Technologies for Living in a Greenhouse

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Energy Leadership Lecture Series
co-hosts: Institute for Energy Efficiency
and Kavli Institute for Theoretical Physics
University of Santa Barbara

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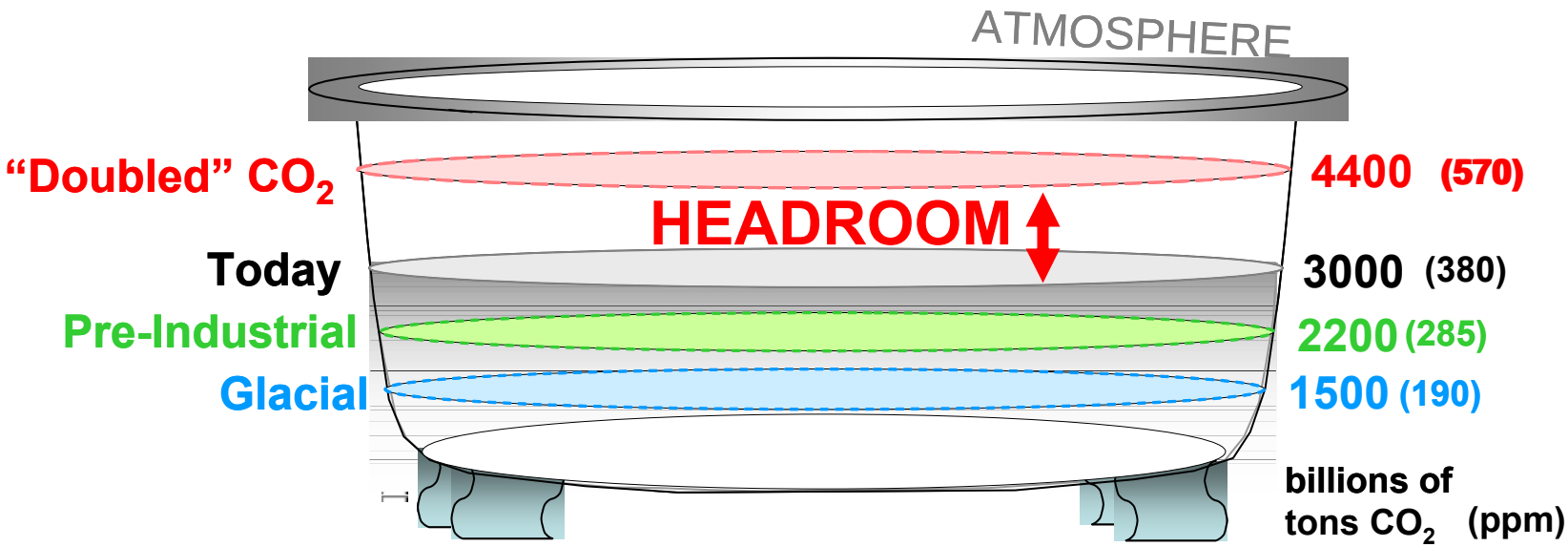
Past, present, and potential future levels of carbon in the atmosphere

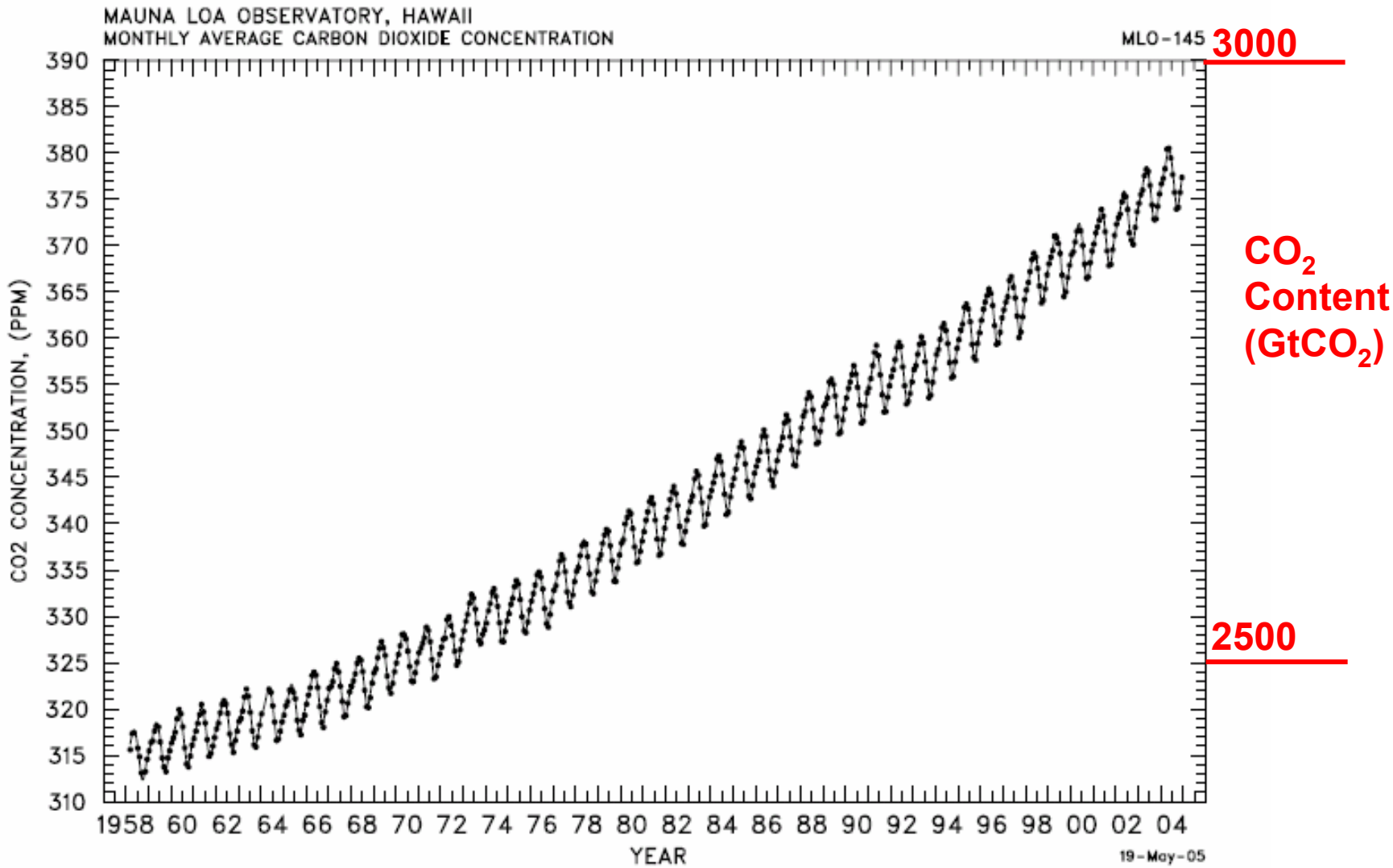


Rosetta Stone: To raise the concentration of CO_2 in the atmosphere by **one part per million:**

add **7.7 billion tons of CO_2,**

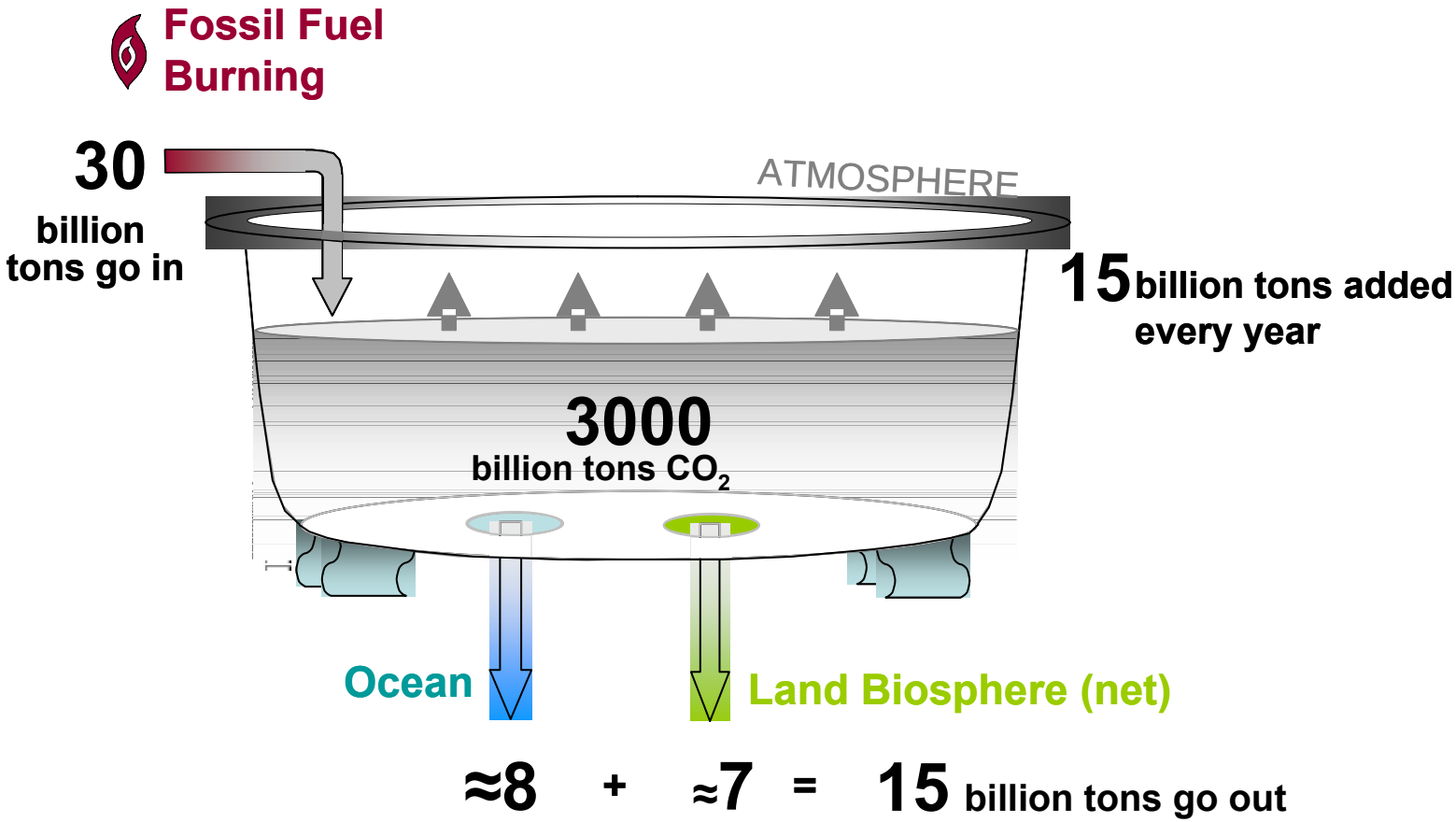
in which are **2.1 billon tons of carbon.**

Mauna Loa CO_2 data, 1958-2004



Source: Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center
http://cdiac.ornl.gov/trends/co2/graphics/mlo145e_thrudc04.pdf

About half of the carbon we burn stays in the atmosphere for centuries



Today, global per-capita emissions are ≈ 4 tCO_2/yr.

