



Le Quéré et al. (2009)

Net CO_2 emissions from land use change in tropical countries



Source: Sarmiento (privately), from RA Houghton 2009, unpublished, based on FAO land use change statistics

Biocarbon and fossil carbon

Can’t tell the difference (except C^{12}, C^{13}, C^{14} ratios).

Land use concerns and energy concerns are merging.

Biocarbon accounting is sometimes perverse, neglecting “carbon debt.”

The interplay is already in view for world energy, world oil, world hunger, and climate change.

Biocarbon

Back of the envelope:
Yield: 10t/ha-yr
Energy content: 20 GJ/t
So 200 GJ/ha-yr
Equivalently: **200 EJ/Gha-yr**

Global primary energy: 500 EJ/yr
All of U.S. (1 Gha) "makes" 200 EJ/yr.

Traditional objectives

- Biofuel to displace oil
- Biopower to displace power from coal and natural gas

Scrubbing CO_2 from the atmosphere

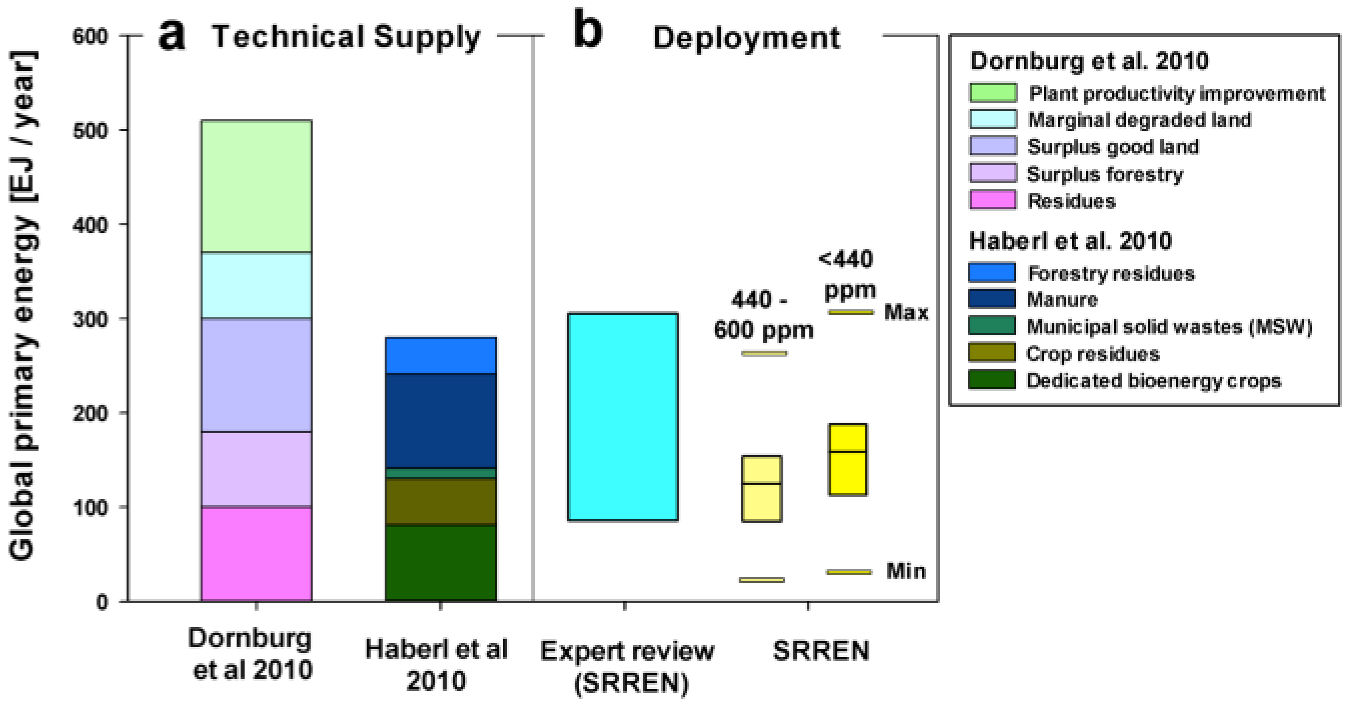
- Biopower with CO_2 capture and storage
- Biocarbon stock augmentation (afforestation)

Net primary production: technical potential from the land

- Benchmark: Current annual global energy consumption: 500 EJ, growing
- Currently: ca. 50 EJ from biomass
- Carbon cycle: 2000 EJ in carbon absorbed by terrestrial plants every year, another 2000 EJ by marine plants (algae)
- This carbon is returned to the atmosphere via respiration, rot, wildfires, etc.
- The question is which part of this carbon cycle can be accessed economically, and without destroying crucial ecosystem services, and food production

Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012

“Significant” primary bioenergy is measured in 100s of EJ/yr



Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012.
Citation: Creutzig *et al.*, 2012

Inputs to biomass calculations

Areas

World surface area: 5×10^{14} m^2 = 50,000 Mha
Land area: 1.5×10^{14} m^2 = 15,000 Mha
Cropland (≈ 10% of land area): 1500 Mha
U.S. land area (50 states) 1000 Mha

Yields (tons of dry biomass per hectare per year): hares and tortoises

Plantations for carbon storage: steady, slow growth, 50 years:
2 to 10 t/ha-yr (Steady state of 100 to 500 t/ha)

Plantations for biofuels: fast growth for short periods (1 - 5 years), frequent harvesting:
10 to 50 t/ha-yr. (Issues: fertilizer, irrigation)

Energy content*:* 15 GJ/t for grasses, 20 GJ/t for wood (lignin is like oil)

Carbon content*:* 0.5 tC/t biomass

Biomass as primary energy

Land for primary energy

Land in plantations to produce **100 EJ/yr** (≈ U.S. today, ≈ 25% of global primary energy today)

Inputs: 10 to 50 t/ha-yr @ 20 GJ/t: thus 0.2 to 1 TJ/ha-yr.

Result: **100 to 500 Mha**.

Note the inefficiency of photosynthesis. What is the **conversion efficiency** for solar energy to bioenergy for yields of 10 to 50 t/ha-yr?

Assume average flux of incident sunlight is 300 W/m^2 = 100 TJ/ha-yr.

Result: **0.2% to 1%** conversion efficiency.

Energy density (GJ/ha/y) is much higher for wind and solar than for bioenergy

Beets are mostly water

Table 8
Input and outcomes of case study.

Region	Input		NED GJ/ha/y	Distance driven[a] 10^4 km
Bioethanol from sugar beet				
SE	47[b]	t/ha/y	10.9	0.55
NL	62[c]	t/ha/y	15.5	0.78
ES	27[d]	t/ha/y	4.8	0.24
Biodiesel from rapeseed				
SE	2.9[e]	t/ha/y	18.8	1.1
NL	3.7[c]	t/ha/y	24.6	1.5
ES	1.3[f]	t/ha/y	7.2	0.43
Electricity from wood				
SE	2.4[g]	t/ha/y	12.3	2.0
NL	2.8[h]	t/ha/y	14.4	2.4
ES	0.5[i]	t/ha/y	2.5	0.41
Electricity from wind				
SE	7.0[j]	m/s	978	160
NL	6.8[j]	m/s	927	151
ES	5.1[j]	m/s	490	80
Electricity from solar PV				
SE	824[k]	kWh/kWp	356	58
NL	873[k]	kWh/kWp	421	69
ES	1473[k]	kWh/kWp	1213	198

Table notes: NED=net energy density;
SE, NL and ES refer to rural areas of Sweden, Netherlands and Spain, respectively.

Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012. *Citation:* Dijkman, T. J., and R. M. J. Benders. *Renewable and Sustainable Energy Reviews* 14.9 (2010): 3148-3155.

Bioenergy from forestry residues	Biomass from silvicultural thinning and logging, and wood processing residues such as sawdust, bark and black liquor. Dead wood from natural disturbances, such as storms and insect outbreaks, represents a second category. Environmental effects of primary residue removal depend on land management practice and local conditions, and removal rates need to be controlled considering local ecosystem, climate, topography, and soil factors.
Bioenergy from forest unutilized forest growth	Biomass from growth occurring in forests judged as being available for wood extraction, which is above the projected biomass demand in the forest industry. Includes both biomass suitable for, e.g., pulp and paper production and biomass that is not traditionally used by the forest industry.
Bioenergy from forest plantations and agroforestry	Includes biomass from woody plants grown in short-rotation coppice or single stem plantations (e.g., willow, poplar, eucalyptus, pine). Both monoculture plantations and mixed production systems including agroforestry are included.

Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012

Bioenergy from crop residues	Use of crop residues for Bioenergy; Use of by- products associated with crop production and processing, both primary (e.g., cereal straw from harvesting) and secondary residues (e.g., rice husks from rice milling) to produce bioenergy.
Bioenergy from dedicated crops	Cultivation of high yielding crops specifically designed for energy end use. Includes cultivation of both conventional agriculture crops and bioenergy feedstock plants such as oil crops (e.g., Jatropha), grasses (e.g., switchgrass, Miscanthus).
Bioenergy from manure mgt (Biogas)	Animal dung from confined livestock production. Currently dung is often burned directly as a cooking fuel in many developing countries. Dung can be converted to biogas in biodigesters.
Bioenergy from Organic Wastes	A heterogeneous category that can include, e.g., organic waste from households and restaurants, discarded wood products such as paper and demolition wood, and wastewaters suitable for anaerobic biogas production.

Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012

Biomass for CO_2 removal (CDR)

Two bio strategies for CDR

Biopower with CCS (BECCS)

Afforestation

Land for afforestation, removing 1 ppm/yr from the atmosphere

Inputs:

10 t biomass/ha-yr (for 50 years)

0.5 tC/t biomass.

1 ppm = 2 GtC

Result: **400 Mha**. (Recall: U.S. area is 1000 Mha.)

BECCS

- BECCS: Bioenergy Carbon Capture and Storage
- Produce energy from biomass and store the CO2 emissions underground
- High uncertainty on costs and storage availability
- Same post-capture issues as fossil fuel CCS (transition to L9)

Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012

Biomass supply complexities

"Dry" biomass

Drying can require significant energy inputs.

Residues

Residues of commercial forestry (slash) and agriculture (rice husks, corn stover), in principle, can become biomass feedstocks. The need to sustain soil nutrients (N, P, …) will limit residue use.

Unavailable land

Steep slopes
Stream banks
Urban areas
Wilderness (deliberately left unmanaged)

Net energy, net carbon

In the back-of-the envelope calculations of land requirements biomass "overheads" are often neglected.

In energy conversion, energy inputs are neglected.

In carbon conversion, carbon inputs are neglected.

Land use/climate change complexities

***If climate change is what matters*:**

Direct emissions of CO_2 in biomass system

- Fertilizer, tractors, distillation

Indirect land use change (ILUC) -- requires planetary analysis

- Conversion of forest managed for pulp and paper to forest for carbon storage may lead to forest conversion to pulp and paper elsewhere.
- Conversion of land for fodder (for corn, soybeans) to land for bioenergy may lead to forest clearing elsewhere to produce equivalent fodder.
- Conversion of pasture to bioenergy may elicit feedlot cattle-raising and land clearing for fodder.