Four ways to emit 4 tonCO_2/yr

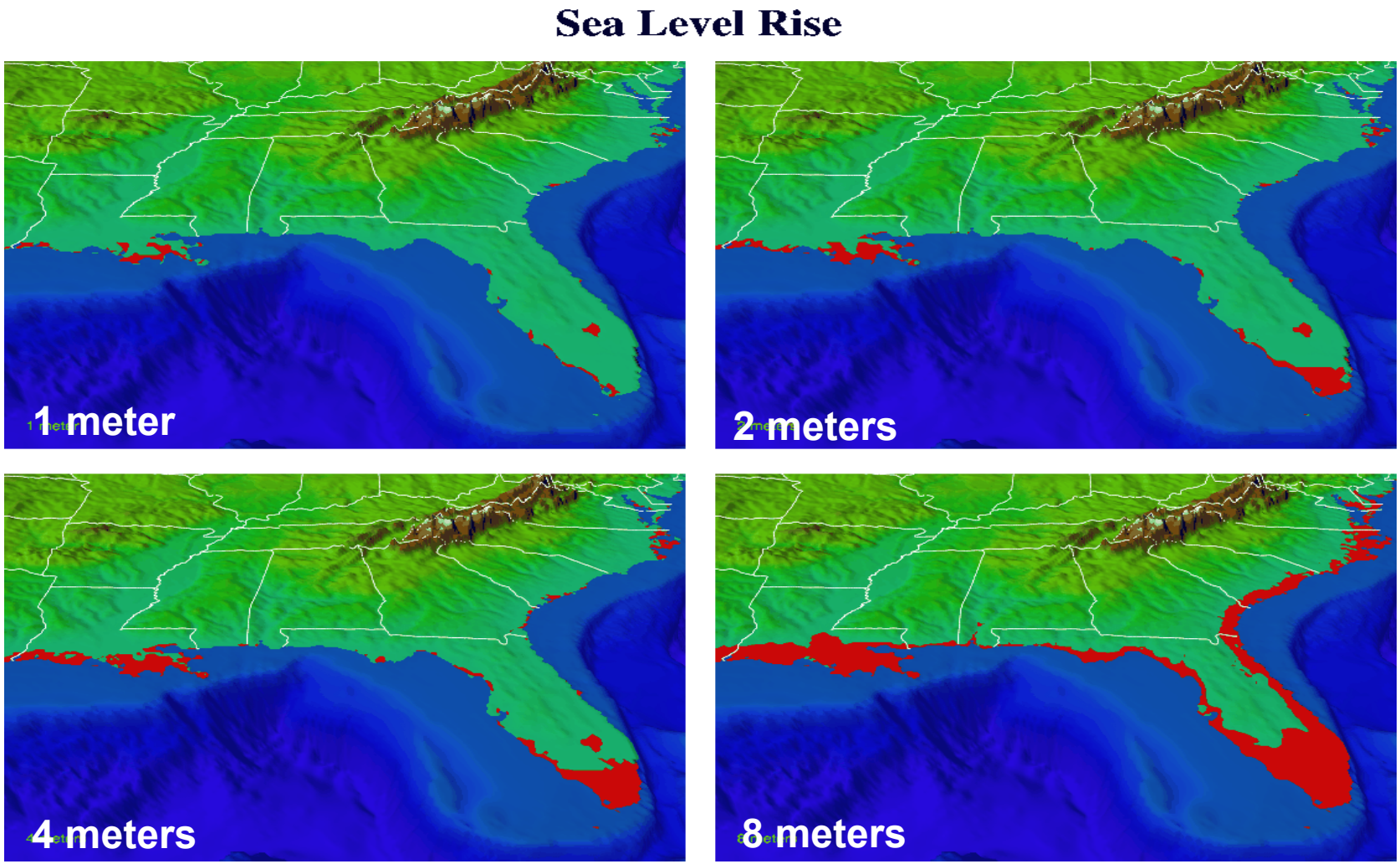
Activity	**Amount producing 4 ton CO_2/yr emissions**
a) Drive	10,000 miles/yr, 30 miles per gallon
b) Fly	10,000 miles/yr
c) Heat home	Natural gas, average house, average climate
d) Use lights and appliances	300 kWh/month when all coal-power (600 kWh/month, natural-gas-power)

Effects of Global Warming

- Climate Change
  - Gradual change (temperature, rainfall)
  - Extreme events (hurricanes, droughts)
- Surface Ocean Change
  - Warmer, fresher, more acidic
- Sea-level Rise, due to
  - Glacial melting
  - Thermal expansion of water
- Changes to Ecology
- Disease Vectors, spreading to new places

Which effects are going to be most salient, when various publics weigh how much mitigation to pursue? VOTE!

Greenland: 7 meters.
West Antarctica : 5 meters



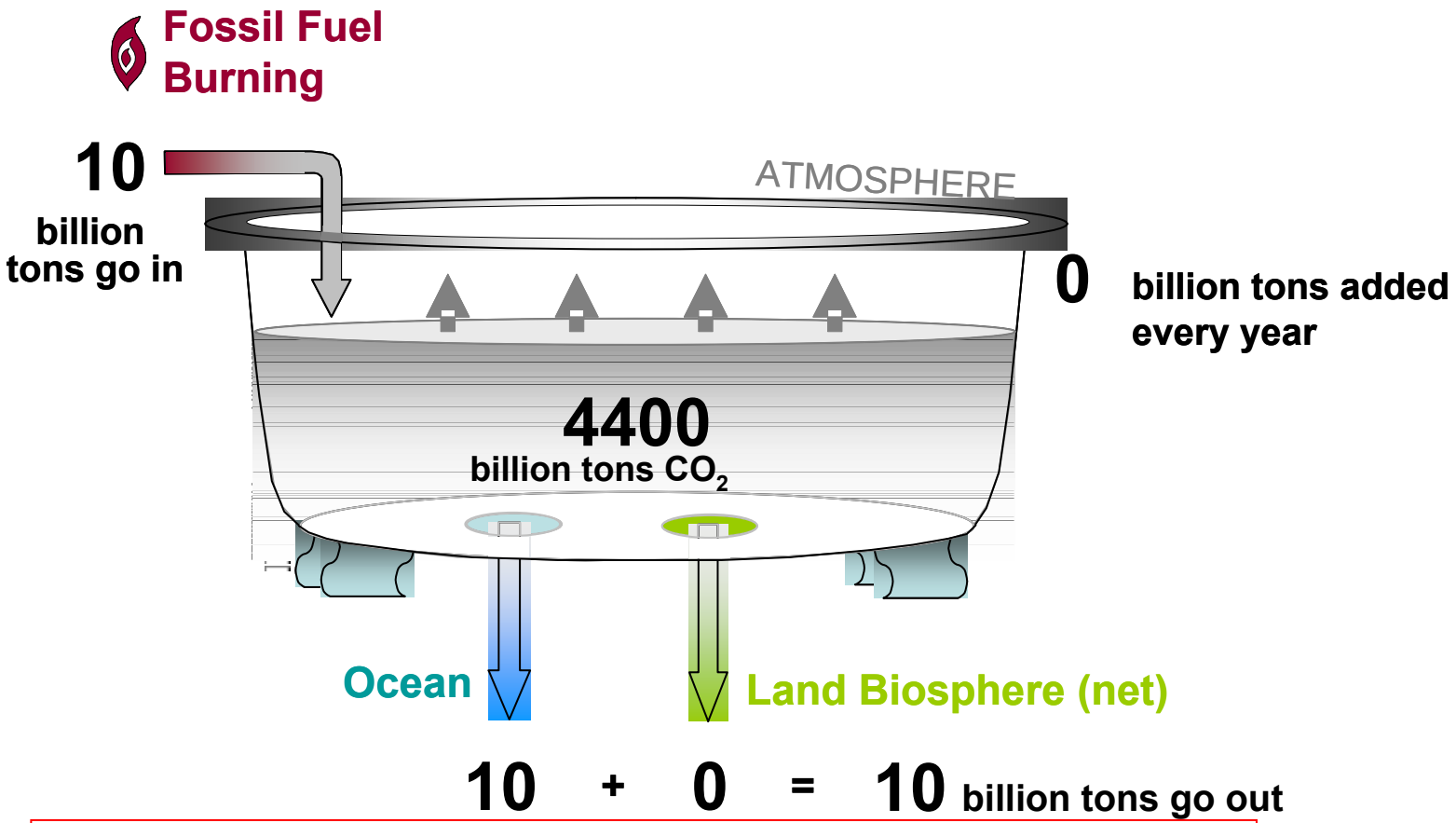
Our current climate is privileged

The choices of our civilizations reflect particular environmental circumstances.

We planted crops where the rain fell and built our cities near rivers and coasts. So, sea level rise means moving inland.

Ahead is distraction and disruption, but survival is not at stake.

At “stabilization,” allowed emissions are about one-third of today’s.



Shown here: Stabilization at double the pre-industrial concentration.

Common Misunderstanding #1

It is *not* sufficient to limit emissions in the prosperous parts of the world and allow the less fortunate to catch up. Such an outcome would overwhelm the planet.

The carbon emissions per capita in a climate-stabilized world, *not much more than 1 ton of CO_2 per year*, are ten times less than those of the average American today.

The emissions of the future rich must equal the emissions of today's poor, …

…not the other way around.

“Never in history has the work of so few led to so much being asked of so many!”

Nonetheless, grounds for optimism:

- The world today has a terribly inefficient energy system.
- Carbon emissions have just begun to be priced.
- Most of the 2058 physical plant is not yet built.