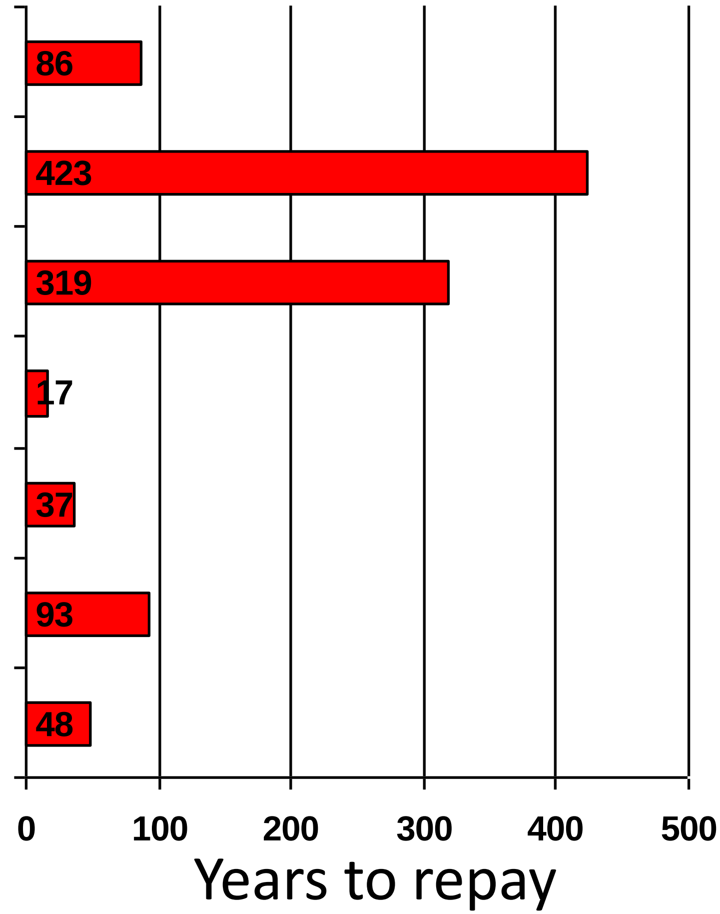
Evapotranspiration change

Emissions of CH_4, N_2O

Albedo change

Time reqired to repay carbon debt

Tropical rainforest	Palm biodiesel (> 85% of global palm production)	Indonesia/ Malaysia
Peatland rainforest		
Tropical rainforest	Soybean biodiesel	Brazil
Cerrado wooded	Sugarcane ethanol	
Cerrado grassland	Soybean biodiesel	
Central grassland	Corn ethanol	US
Abandoned cropland		



Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012
Citation: “Land Clearing and the Biofuel Debt,“ Fargione et al., 2008.
Slide courtesy of Heiner von Bothmer.

Biomass as fuel

Land for oil

If oil is what matters, everything that grows is a potential liquid-fuel feedstock.

Land in plantations to produce the feedstock for biomass synthetic fuels plants for **1 million barrels per day** (mbd) of fuels:

Examples: sugar cane to ethanol, palm oil to diesel

Assume 10,000 liters/ha-yr (above what can be done today)
(100 liters/t biomass * 100 t biomass/ha-yr)

1 mbd = $365 \times 10^6 \times 150$ liters/yr = 50×10^9 liters/yr.

So, **5 million hectares for 1 mbd**. A very different ballpark.

If liquid fuel is the objective, inputs of coal and natural gas do not need to be charged against the liquid-fuels balance. But these inputs could have become fuels by direct conversion (CTL, GTL).

AR5 WG2 leak: food impacts of climate change

On the food supply, the new report finds that benefits from global warming may be seen in some areas, like northern lands that are now marginal for food production. But it adds that over all, global warming could reduce agricultural production by as much as 2 percent each decade for the rest of this century.

During that period, demand is expected to rise as much as 14 percent each decade, the report found, as the world population is projected to grow to 9.6 billion in 2050, from 7.2 billion today, according to the United Nations, and as many of those people in developing countries acquire the money to eat richer diets.

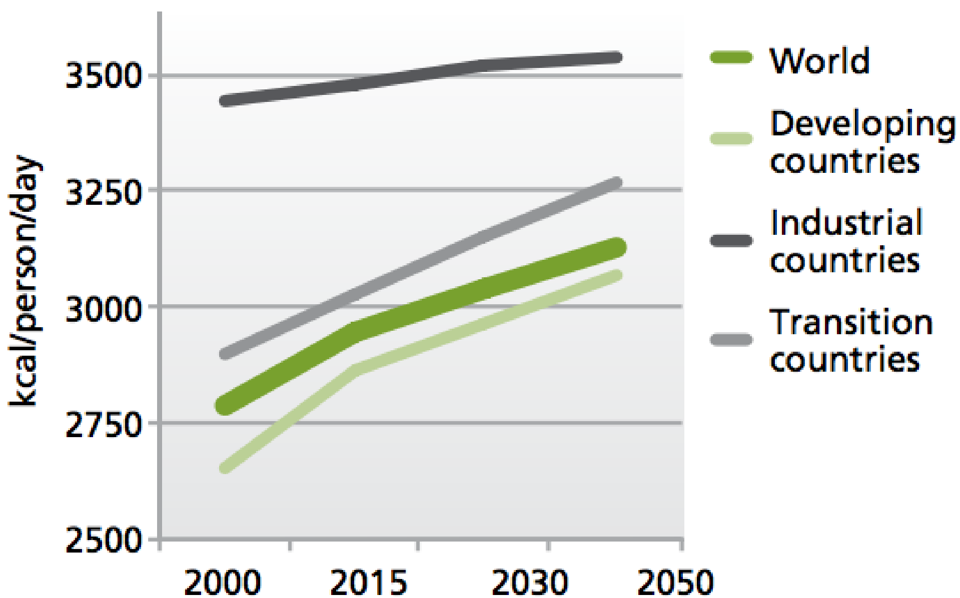
Any shortfall would lead to rising food prices that would hit the world's poor hardest, as has already occurred from price increases of recent years. Research has found that climate change, particularly severe heat waves, was a factor in those price spikes.