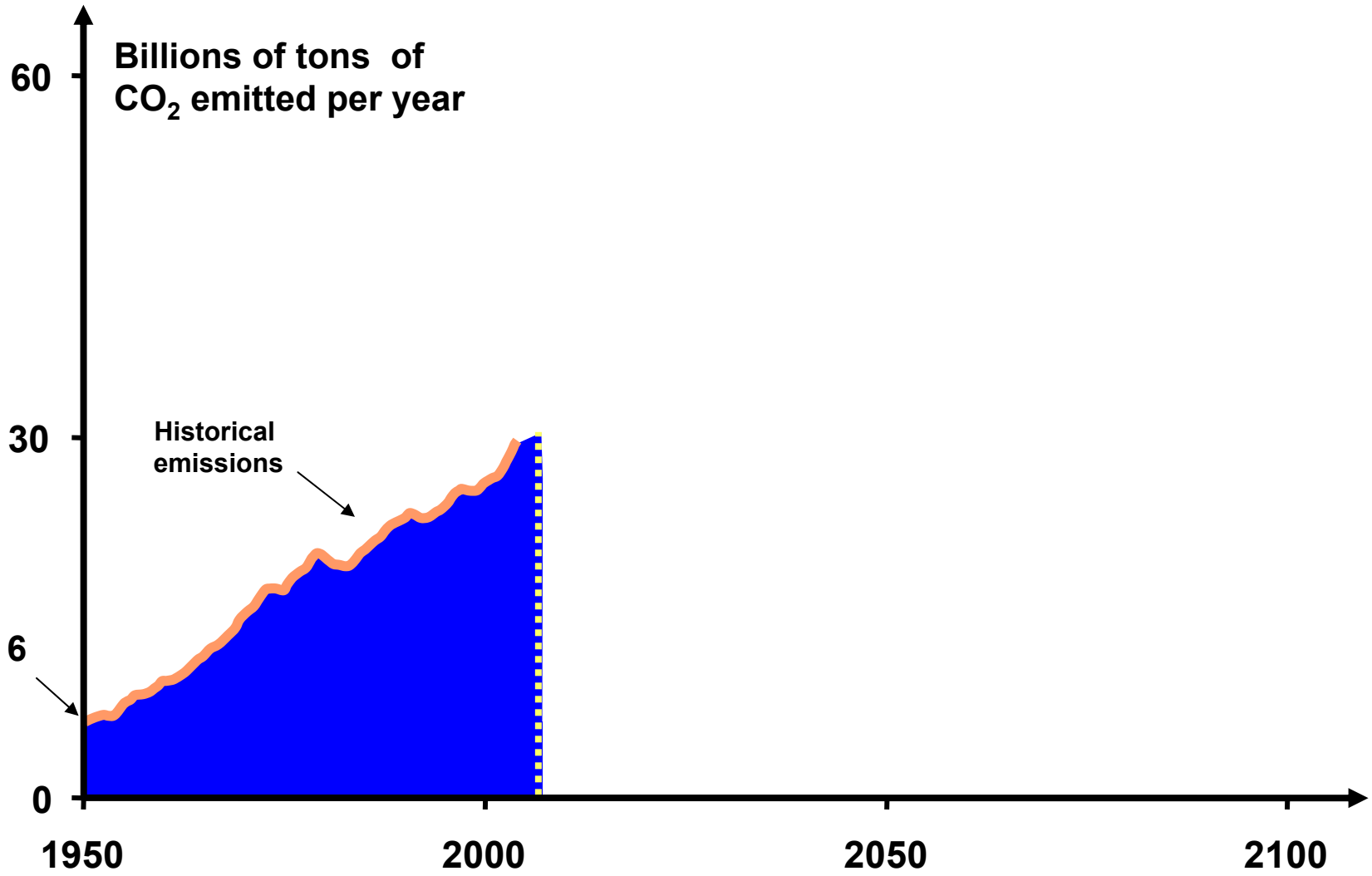
Outline of Talk

1. **The Wedges Model: A simple quantification of carbon mitigation**

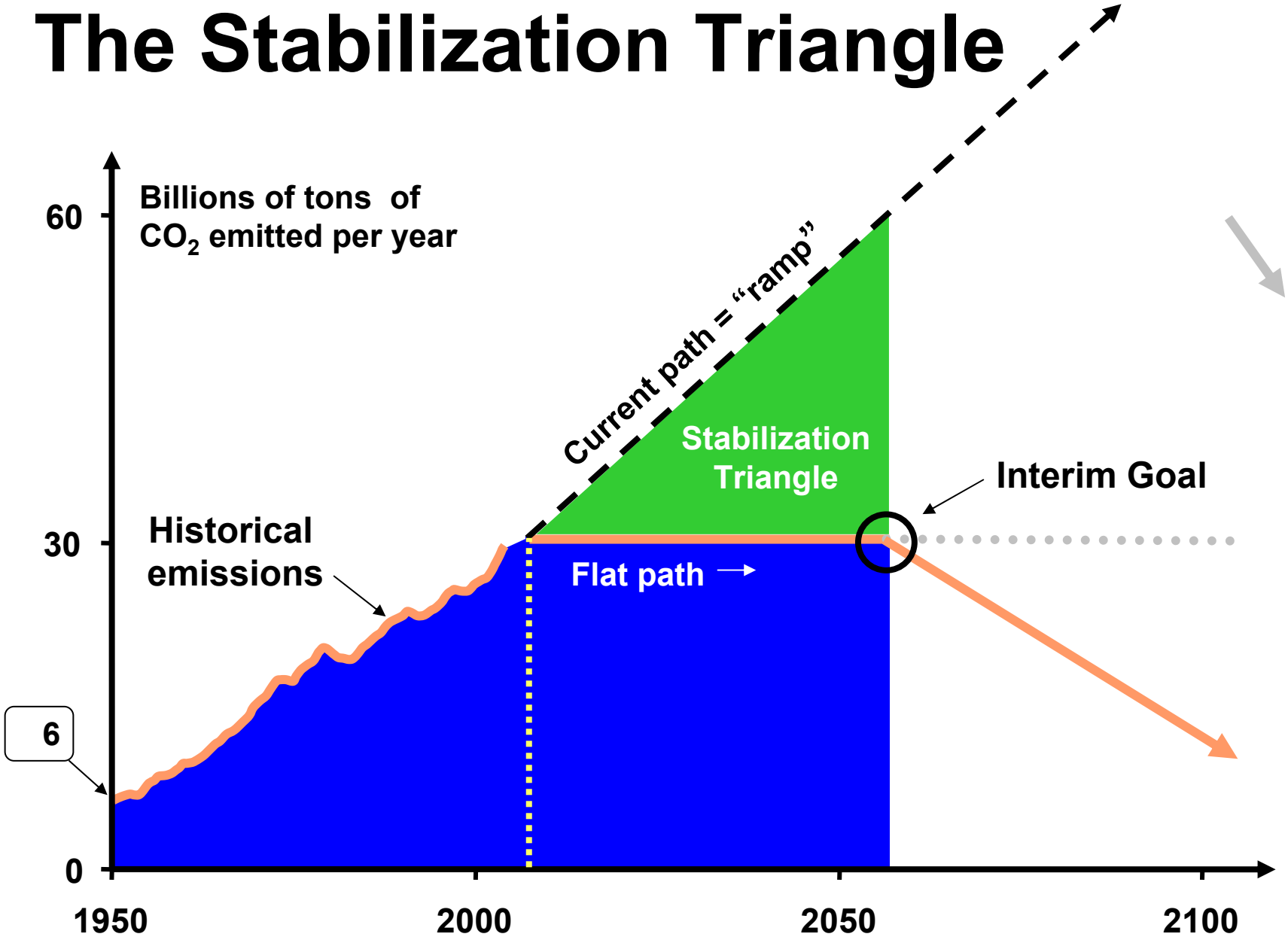
2. Some specific wedges

3. A new route to a global deal

Historical Emissions

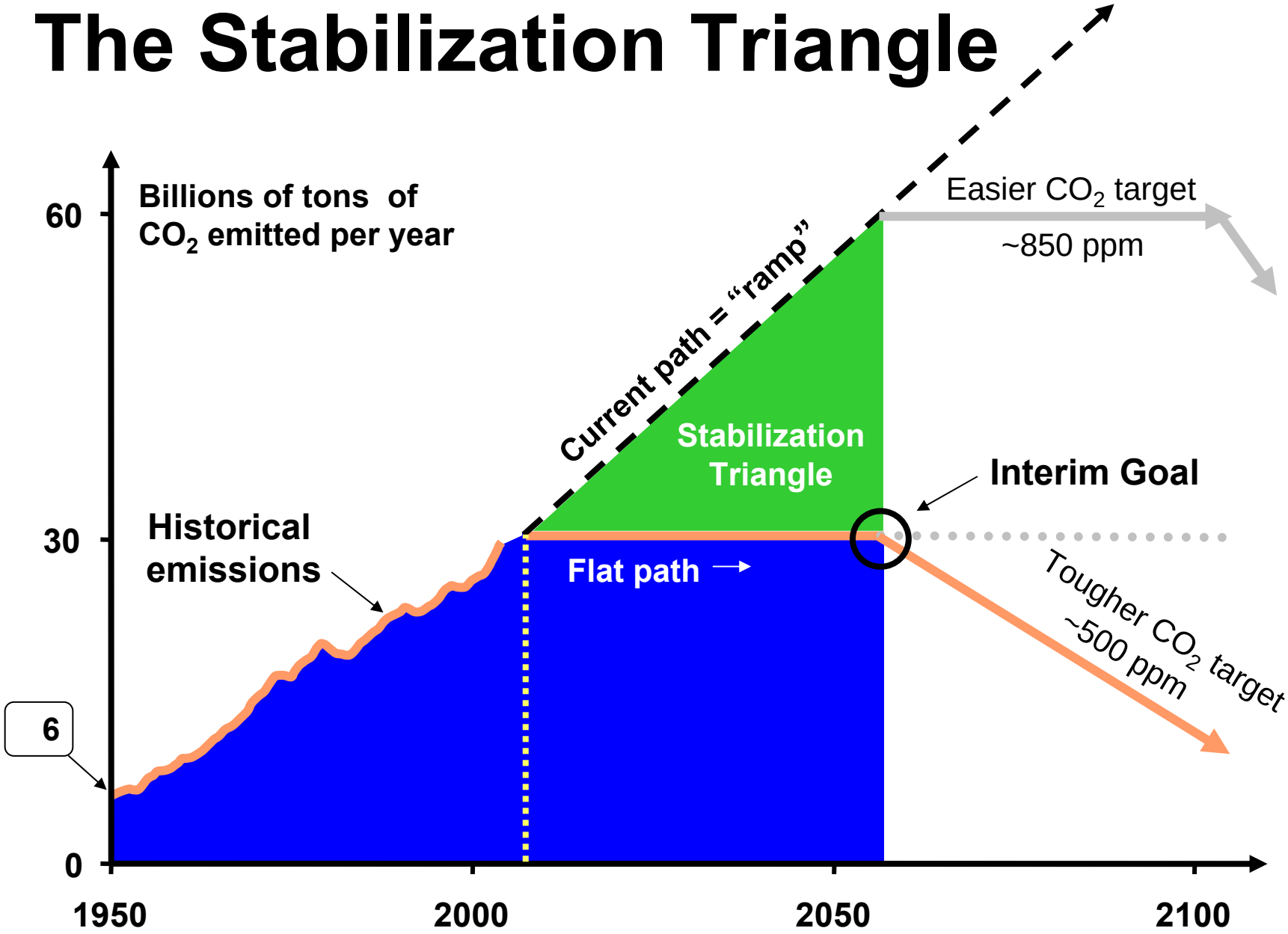


The Stabilization Triangle

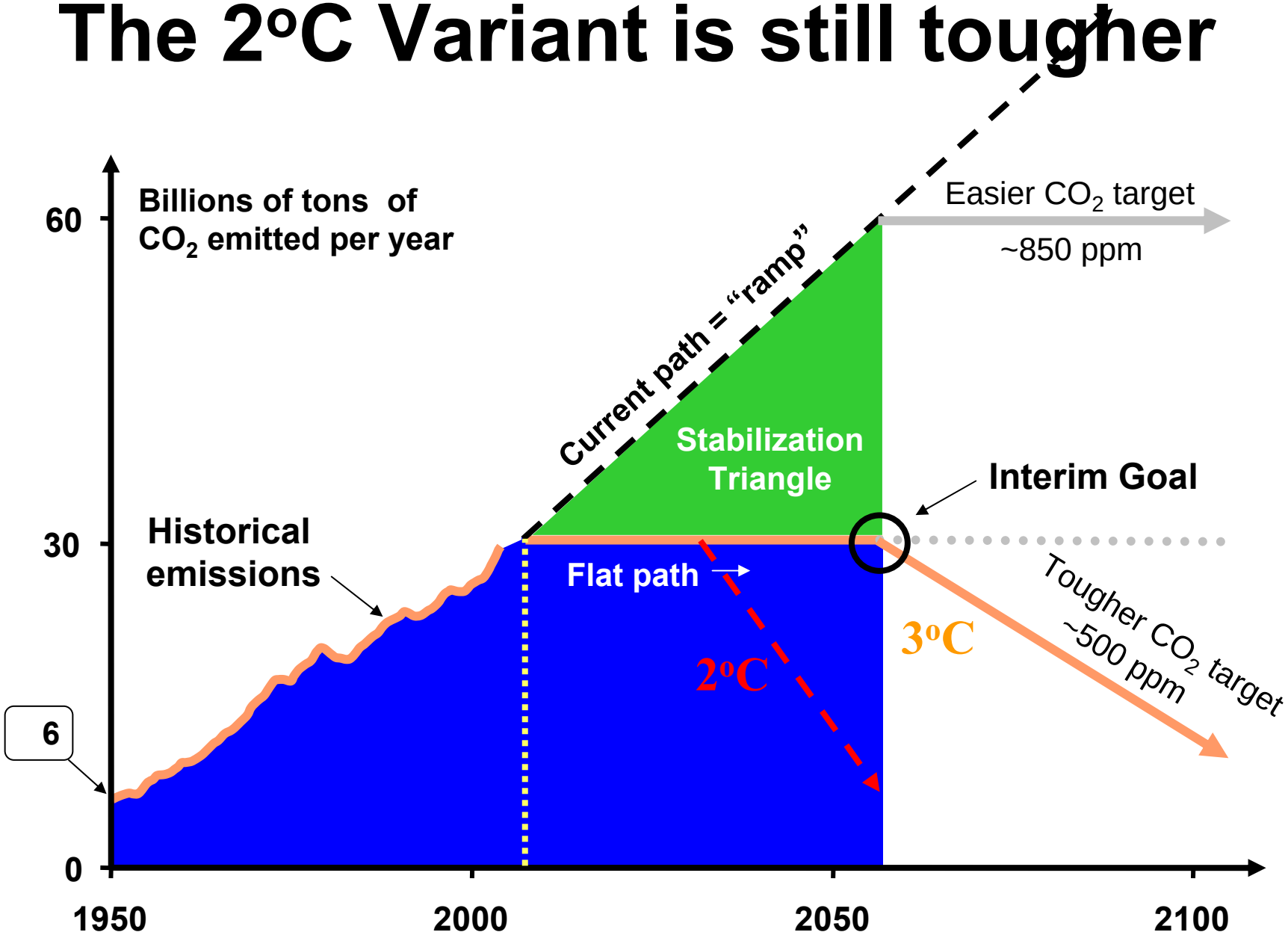


Today and for the interim goal, global per-capita emissions are ≈ 4 to 5 $tCO_2/yr.$

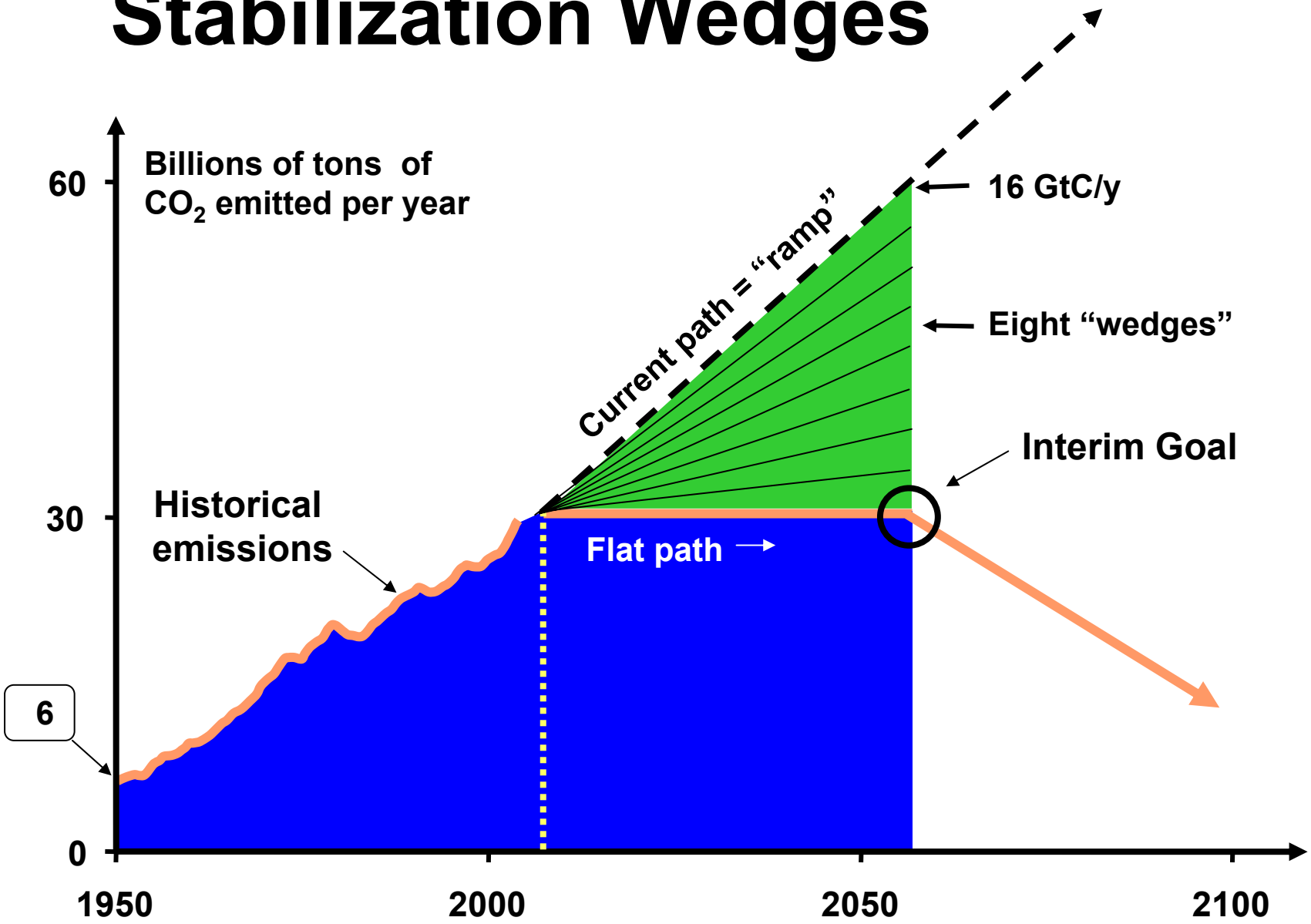
The Stabilization Triangle



The 2ºC Variant is still tougher

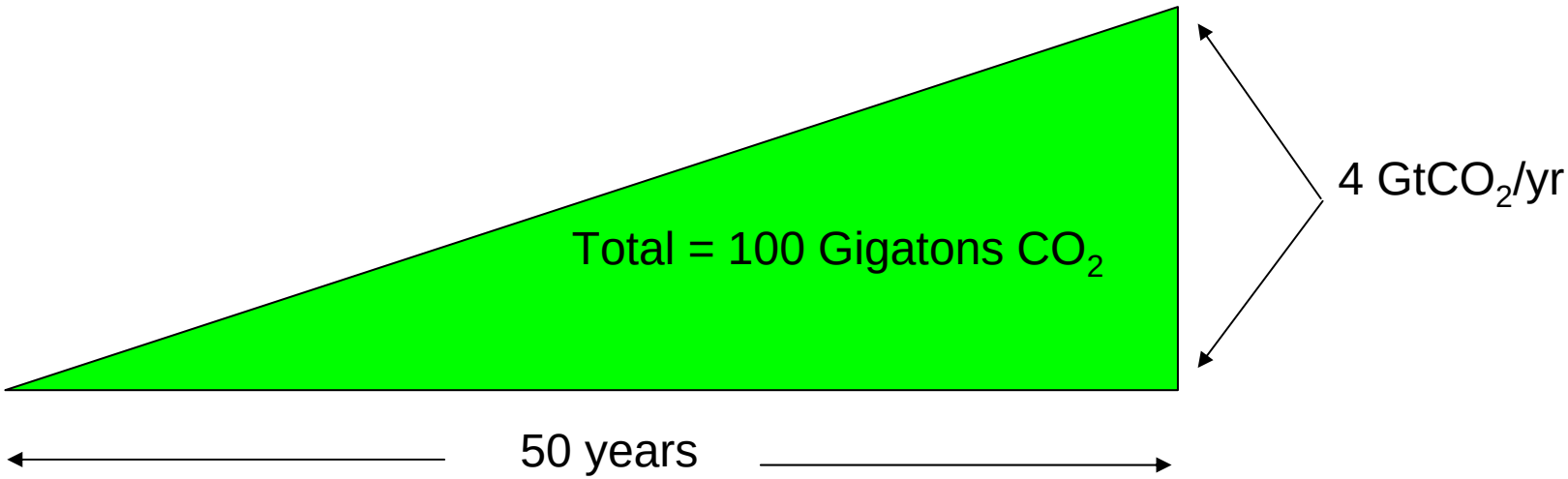


Stabilization Wedges



What is a “Wedge”?

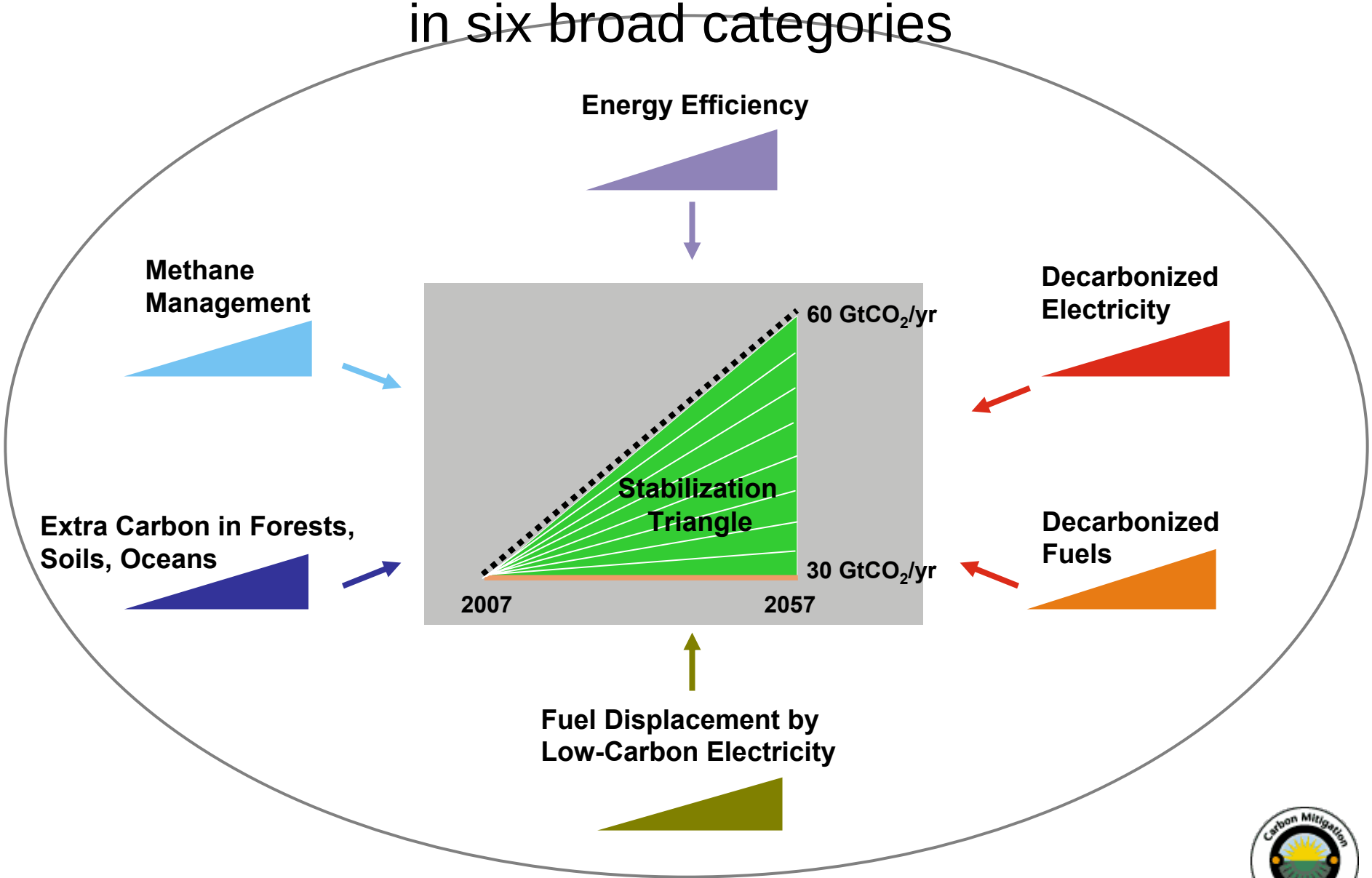
A “wedge” is a strategy to reduce carbon emissions that grows in 50 years from zero to 4 $GtCO_2$/yr. The strategy has already been commercialized at scale somewhere.



Cumulatively, a wedge redirects the flow of 100 $GtCO_2$ in its first 50 years. This is **three trillion dollars** at \$30/tCO_2.

A “solution” to the CO_2 problem should provide at least one wedge.