The agricultural risks "are greatest for tropical countries, given projected impacts that exceed adaptive capacity and higher poverty rates compared with temperate regions," the draft report finds.

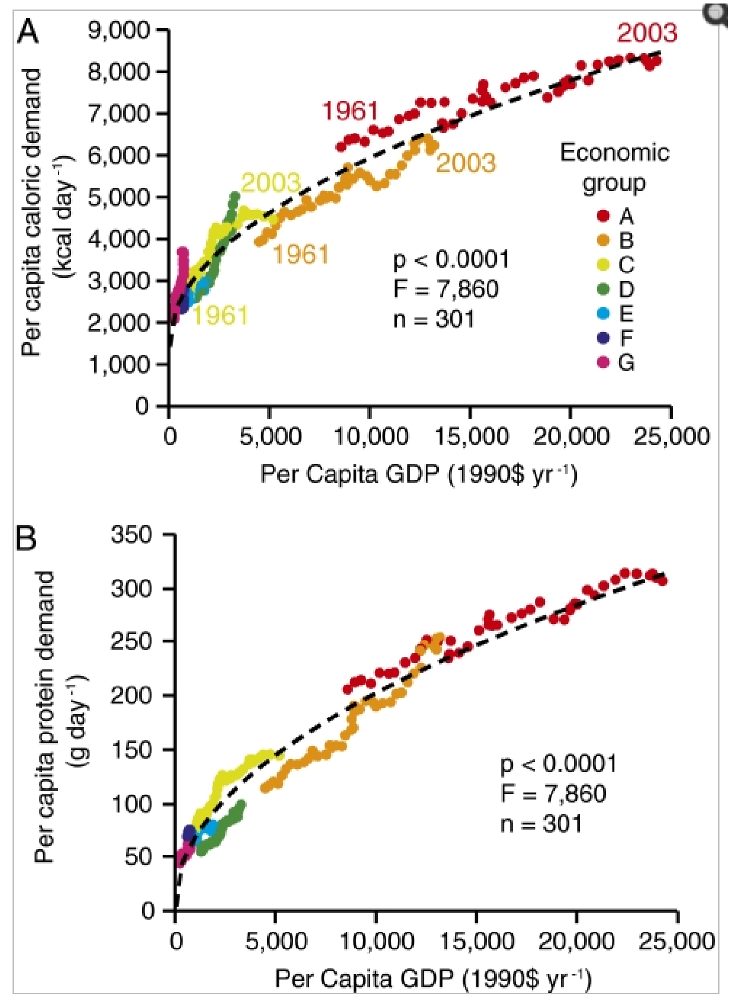
If the report proves to be correct about the effect on crops from climate change, global food demand might have to be met — if it can be met — by putting new land into production. That could entail chopping down large areas of forest, an action that would only accelerate climate change by sending substantial amounts of carbon dioxide into the air from the destruction of trees.

Source: Justin Gillis, "Climate change poses risk to food supply." *New York Times*, Nov. 1, 2013, p. 1.

Population *and* per capita consumption projected to increase



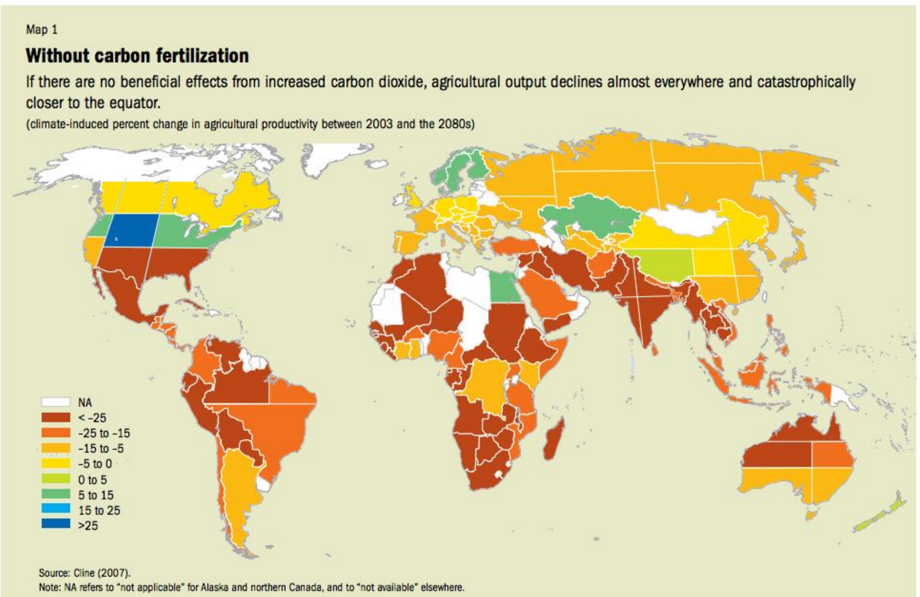
By 2050, people will be eating 60 percent more food, increasing the demand for, and prices of, agricultural products. Source: FAO, 2006[1]

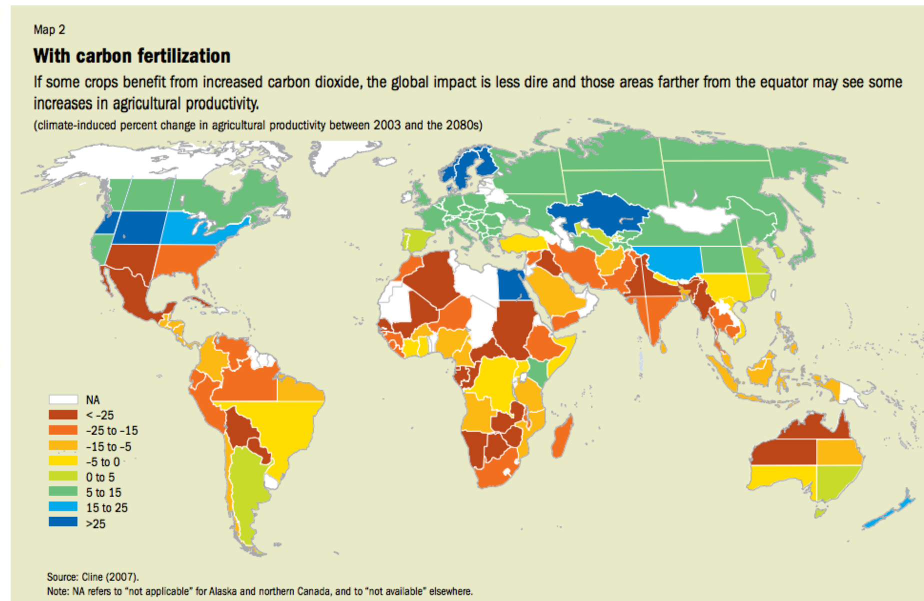


Source: David Kanter, Guest contribution WWS 585b – Nov. 28, 2012

Meridian Institute, 2011; *Tilman et al. 2011*

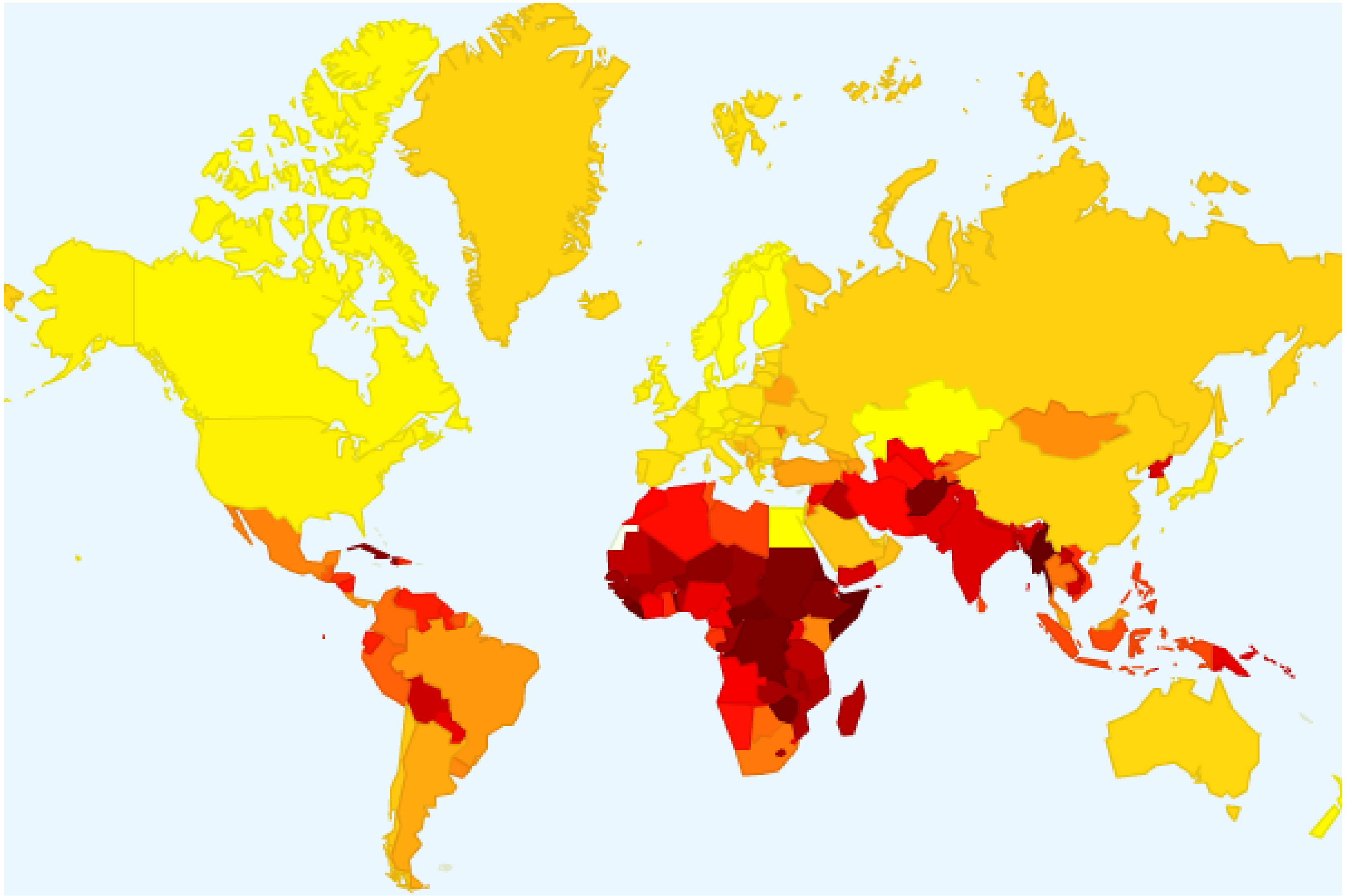
Climate impacts on agricultural productivity
without and with CO_2 fertilization