Fill the Stabilization Triangle with Eight Wedges in six broad categories

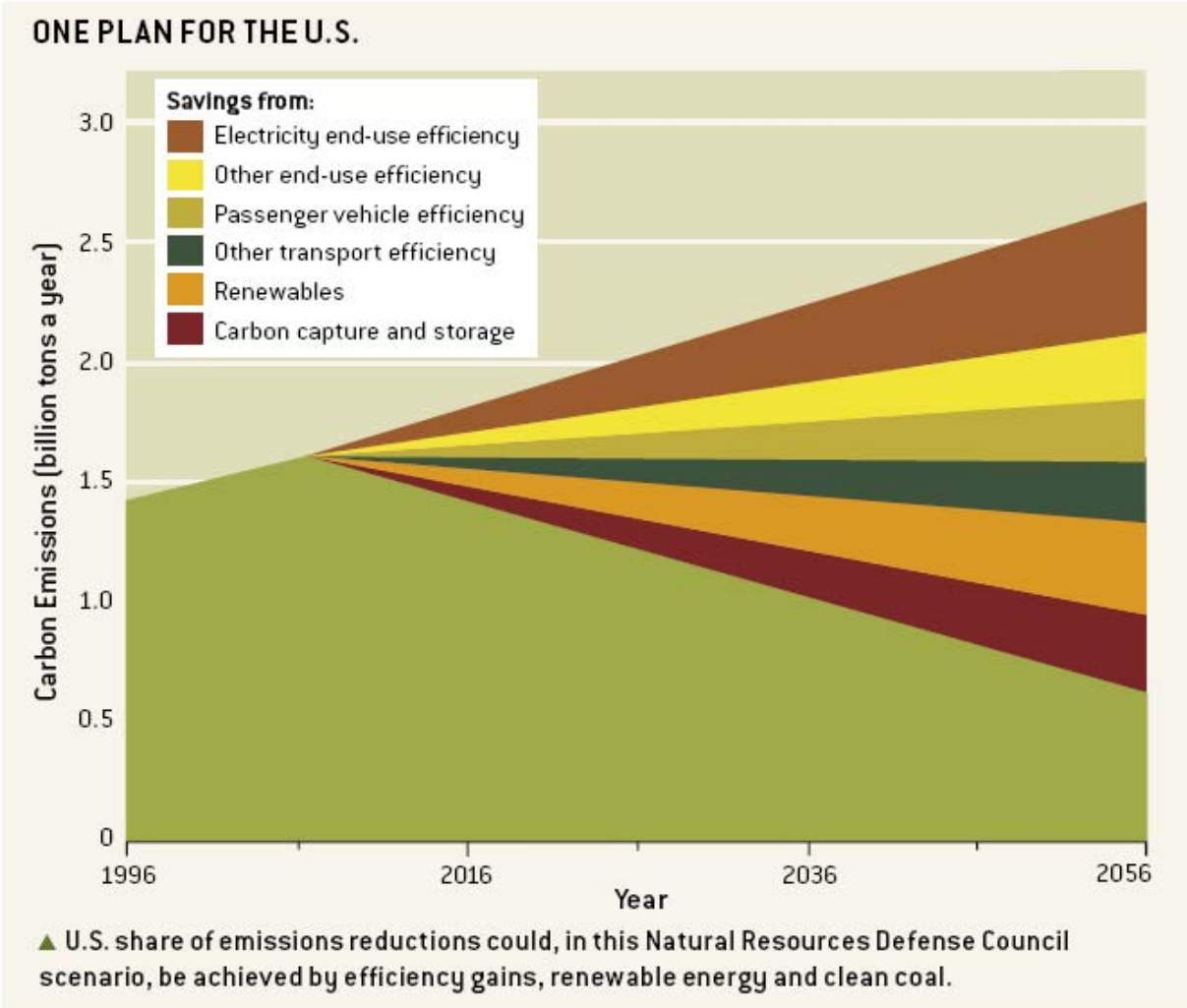


“The Wedge Model is the iPod of climate change: You fill it with your favorite things.”

David Hawkins, NRDC, 2007.

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

U.S. Wedges



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

Outline of Talk

1. **The Wedges Model: A simple quantification of carbon mitigation**

2. **Some specific wedges**

3. A new route to a global deal

Priority #1: Invent a smart-carbon post-industrial society

The post-industrial age features unprecedented private consumption. In industrialized countries more than 60% of oil is used in vehicles, more than 60% of electricity in buildings.

Efficient Use of Fuel

Effort needed by 2055 for 1 wedge:

Note: 1 car driven 10,000 miles at 30 mpg emits 4 tons of CO_2.

2 billion cars driven 10,000 miles per year at 60 mpg instead of 30 mpg.

2 billion cars driven, at 30 mpg, 5,000 instead of 10,000 miles per year.

Property-tax systems that reinvigorate cities and discourage sprawl

Video-conferencing

Efficient Use of Electricity

motors

lighting

cogeneration

Effort needed by 2055 for 1 wedge:

.

25% reduction in expected 2055 electricity use in commercial and residential buildings

Target: Commercial and multifamily buildings as well as single-family homes.

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.

Priority #2: End the construction of conventional coal plants

700 GW of baseload coal plants, with CO_2 vented, emit 1 billion tons of carbon each year. So, one wedge results from not building these plants.

Wind Electricity

Effort needed by 2055 for 1 wedge:

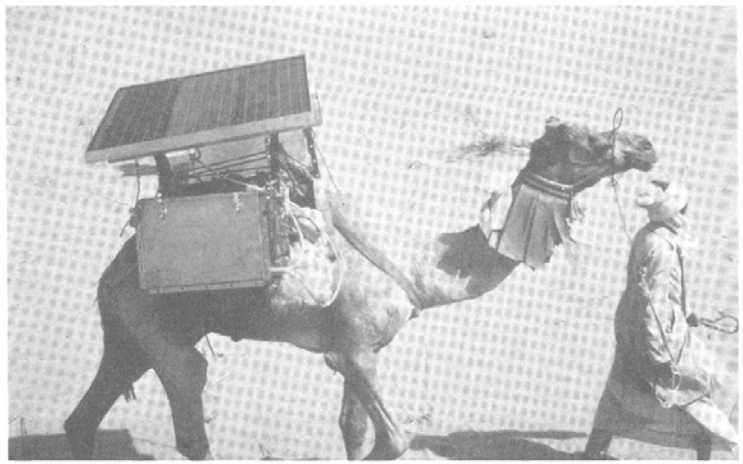
One million 2-MW windmills displacing coal power.

2008: 100,000 MW (5%)

Wind turbines invisible from the shore.

Source: Hal Harvey, TPG talk, Aspen, CO, July 2007

Photovoltaic Power



Effort Needed by 2055 for one wedge:

2000 GW_{peak} (400 x current capacity)

2 million hectares (80 x 100 miles)

Graphics courtesy of DOE Photovoltaics Program

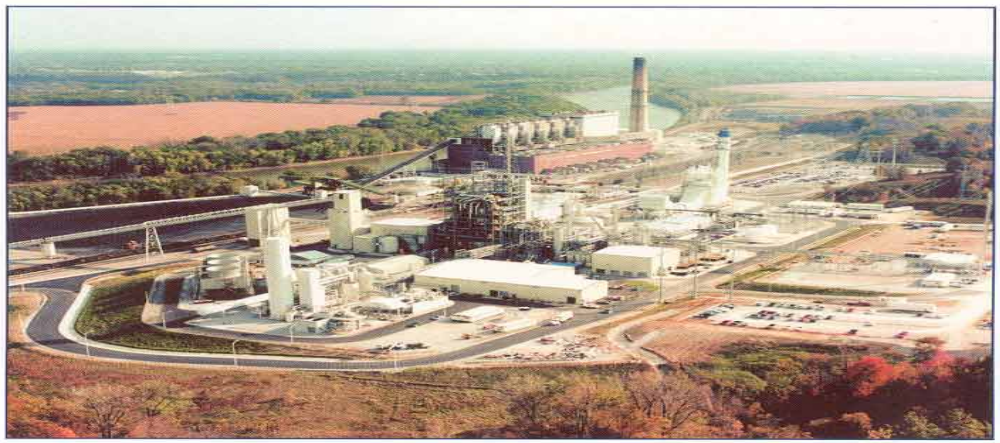
Nuclear Electricity

Effort needed by 2055 for 1 wedge: 700 GW (twice current capacity) displacing coal.

Phase out of nuclear power creates the need for another half wedge.

Dry cask storage, not for forever.

Coal with Carbon Capture and Storage



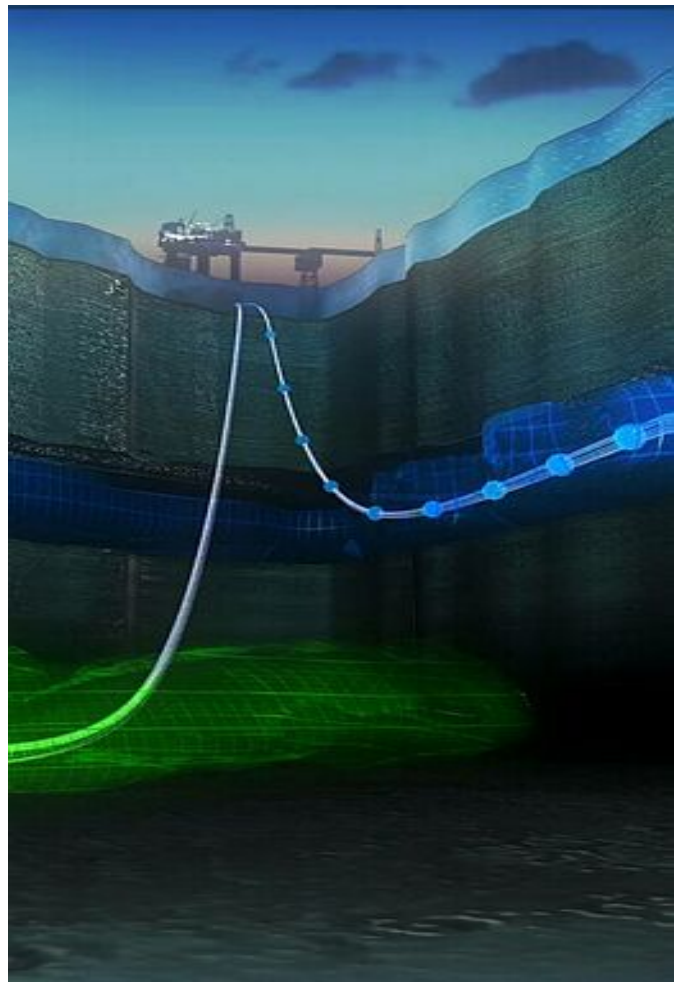
The Wabash River
Coal Gasification Repowering Project

Effort needed by 2055 for 1 wedge:

Carbon capture and storage (CCS) at 800 GW coal power plants.

CCS at “coal-to-liquids” plants producing 30 million barrels per day.

Which will happen first?



Graphics courtesy of DOE Office of Fossil Energy and *Statoil ASA*

Already, in the middle of the Sahara!

At In Salah, Algeria, natural gas purification by CO_2 removal plus CO_2 pressurization for nearby injection

Separation at amine contactor towers

The Future Coal to Power + Fuels Plant

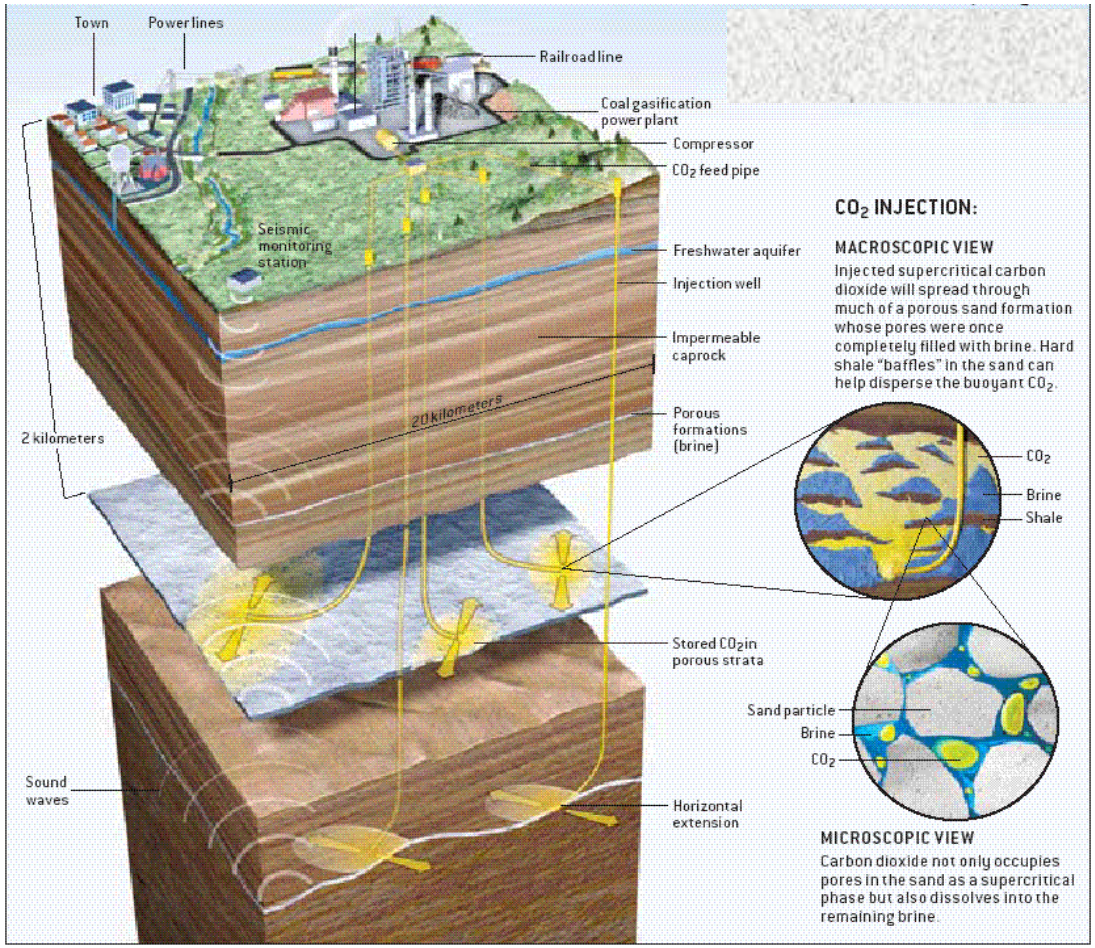


ILLUSTRATION BY DAVID FIERSTEIN; CONCEPT BY JULIO FRIEDMANN Lawrence Livermore National Laboratories

www.sciam.com

Shown here: After 10 years of operation of a 1000 MW coal plant, 60 Mt (90 Mm^3) of CO_2 have been injected, filling a horizontal area of 40 km^2 in each of two formations.

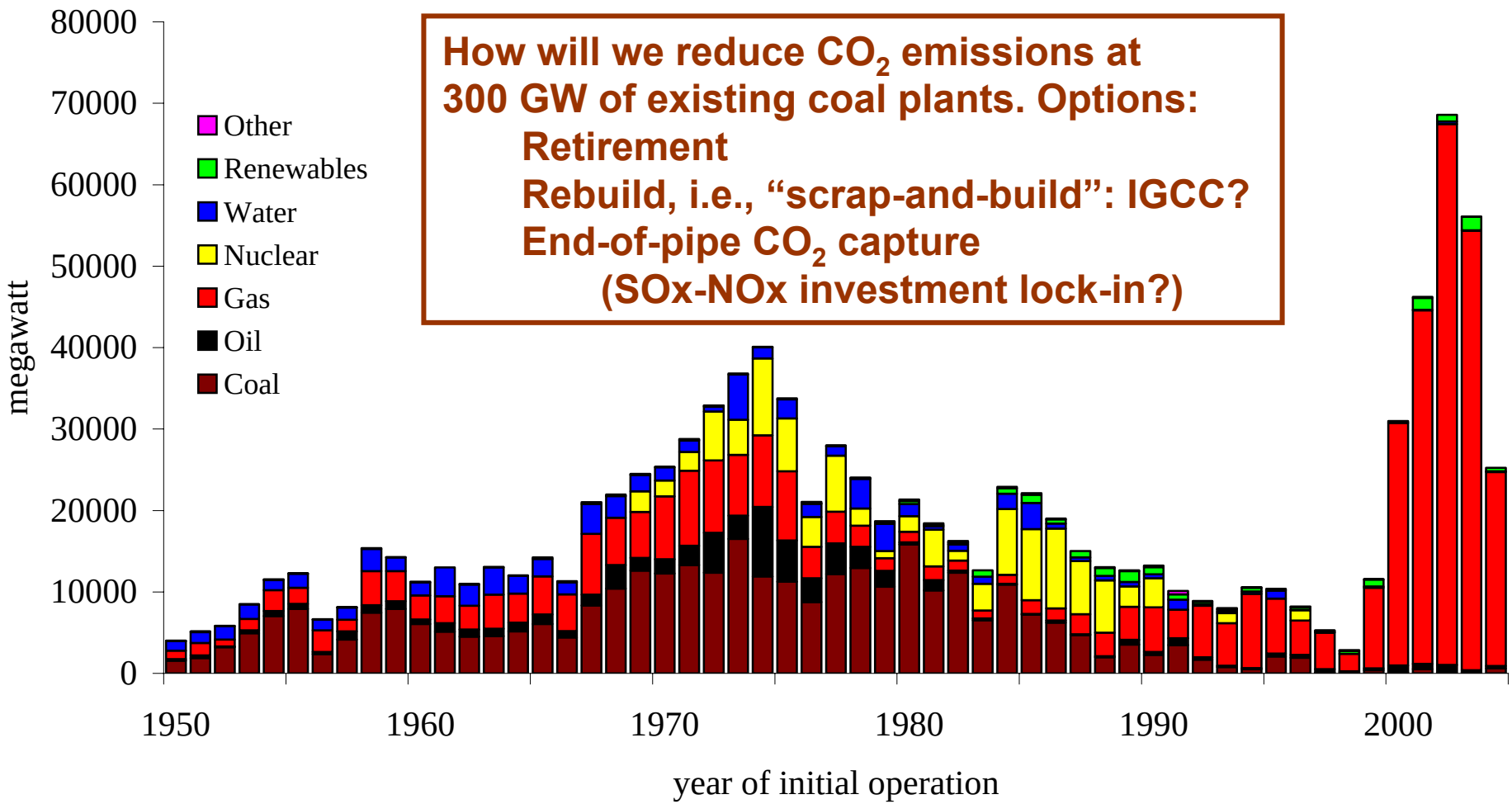
Assumptions:

- 10% porosity
- **1/3 of pore space accessed**
- 60 m total vertical height for the two formations.

- *Note:* Plant is still young.

Note: Injection rate is 150,000 bbl(CO_2)/day, 3 billion barrels over 60 years.

U.S. Power Plant Capacity, by Vintage



If we push hard on end-use efficiency, will our current fleet suffice for >20 yrs?

Source: EIA

Benchmark: $60/tCO$_2$

Carbon emission charges in the neighborhood of $60/tCO$_2$ can enable scale-up of most of the wedges, if supplemented with sectoral policy to facilitate transition.

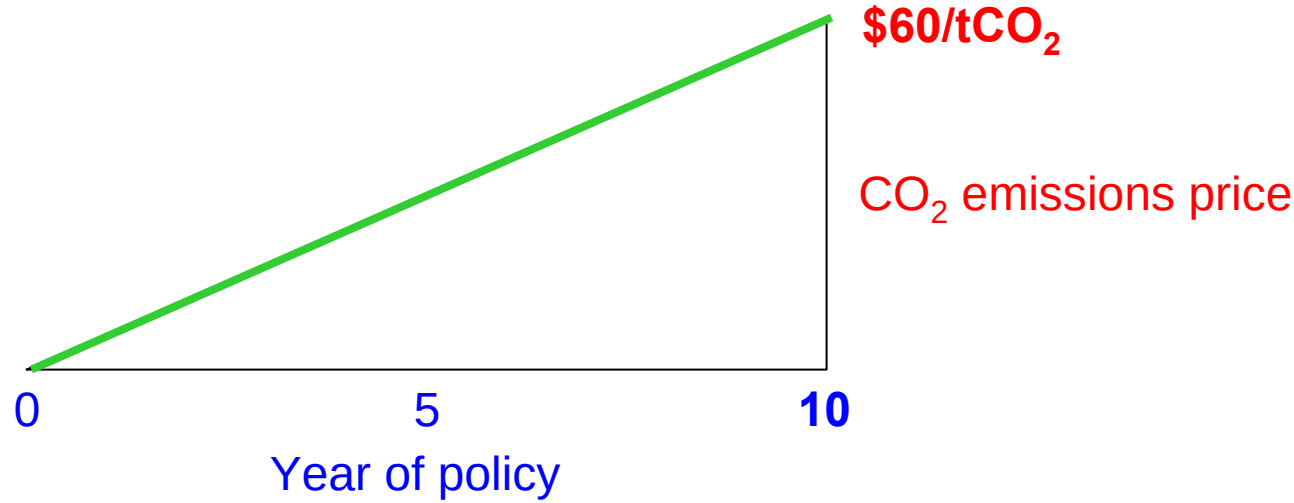
Form of Energy	**Equivalent to $60/tCO$_2$ (≈ $200/tC)**
Natural gas	**$3.20/1000 scf**
Crude oil	**$26/barrel**
Coal	**$140/U.S. ton**
Gasoline	50¢/gallon (ethanol subsidy: 50¢/gallon)
Electricity from coal	4.8¢/kWh (wind and nuclear subsidies: 1.8 ¢/kWh)
Electricity from natural gas	2.2¢/kWh

$60/tCO$_2$ is about 1.5 times the current European Trading System price.
Values current global emissions (30 GtCO$_2$/yr) at $1.8 trillion/yr, 3% of GWP.

Pull: Avoid Mitigation Lite

Mitigation Lite: The right words but the wrong numbers. Companies' investments are unchanged: the emissions price is a cost of business. Individuals change few practices.

Instead, calculate the price schedule required to produce the desired actions (e.g., CO_2 capture and storage), then the schedule for the shrinking cap.



A price ramp that is *not* "lite": one rising from zero to \$60/tCO_2 over 10 years.

Every strategy can be implemented well or poorly

Every “solution” has a dark side, generating opposition that thwarts implementation.