Source: David Kanter, Guest contribution
WWS 585b – Nov. 28, 2012

Poorest most vulnerable



Rank 1 169

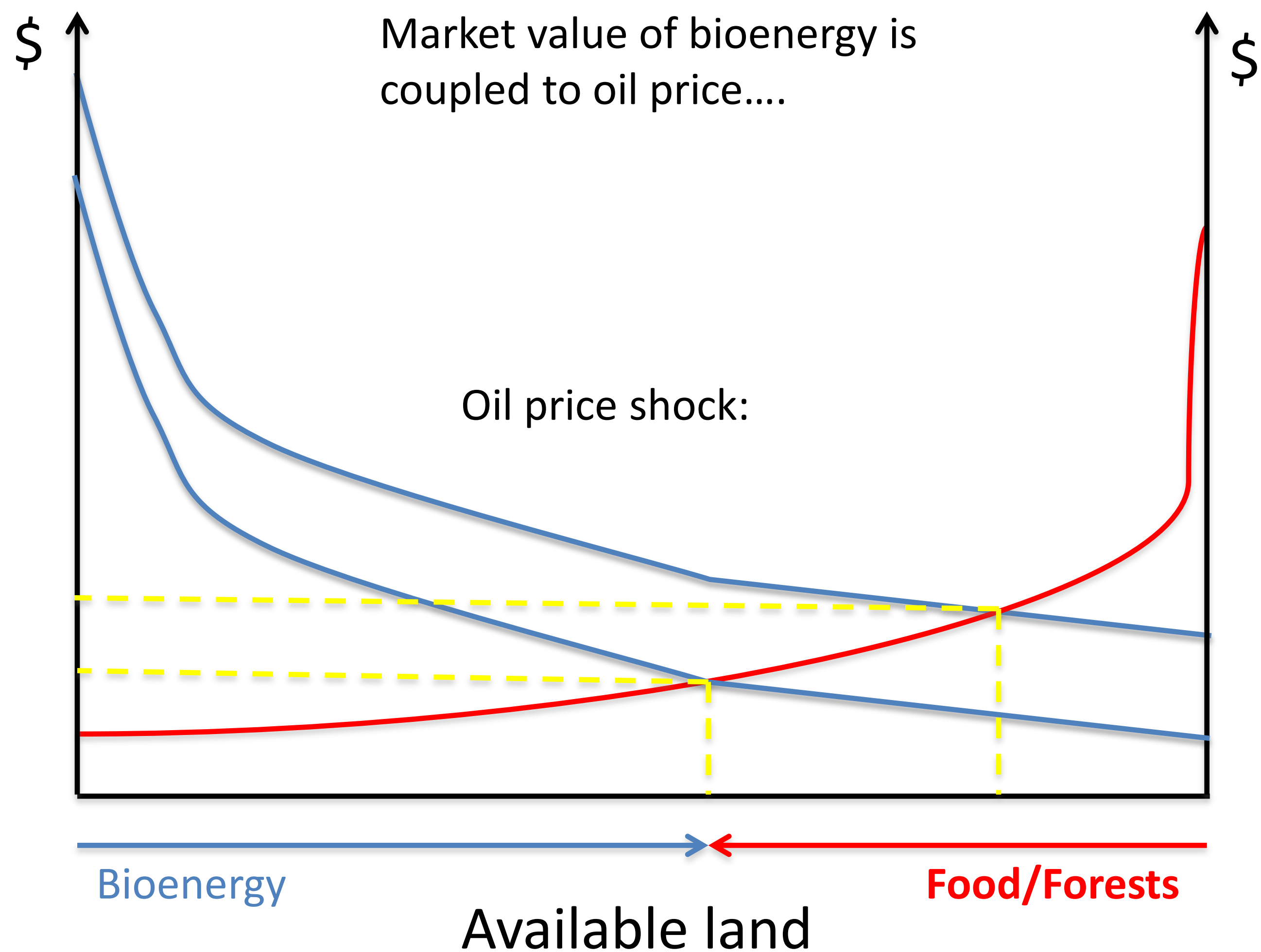
Agricultural Productivity Loss Overall Vulnerability:
Physical Impacts Adjusted For Coping Ability

1. Somalia
2. Myanmar
3. Burundi
4. Liberia
5. Central African Republic
6. Zimbabwe
7. Eritrea
8. Guinea-Bissau
9. Congo, Dem. Rep.
10. Afghanistan
11. Sudan
12. Sierra Leone
13. Ethiopia
14. Togo
15. Cuba
16. Rwanda
17. Niger
18. Guinea
19. Haiti
20. Malawi

Source: David Kanter, Guest contribution
WWS 585b – Nov. 28, 2012

Center for Global Development
Mapping the Impacts of Climate Change

Coupling of energy and land markets



Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012

Summary: bioenergy impacts

	Benefits	Harms
green house gases	low	high
poverty	• more jobs, • improved infrastructure	• less food/ food insecurity, • little labour needed, • if hired - low salaries,
environment	• upgrade marginal/ in-fertile land	• biodiversity loss, • land use change (deforestation, drainage of wetlands etc.), • soil degradation, • influence of pesticides
energy security	• resource “land” more or less available in all parts of the world (in contrast to fossil fuel)	

Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012

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energy security	• resource "land" more or less available in all parts of the world (in contrast to fossil fuel)	What would you put here?

Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012

Key conditionalities

	Condition	Failure of condition
Land-intensity	Produce bioenergy by land-intensive biomass, not by land expansion	• Land carbon loss • Biodiversity loss • Competition with food
Food demand	Reduce consumption of red meat	• Less land available for bioenery crops • →see above
Costs	Reduce costs of cellulosic biofuels	• Not economically viable OR • False options chosen • → see above
Regulation	Global forest/peatland protection	• Very high risks of "leakage" • → see above
Labor and value chain	Rural communities take part in value chain, get labor, ownership & keep land rights	• Disempowerment • Inequality • Exclusion

Source: Felix Creutzig, Guest contribution, WWS 585b – Nov. 28, 2012

Conditionality for biocarbon

What will go wrong if we move headlong to maximize either global biostocks or global biofuels without conditionalities?

Suppose you were a forester or an agronomist in a world where the carbon price was very high. You were told that storing carbon was your only objective. What would you do? Establish a monocrop? Pour on fertilizer? Be inventive.…

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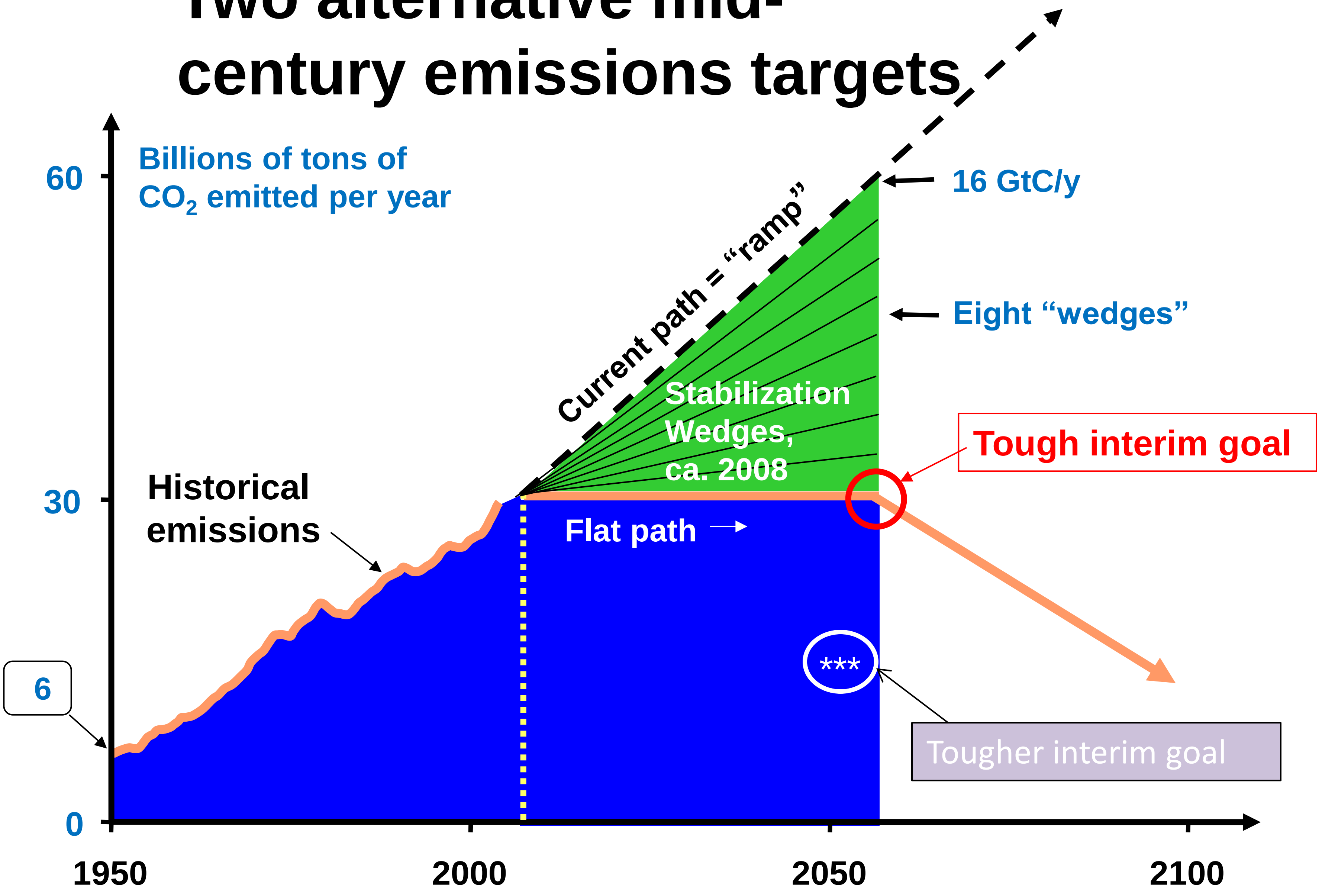
Now, change roles. You are the policy maker in the same world. What conditionalities would you place on the carbon market for biostocks in the interest of eliciting actions you would welcome and deterring out comes you would decry?