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

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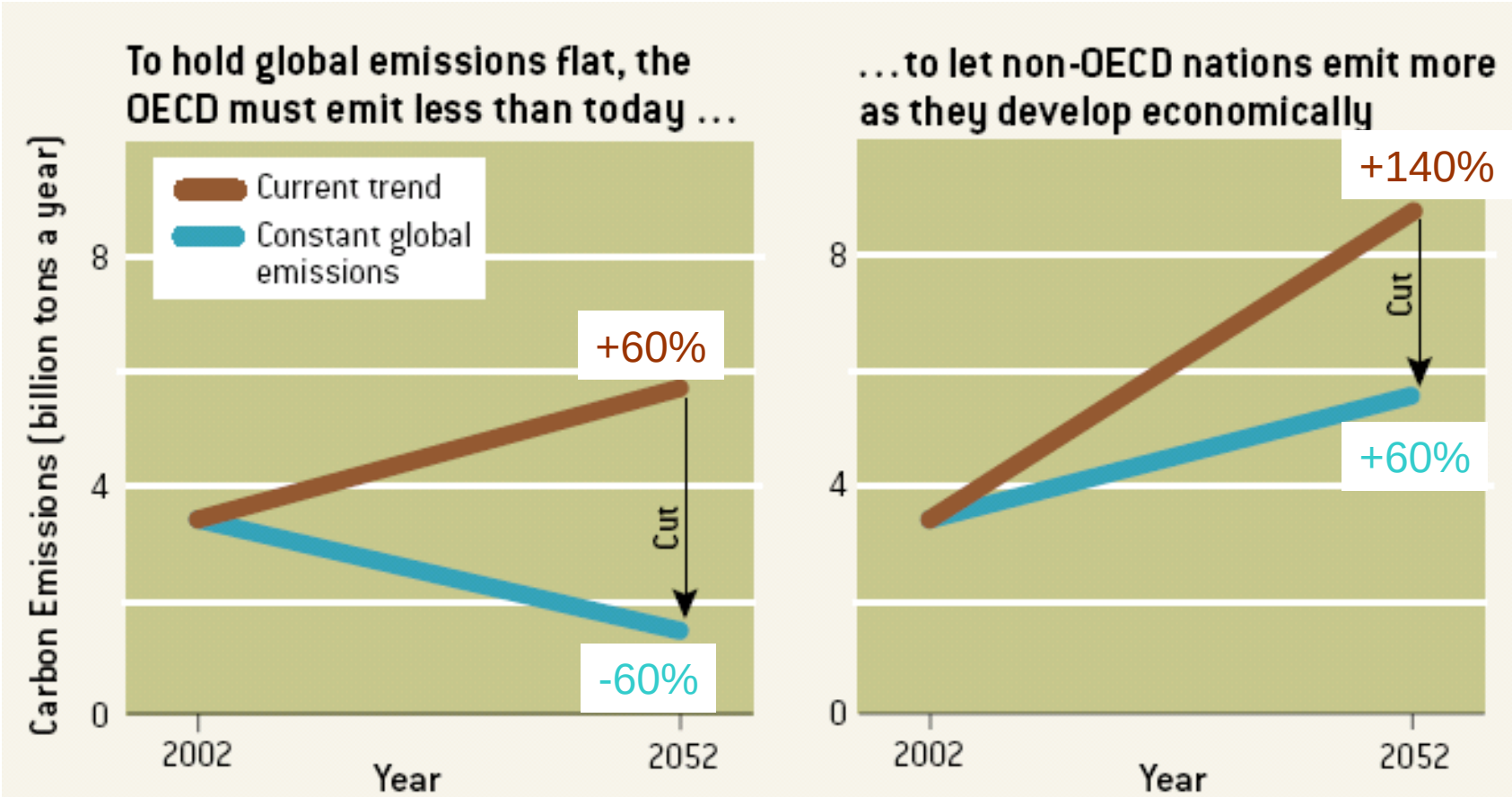
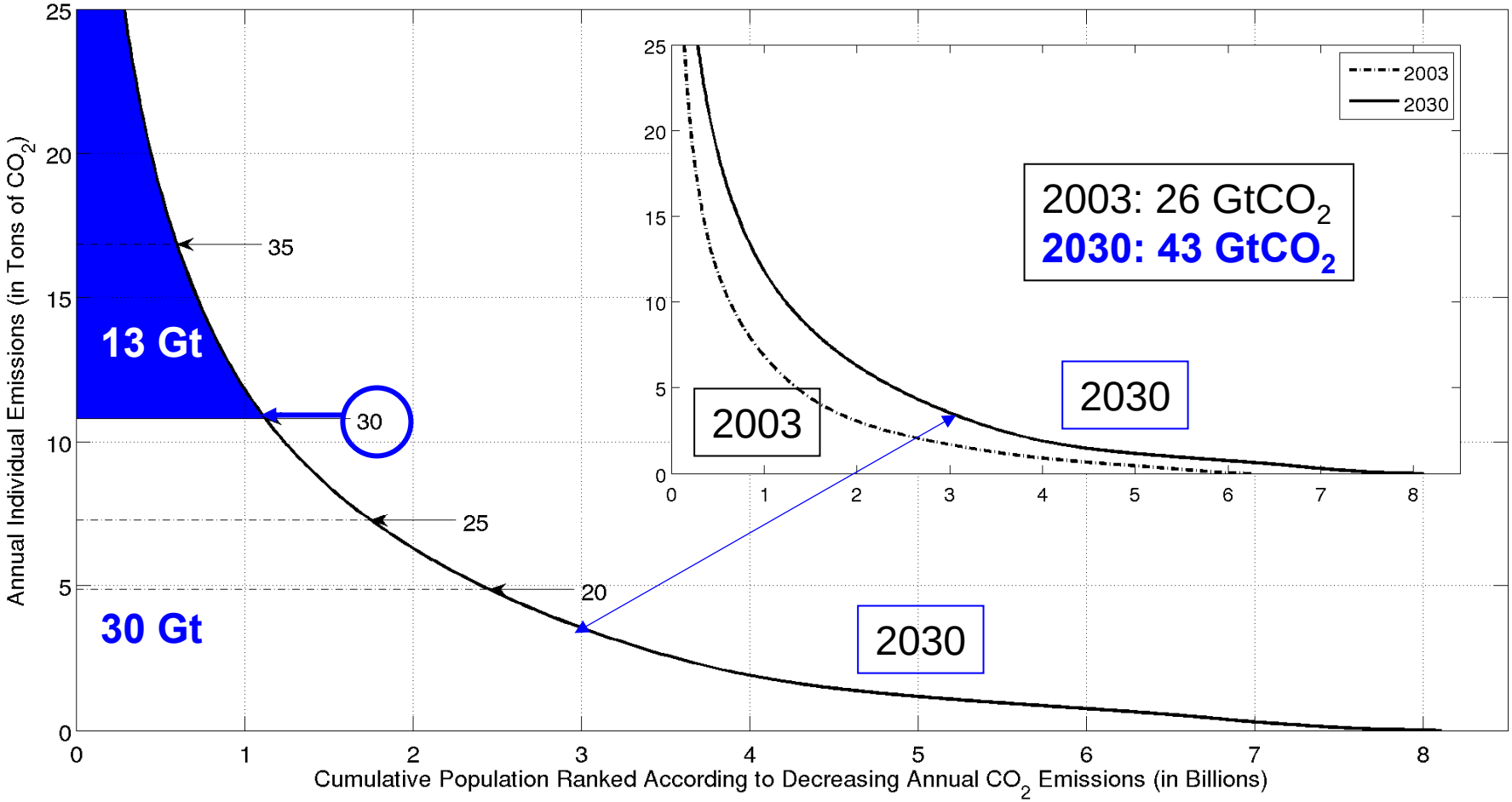
OECD and non-OECD shares 50-year view



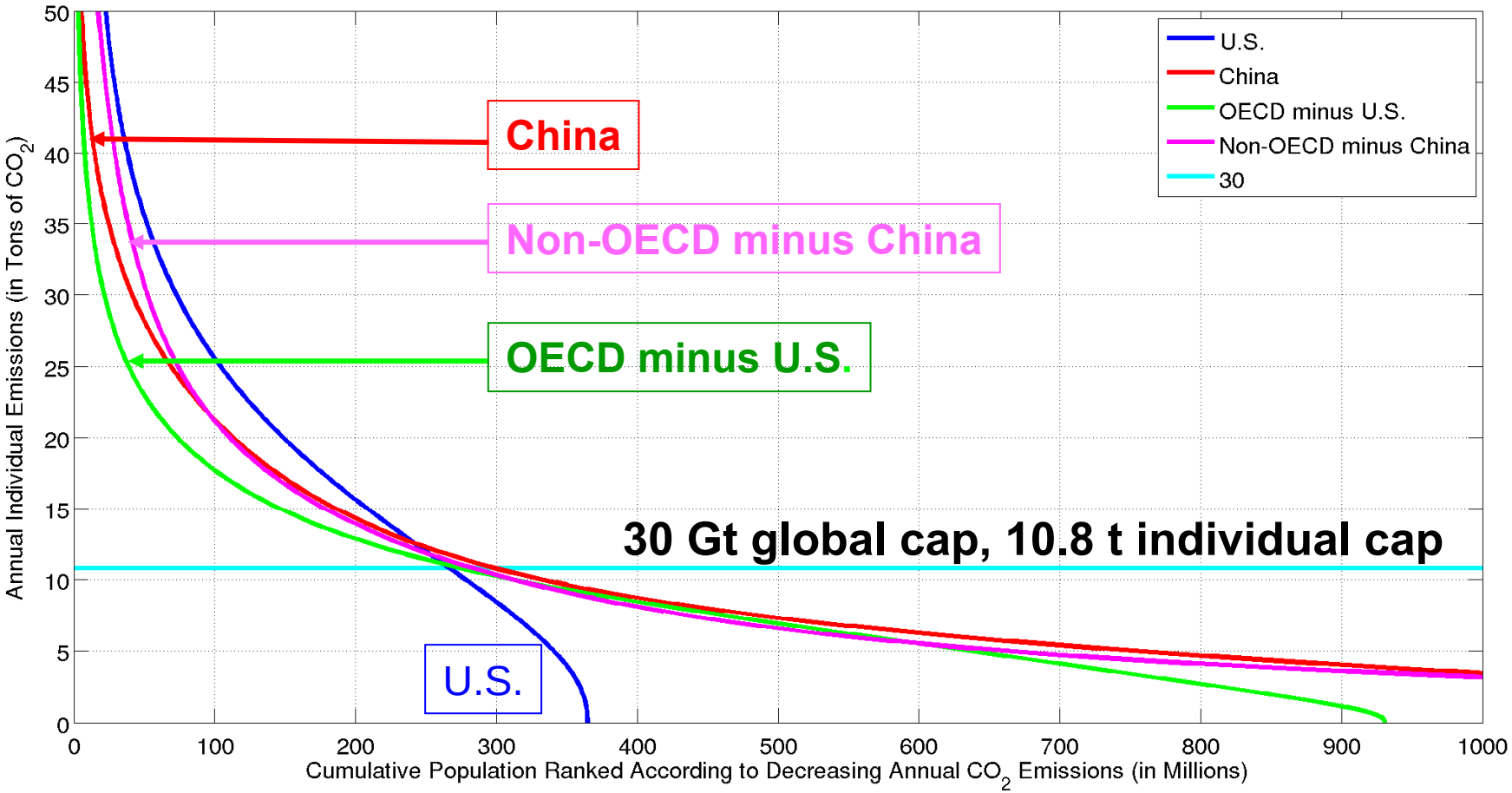
*Source*l Socolow and Pacala, *Scientific American*, September 2006, p.56

CO_2 mitigation allocation based on high-emitting individuals, wherever they live