EXTRA SLIDES

Two alternative mid-century emissions targets



Carbon in fossil fuels by region, 1860-91

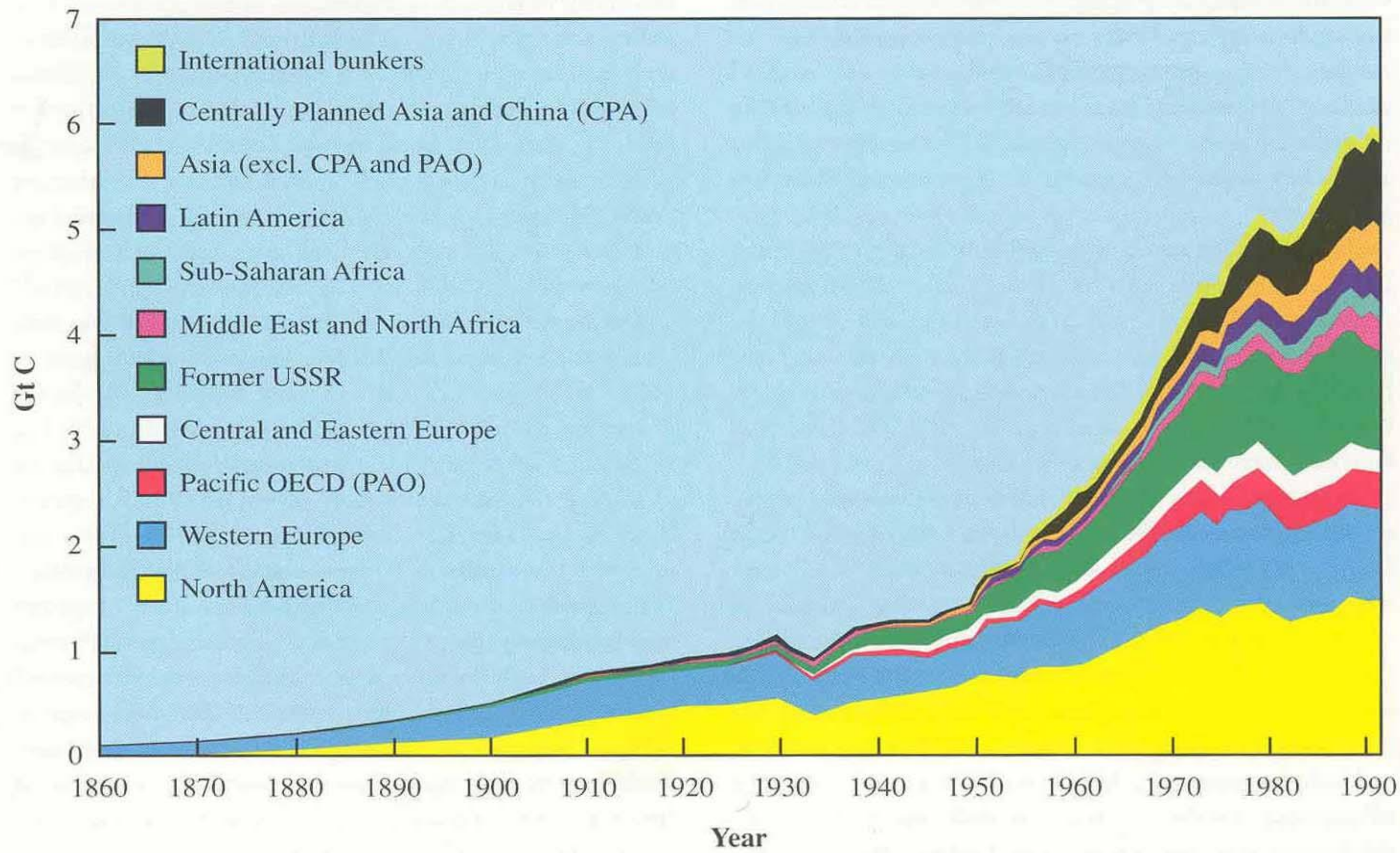
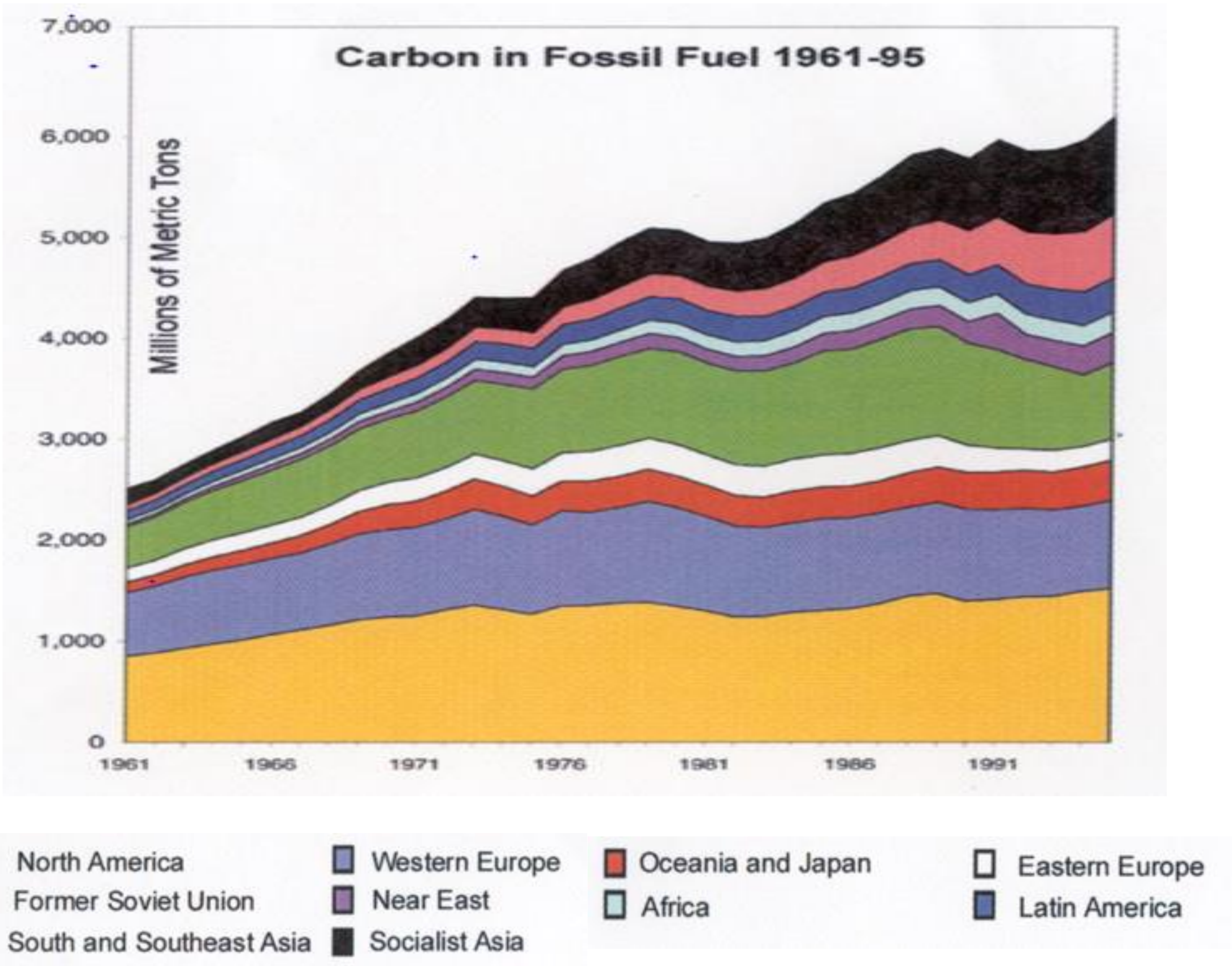


Figure 4: *Global energy-related CO_2 emissions by major world region in Gt C/yr (see the Energy Primer in the Working Group II SAR volume).*

Carbon in fossil fuels by region, 1961-95



McKinsey abatement curve