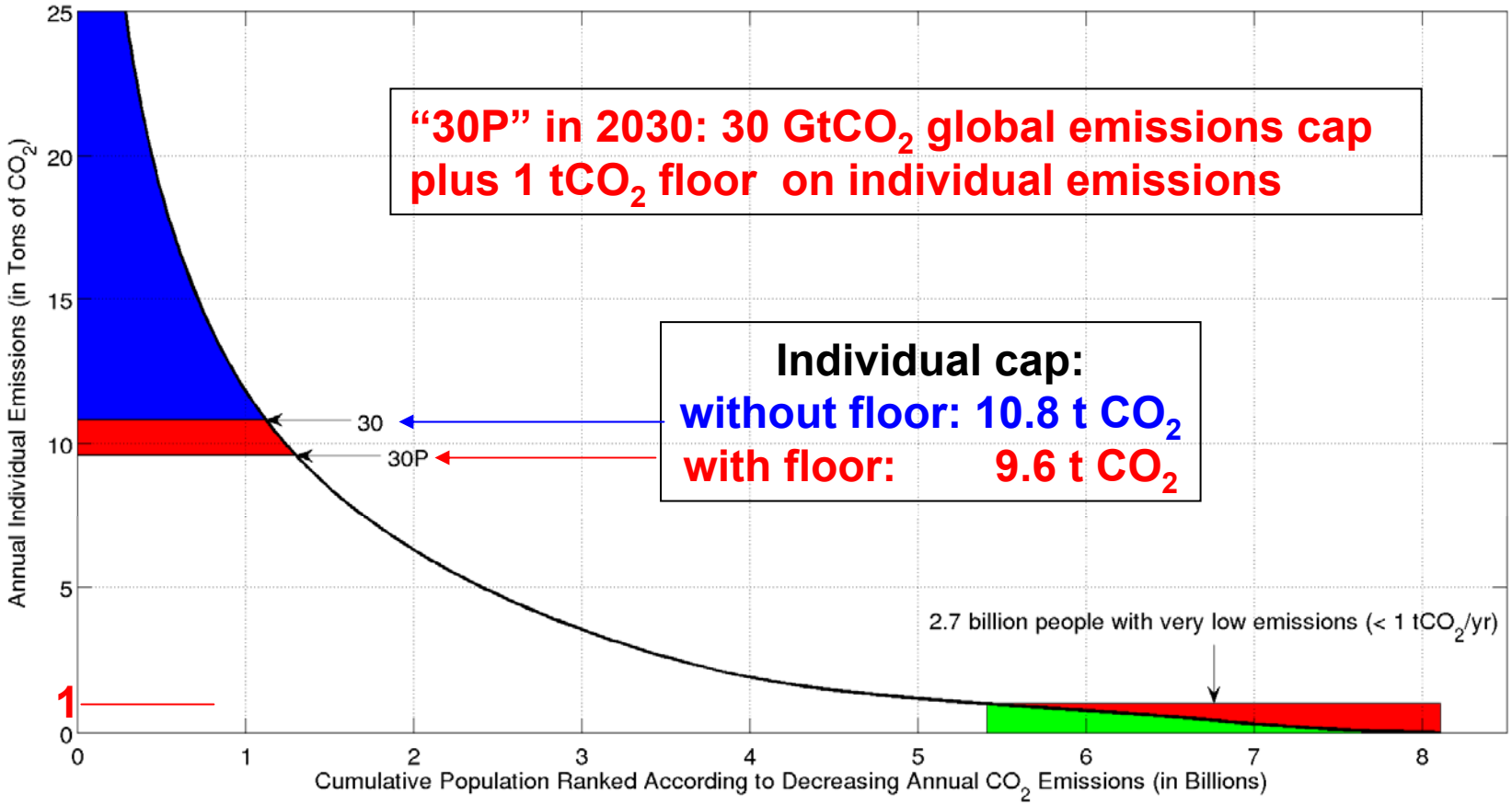
Projected 2030 emissions of 43 $GtCO_2$ are the sum of 30 $GtCO_2$ below and 13 $GtCO_2$ above the 10.8 tCO_2 cap.

Regional emissions in 2030

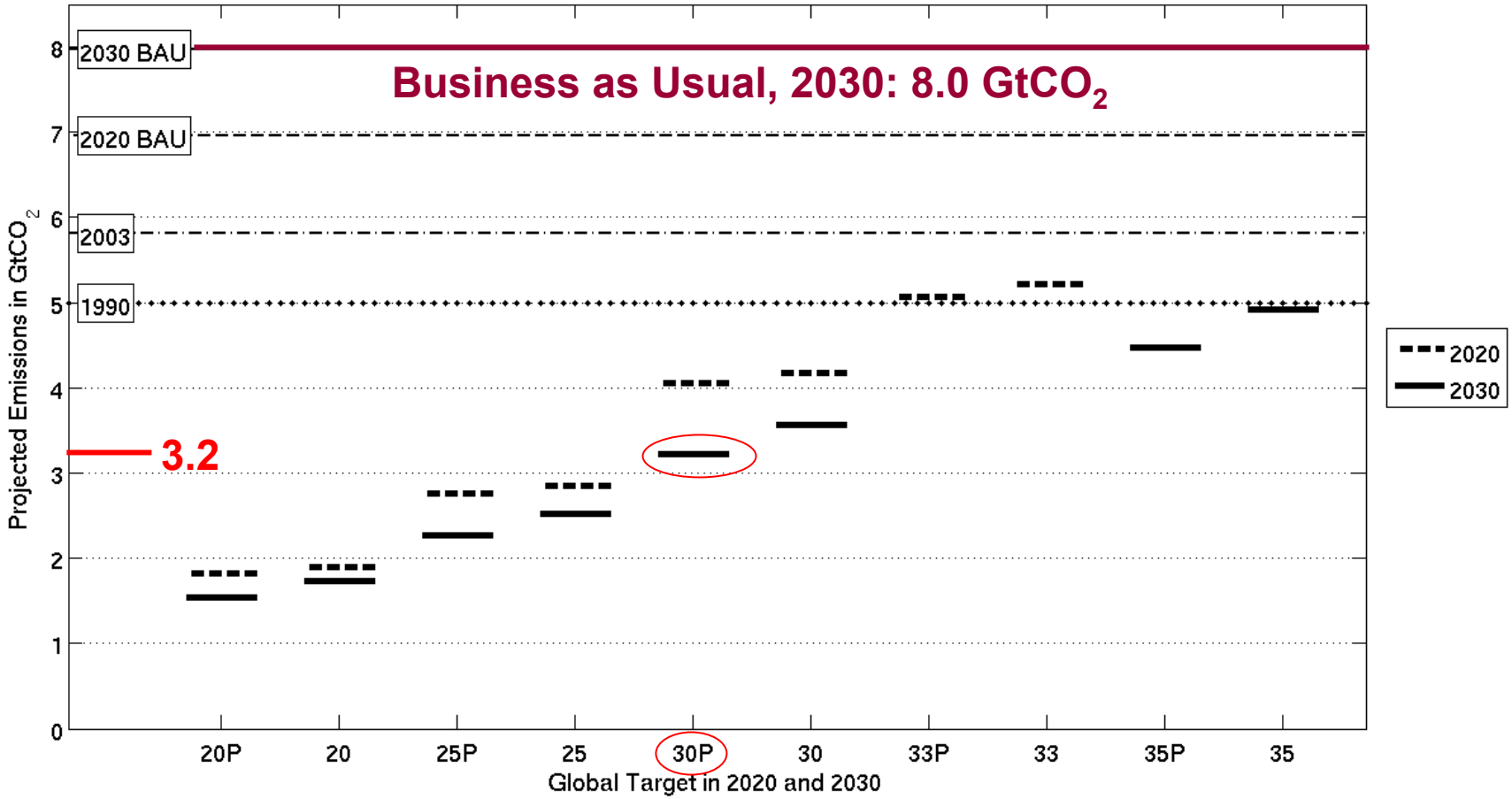


For a 30 $GtCO_2$ global cap in 2030, four regions have comparable assignments

Combine global-emissions cap and individual-emissions floor



U.S. targets


2030 BAU
Business as Usual, 2030: 8.0 GtCO2
2020 BAU
2003
1990
3.2
Projected Emissions in GtCO2
0
1
2
3
4
5
6
7
8
20P
20
25P
25
30P
30
33P
33
35P
35
Global Target in 2020 and 2030
2020
2030

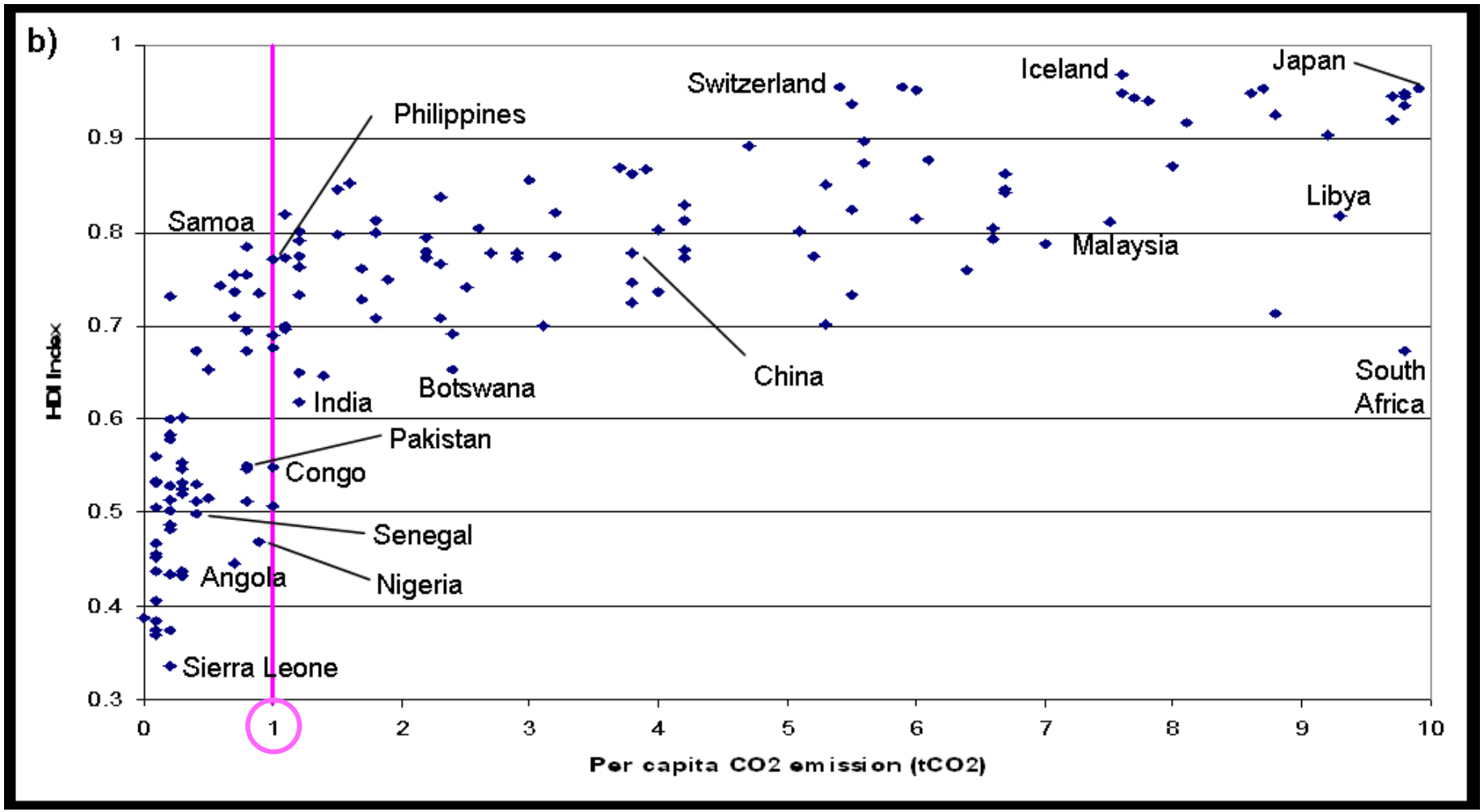
Mitigation based on individual emissions

1. ***Mitigate uniformly for the same personal emissions level across all countries.***

2. ***Attain all savings from the largest emitters.***

3. ***Put a floor on emissions to meet and surpass Millennial Development Goals.***

Per capita CO_2 vs the U.N.'s Human Development Index



Today, 1 tCO_2/per person per year

Direct Energy Use	*Household rate of use (4.5 people)*	*Individual emissions ($kgCO_2/yr$)*
Cooking	1 LPG canister per month	120
Transport	15 km per day	220
Electricity	800 kWh per yr	160
Total		*500*

1 tCO2/yr: Double the "direct" emissions to account for "indirect" emissions.

Common Misunderstanding #1

It is *not* sufficient to limit emissions in the prosperous parts of the world and allow the less fortunate to catch up. Such an outcome would overwhelm the planet.

The carbon emissions per capita in a climate-stabilized world, *not much more than 1 ton of CO_2 per year*, are ten times less than those of the average American today.

The emissions of the future rich must equal the emissions of today's poor, …

…not the other way around.

References

- “Stabilization wedges…,” *Science*, August 4, 2004 (with Steve Pacala)
- “Can we bury global warming?”, *Scientific American*, July 2005
- “A plan to keep carbon in check,” *Scientific American*, September 2006 (with Steve Pacala)